Chapter 3
Analysis of Environmental Protection Constraint of Energy Development

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3.1 Coal Development

3.1.1 Environmental Impacts and Present Situation of Control

3.1.1.1 Major Environmental Impacts

In the process of coal development, it is inevitable that the natural environment will be changed and destroyed, producing a large amount of pollutants. Main environmental impacts include land subsidence, water loss and soil erosion, land occupation, river system damage, discharge of solid waste such as coal gangue, discharge of mine water, gas emissions, destruction of vegetation, smoke and dust emissions, impact of biodiversity, autoignition caused by mining.

(1) Land subsidence. Due to coal mining, especially underground mining, the coal layer of tens of meters thick that was originally buried hundreds of and even tens of hundreds of meters under the ground is lifted to the ground. Without effective filling measures, the rocks around the coal mining face will collapse due to unbalanced forces. The collapse will extend to the earth's surface and result in earth surface collapse, namely land subsidence. According to

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incomplete statistics, on average the land subsides 0.2 hm^2 for mining 10,000 tons of coal. What is more, land subsidence is the main cause of environmental impacts such as geological disasters, soil erosion, and ecological destruction. In addition, owing to the limitation of natural endowment of coal resources, China's coal is mainly mined in the way of underground mining. As a result, land subsidence is an important environmental impact in China's current coal development.

(2) Water loss and soil erosion. In the coal development process, activities such as underground mining, open-air strip, and pumping of mine water lead to land subsidence, topsoil stripping, and decline of groundwater level in mining areas, which increases the local water loss and soil erosion, result in soil depletion and vegetation degradation, and further exacerbate water loss and soil erosion, forming a vicious cycle. Therefore, water loss and soil erosion are another environmental impact in China's coal development.

(3) Land occupation. It mainly refers to the land occupied by solid waste such as coal gangue and open-air stripping soil in the coal development process.

(4) River system damage. It includes water pollution and destruction of underground hydrogeological conditions. The discharge of industrial wastewater produced in the coal development process will result in water pollution in the mining areas as well as surrounding water areas. What is worse, the coal development might result in more serious water system damage without good solutions. The pumping of groundwater or discharge of drainage leads to the change in underground hydrogeological conditions in mining areas and the decline of groundwater level. As a result, the ground vegetation further degrades due to inadequate water supply and soil becomes increasingly barren, increasing water loss and soil erosion.

(5) Discharge of solid waste such as coal gangue, mine water, gas, smoke, and dust. In the coal development process, solid waste such as coal gangue, mine water or production wastewater, gas, smoke, and dust will be produced. At present, in addition to comprehensive utilization, the "three wastes" (wastewater, waste gas, and solid waste) generated in the coal development process will be discharged into the environment through reasonable treatment and make certain impacts on the environment.

(6) Impacts of vegetation destruction and biodiversity. The above-mentioned environmental impacts will definitely lead to vegetation destruction and changes in ecological function and biodiversity in mining areas.

(7) Autoignition caused by mining. When coal is exposed to the air, due to oxidative heat release, the temperature gradually rises to 70–80 °C and then rises sharply. When it reaches the coal ignition temperature, coal is ignited, which is called spontaneous combustion of coal seam. If in the coal mining process the coal resources stored deep down underground are exposed to the air, the possibility of the spontaneous combustion of coal will increase. The autoignition caused by mining is also related to coal quality. For example, coal which is easy to be oxidized and has intense exothermic oxidation reaction and low ignition temperature is prone to autoignition in the mining process. The

spontaneous combustion of coal seam is the incomplete oxidation of coal and produces a large amount of harmful gases including CO, SO_2, and NO_x, polluting the environment.

3.1.1.2 Present Situation of Control Technology

In terms of the "three wastes" problem, improving the comprehensive utilization rate of resources can fundamentally reduce the pollution of "three wastes". For the earth's surface vegetation destruction, reclamation plans can be made in accordance with local conditions. For example, land suitable for tree planting or fishing should be reclaimed for tree planting or fishing. Sources of domestic water for local residents should be developed in a protective way, and it is strictly forbidden to destroy them. When the decline of the groundwater level does affect water for production and living of local residents, local residents should be compensated according to the actual situation or be provided with well water or tap water. For areas where geological disasters might occur, local residents should be relocated. The relocation site and schedule should be arranged by the local government and funded by enterprises. See Table 3.1 for pollution control of coal enterprises.

3.1.1.3 Control Effectiveness and Existing Problems

1. Control effectiveness

China's coal industry has done a lot of work in environmental protection and has made positive progress. In terms of management scope, it is changed from focusing on key state-owned coal mines to the whole coal industry; in terms of management means, the administrative management in the past is changed into the comprehensive services integrating supervision according to laws, industry guidance, technology, and information guidance. In terms of work focus, it is changed from focusing on solving environmental pollution problems in coal development process to focusing on solving both pollution problems and ecological problems. In terms of technology roadmap, it is changed from end-of-pipe treatment and focusing on discharging pollutants in accordance with standards to process control, ecological renovation, and comprehensive utilization of resources. In terms of economic policy, it is changed from relying on sole financing of enterprises to joint financing of the central government, local governments, and enterprises for comprehensive control of environmental pollution. The investment has increased year by year, and channels have gradually expanded. These changes have effectively promoted the environmental protection of the coal industry. In recent years, China's coal industry has mainly made the following achievements:

(1) Positive progress has been made in green mining and ecological mine construction. Since the "12th Five-Year Plan" period, more and more coal

Table 3.1 Pollution control of coal enterprises

Pollutant	Pollution producing process	Pollution control measure	Process and technology used	Control effect
Coal gangue	Coal gangue produced in the coal mining and excavation process; washery rejects produced in the coal washing process	Comprehensive utilization	Coal gangue power plant, coal gangue brick field, filling subsidence area, road paving, backfilling mined-out areas, filling the mined-out areas when gangue is directly crushed without being lifted out of the well	Coal gangue can be comprehensively utilized to eliminate pollution, develop circular economy, and achieve certain economic benefits
Mine water	Mine drainage discharged in the coal mining process	Treat mine water in different ways based on the usage, for example, purification, in-depth treatment and simple treatment	Precipitation → filtration → disinfection → utilization Precipitation → filtration → reverse osmosis → disinfection → utilization Precipitation → agricultural irrigation and dust reduction	Mine water can be comprehensively utilized to improve the environment, save resources, and develop circular economy; if excess water yield of mine cannot be used otherwise, it can be discharged; highly mineralized mine water treatment has a high cost, but direct discharge might have a negative impact on environment
Mine gas	Coal seam gas extracted in the coal mining process	Comprehensive utilization	The coal mine gas with concentration higher than 6% can be used as fuel for low concentration gas power station; the coal mine gas with concentration higher than 30% can be used as fuel for gas power station or household fuel	The coal mine gas with concentration higher than 6% can be used as clean fuel to eliminate pollution. Coal mine gas with low concentration is mainly discharged into the atmosphere currently, but with the improvement of

(continued)

Table 3.1 (continued)

Pollutant	Pollution producing process	Pollution control measure	Process and technology used	Control effect
				low concentration coal mine gas comprehensive utilization technology, low concentration coal mine gas can be gradually realized
Sulfur dioxide	Coal-fired boiler flue gas	Desulfurization with calcium content in furnace	Co-firing of coal and limestone $SO_2 + CaO \rightarrow CaSO_3 + CaSO_4$	Low desulfurization efficiency
		Calcium injection desulfurization in furnace	Injection of limestone powder to a circulating fluidized bed furnace; desulfurization reaction is the same as above	Desulfurization efficiency can reach 70%
		Semi-dry flue gas desulfurization	Flue gas is put into reactor and mixed with water +desulfurization agent; SO_2 is absorbed	Desulfurization efficiency is 80–90%
		Wet flue gas desulfurization	Use desulfurization agent to spray, and wash flue gas containing SO_2 in the absorption tower; SO_2 is absorbed	Desulfurization efficiency is higher than 95%
Chemical oxygen demand	Coal mine drainage is mainly mine water. The COD concentration of the mine water is generally not high. If the displacement is large, total amount of COD will increase accordingly	Mine water is used after treatment and is not discharged	Precipitation → filtration → disinfection → utilization Precipitation → filtration → reverse osmosis → disinfection → utilization Precipitation → agricultural irrigation and dust reduction	Mine water can be comprehensively used to completely eliminate COD. If the mine water in large quantity cannot be completely utilized, some of the mine water will be discharged, forming discharge COD

enterprises have carried out the green mine and ecological mine construction activities. Coal enterprises have actively explored and implemented green mining technologies such as filling mining and water-preserved mining which not only improve the recovery rate of coal resources, save valuable resources of coal and water, but also reduce the impact on and damage to environment of coal mining.

(2) New progress has been made in energy conservation and consumption reduction. In recent years through technical progress, management improvement, industry and product structure adjustment, and other measures, the coal industry has improved the energy efficiency of enterprises and the unit product energy consumption has been constantly reduced. According to statistics, in 2012 comprehensive energy consumption of raw coal production and power consumption of raw coal production of large state-owned coal mines reached 13.1 kg standard coal/t and 22.5 kWh/t, respectively, down 2.6 and 3.0% over 2011, respectively.

(3) Continuous improvement of comprehensive utilization level. With the continuous development of the coal gangue, mine water, and coal gas comprehensive utilization technology, remarkable achievements have been made in the development and utilization of "three wastes" of mines and associated resources of coal measures. In 2012, the mine inflow was 6.75 billion tons and the mine inflow utilization rate was 62%; coal gangue production was 720 million tons, and the utilization rate was 62.7%; the mine gas production was 18.25 billion m^3; underground drainage was 9.5 billion m^3, and the utilized quantity and utilization rate are 4 billion m^3 and 42%, respectively. The scale of using coal gangue and fly ash to produce new types of buildings materials has steadily expanded. The technology of exchanging coal gangue for coal and filling mining has constantly improved. The utilized quantity of coal gangue and fly ash has gradually increased.

(4) Construction of circular economy park has been steadily promoted. At present, in the coal industry the circular economy development concept has been deeply rooted in everybody's mind. A lot of coal enterprises have particularly prepared circular economy development plans and explored and created distinctive circular economy development patterns.

(5) Ecological environment governance has promoted harmonious mining area construction. Ecological environment governance of mining areas is not only an important part of the construction of ecological civilization, but also closely related to the construction of harmonious mining area. The governance of coal mining subsidence area and the renovation of the shanty towns are steadily advanced. In 2012, the average annual income of large coal enterprises was about RMB 68,000, up 5.7% year-on-year. Combining ecological environment governance and harmonious mining area construction, the state-owned enterprises better fulfilled their due social responsibility. Eighteen large coal enterprises issued the social responsibility report, and 156 coal enterprises carried out the credit rating evaluation.

2. Major existing problems

Since the "12th Five-Year Plan" period, with the growing demand for social development, coal mining areas have made gratifying achievements in environmental protection. However, compared with the advanced world level, there are the following problems:

(1) High strength development and rapid growth of production have made a great impact on environment, and ecological damage has been constantly exacerbated. China's total coal production in the past 30 years totals 45 billion tons, and coal washing and processing capacity is about 11 billion tons. However, emissions of various wastes have not been synchronously used and treated. China's coal mining subsidence area increases by 20,000–25,000 hm^2 annually, and the area of open pit mining and land occupation is about 10,000 hm^2 annually. In the development mode of mining and discharging followed by governance or without governance, the discharge and reserves of pollutants also increase with the production, processing capacity, and utilization. Besides, the Chinese government has issued the pollution charge policy. Coal enterprises have difficulties bearing the double pressures.
(2) China has a large number of coal mines covering a broad area. As a result, coal mines have a great impact on environment. The strategy of the westward movement of coal development has made the ecological environment problem more prominent. In the twentieth century, China's coal mines were distributed in 1458 counties (cities) and at most there were over 80,000 coal mines. The ecological damage caused by coal mining affected more than 50% of these counties (cities), increasing the difficulty of environmental governance. Moreover, due to the serious shortage of the Chinese government's investment in environmental governance of mining areas, the governance effect is affected.
(3) Due to the low proportion of coal processing and raw coal-oriented product structure, environmental pollution has become increasingly exacerbated. Washing and processing raw coal are the effective ways to reduce emissions of pollutants, improve product quality, and obtain the best economic benefit. At present, most coal mines in China have not constructed the supporting coal washeries and the proportion of raw coal washing is quite low. In 2012, the raw coal washing proportion was 52.6%, but compared with the proportion of 80–90% of the world's major coal producers, it is quite low.

As the ecological environment protection has played an increasingly important role in coal development, the ecological environment protection system for coal development has been basically formed in China's newly built mining areas, improving the ecological environment around the mining areas. China is gradually advancing toward green mining.

3.1.2 Analysis of Major Environmental Protection Constraints

3.1.2.1 Analysis of Laws, Regulations, and Policies

1. Requirements of existing laws, regulations, and policies

Since the beginning of the twenty-first century, China's coal industry has entered the unprecedented rapid development stage of increasing production and improving efficiency. The Chinese government has identified the "coal-dominated and electric power-centered" development strategy and put forward the development idea of "constructing large coal production bases, adjusting and transforming medium and small coal mines, developing and utilizing coal seam gas, and encouraging coal and electricity production joint venture." In addition, it has made more than 20 economic and technical policies.

With the continuous development of China's economy, the progress of science and technology, and the gradual improvement of the coal industry's environmental protection mechanism, environmental governance effect has gradually improved. Especially in recent years, relevant state ministries and commissions have developed policies such as Township Coal Mine Environmental Protection Management Regulations, Notice on Strengthening Soil and Water Conservation in Coal Mine Production, and Construction Projects and Land Reclamation Management Ordinance and issued standards, laws, and regulations such as Clean Production Standard Coal Mining Industry, Emission Standard for Pollutants from Coal Industry and Rules for the Construction of Coal Pillars in Buildings, Water Bodies, Railways and Main Mine Lanes and Pressed Coal Mining to lay a solid foundation for further standardizing environmental protection in coal industry.

2. Judgement of laws, regulations, and policies during the "12th Five-Year Plan" period

Since the establishment of environmental protection mechanism, the coal industry has achieved remarkable results and effectively curbed the further deterioration of the mining area environment. However, with the progress of society and the development of science and technology, the existing environmental protection policies and measures cannot meet the increasingly higher environmental requirements. During the "12th Five-Year Plan" period, China should issue supporting laws, regulations, and policies on changing the development mode, environmental compensation mechanism, ecological environmental standards, environmental supervision system, and broadening channels of funds and meanwhile put forward development goals to promote the coordinated development of economy and environment.

3.1.2.2 Analysis of Major Environmental Protection Constraint Factors

From the point of view of environmental impact factors in a single mining area, coal development will inevitably lead to surface subsidence, damage of ground vegetation and groundwater, geological disasters such as landslide and ground cracks, secondary disasters such as surface vegetation destruction, soil degradation, and water pollution. Through comprehensive analysis, we find environmental protection constraints in coal development are mainly reflected in the following aspects:

1. Water resource destruction constrains coal mining

Coal mining causes serious damage to the groundwater and surface water resources, exacerbating the loss of water resources. Especially in water-deficient areas, due to the loss of groundwater and pollution of surface water, local residents have difficulty having access to production and living water. According to the survey, about 1.87 m^3 water resources are destroyed for producing 1t of raw coal on average. China's raw coal production in recent 7 years totals 13.1 billion tons and about 25,152 billion m^3 water resources are lost. According to incomplete statistics, the area of water resources destroyed by coal mining in Shanxi province reaches 20,352 km^2. Therefore, relevant Chinese ministries and commissions have made strict requirements for discharge of pollutants and required that the comprehensive utilization rate of mine water and domestic sewage should be higher than 75% and achieve zero discharge preferably.

2. Solid waste discharge constrains coal mining and selection

It is inevitable that some solid wastes including coal gangue, coal slime, and fly ash are discharged in the coal mining and washing process. These solid wastes have three distinct characteristics: large quantity, containing a large amount of low-grade energy, and low man-made (chemical) pollution degree. With the increase of coal production, the production of coal gangue, coal slime, and fly ash has also increased sharply, exacerbating the destruction of the ecological environment in mining areas. Moreover, the accumulation of a large amount of coal gangue and fly ash directly results in the unorganized discharge of SO_2 and dust.

3. Land and vegetation damage constrains coal mining

Large-scale energy base construction and coal mining leads to large area land subsidence in mining areas. According to statistics, the earth's surface subsides 0.2 hm^2 (about 3 acres) for China's coal mines mining every 10,000 tons of coal. It has been more than 60 years since the founding of the new China, and about 50 billion tons coal have been produced to meet the demand of rapid development of national economy. However, a cumulative area of 960,000 hm^2 of the earth's surface has subsided, causing damage to the land and surface vegetation.

Coal mining leads to the destruction of forest vegetation and exacerbates water loss and soil erosion. China's 13 large coal bases are distributed in 100 mining areas in 14 provinces and have a mining area of 355,130 km^2. The coal production of the eight large coal bases in Shanxi, Shaanxi, and Inner Mongolia accounts for 60% of China's total coal production. These eight large coal bases cover an area of 33,000 km^2. With the water and soil loss area reaching 1.14 million km^2, these areas have the most serious problem of water loss and soil erosion in China. Shanxi, Shaanxi, and Inner Mongolia lose about 1.6 billion tons of water and soil annually.

3.1.2.3 Analysis of Main Environmental Protection Indicator Limit

1. Limit of environmental protection indicators during the "12th Five-Year Plan" period

In terms of efficient utilization of waste resources, China's coal industry has focused on the efficient utilization of coal gangue, mine water, and gases, vigorously reformed the backstopping process and utilization means, strengthened the control of the discharge and storage of pollutants, and implemented land reclamation in mining areas. The Chinese central government, local governments, and enterprises have joined hands to establish unified standards, improve laws, regulations and policies, increase investment, and construct a batch of resource-saving and environment-friendly mining areas. See Table 3.2 for development goals and major measures for efficient utilization of waste resources in all regions in 2015.

With the adjustment of coal production structure and production capacity, China's coal industry aims to, with large coal bases as the leader, improve management level and technical equipment, adjust and optimize the industrial structure, use clean production technologies, reduce resource and energy consumption, and construct a batch of ecologically harmonious mining areas during the "12th Five-Year Plan" period. By 2015, the coal industry will basically achieve the goal that the discharge of all pollutants meets the standards; the ecological environment of mining areas improves significantly; a batch of large and medium coal mines are established as clean coal production demonstration mine areas.

2. Long-term environmental protection indicator limit

Based on the coal environmental control during the "12th Five-Year Plan" period, by 2020, environment quality of China's coal mining areas and key coal producing cities (counties and districts) will be comprehensively improved; the system of sustainable development of coal economy and ecological benign cycle will be established; 80% of coal mining areas will reach the level of clean production demonstration coal mining areas. See Table 3.3 for development goals for efficient utilization of waste resources in all regions in 2020.

Table 3.2 Development goals and major measures for efficient utilization of waste resources in all regions in 2015

Region	Main indicators (%)				Major measures
	Mine water utilization rate	Coal gangue utilization rate	Coalbed gas utilization rate	Land reclamation rate	
North China and East China	75	75	60	40	All large, medium, and small coal enterprises have perfect environmental protection facilities to realize the coordinated development of regional economy and ecological mining areas
Northeast China	75	75	55	45	In restoring and developing production implement the clean production strategy, strengthen environmental protection, and carry out the governance and restoration of ecological environment after the shutting down of coal mines
Central China	75	75	55	45	Actively solve the ecological and environmental problems in coal production, and carry out the promotion of clean production and circular economy
Northwest China	95	75	60	40	The coal mine development and construction layout, development scale and development strength must be identified; prior to the completion of new mining areas, coal mining water conservation test must be conducted and detailed planning and measures for soil and water conservation must be made; coal environmental control must be strengthened to achieve the goal that the discharge of all pollutants meets standards and the comprehensive utilization of associated resources and wastes of coal must be improved
Southwest China	70	75	55	50	Comprehensively promote clean production, realize the combination of clean production and clean coal technologies and close integration of comprehensive utilization of associated resources of coal measures and environmental and geological disaster prevention and control and change the present situation of backward environmental protection

Table 3.3 Development goals for efficient utilization of waste resources in all regions in 2020

Region	Main indicator (%)			
	Mine water utilization rate	Coal gangue utilization rate	Coalbed gas utilization rate	Land reclamation rate
North China and South China	80	80	65	50
Northeast China	80	80	60	45
Central China	85	85	55	45
Northwest China	95	80	55	45
Southwest China	70	85	55	70

3.1.3 Solutions and Policy Suggestions

Coal development, especially large-scale coal base construction, should be based on the protection of the ecological environment. In the long run, there are many factors affecting and constraining the large-scale development and utilization of coal bases, especially the shortage of water supply. As 13 large coal bases are located in areas characterized by fragile environment and water shortage or in densely populated and economically developed areas, the highly centralized and large-scale coal mine-dominated coal mining and utilization mode will definitely result in the large area underground water-level decline, farmland subsidence, house cracking and depression and relocation of villages and lack of comprehensive planning might lead to social instability.

During the "12th Five-Year Plan" period, China's coal industry should take into consideration its own characteristics and balance industrial development and environmental protection based on the principle of protective development and increasing income and reducing expenditure. Specific measures include: ① base production on water supply and make reasonable planning to control the coal production of areas with fragile ecological environment. ② Vigorously adjust economic structure; strictly limit the development of heavy chemical industry enterprises that use a large amount of water; actively develop circular economy and ecological economy; protect environment and promote the benign development of coal development. ③ Explore underground water and surface water resources in a protective way. ④ Vigorously improve the comprehensive utilization of waste resources.

The guiding ideology is as follows: To continue to thoroughly implement the scientific outlook on development, take a new road to industrialization, speed up the industrial and product structure adjustment of coal enterprises, and utilize and dispose of the "three-waste" resources of coal mines in a concentrated, scientific, reasonable, and effective way based on the scientific mode of developing mining areas into circular economy parks; carry out "exchanging coal gangue for coal" to realize terminal solid waste disposal and vertical ecological renovation of the well underground and above the ground in the subsidence area, develop the vegetation greening of mining areas in the carbon sequestration model and set the producing of thermal and clean products by the circular economy parks as the goal to achieve the basic balance between coal development and environmental capacity, promote the healthy and sustainable development of the coal industry, and construct ecologically civilized mining areas.

3.1.4 Summary of Environmental Protection Constraints in Coal Development

Environmental problems in coal mining areas are in essence development problems and will finally be solved through economic laws and market mechanism. In recent 5 years, China's coal industry has developed very rapidly and the development layout, development mode, development scale, economic structure, and management methods of the coal industry have undergone fundamental changes. However, at present the coal industry still has a lot of problems; for example, the preferential tax policy for comprehensive utilization of waste resource is not implemented; environmental protection funds are not in place; environmental protection technology research is not in place; relevant environmental protection standards are not in place. The delayed formulation of environmental protection policies and measures affects the successful promotion of environmental protection work conducted by enterprises. In order to solve environmental protection constraint factors in coal development, we should carry out work in the following aspects:

(1) Speed up the comprehensive control of subsidence areas to construct ecological economy. A lot of resource-based cities in China, especially many mining areas where resources will soon be exhausted, are built up based on coal development. From the perspective of vigorously developed ecological economy, we should carry out all-round rectification and governance including gangue dump management, land reclamation, and renovation of the shanty towns, actively promote the experience of constructing ecological economy of Fuxin, Huainan and Kailuan mining areas, and compile unified ecological construction plan. The Chinese central government and all provincial governments should make unified land reclamation standards and the standards for the collection of the ecological environment governance deposit and strengthen the research on the subsidence area control technology.

(2) Vigorously implement comprehensive utilization of resources to save energy and reduce emission.

    (1) Promote advanced energy-saving and emission reduction technologies and experiences, develop carbon reduction measures and technologies in the coal industry, constantly increase coal seam gas drainage and utilization,

expand utilization of cooking gas and tar oil, and gradually reduce the venting amount.

(2) Rectify and ban ecological damage and environmental pollution, waste of resources, and the mining of high-sulfur coal mines in accordance with the law, appropriately control total raw coal production, reduce total discharge of the waste, and promote the advanced experience of "zero" discharge of pollutants.
(3) Reform mine development layout and mining process, reduce coal gangue discharge by forbidding the discharge of coal gangue in new mines and encouraging old mines to create conditions to prevent discharge of coal gangue, strengthen the underground filling technology, and greatly reduce surface subsidence.
(4) Adjust the economic structure of the coal industry, and change the economic growth mode. Based on environmental capacity of the coal development regions, increase the strength of macroeconomic regulation and control; in the coal development process, focus on clean production, change the economic growth mode, and formulate economic and technical policies for the development of ecological, circular, and low carbon economy.
(5) Establish the industry environmental protection supervision system, and improve environmental protection level. In recent years, coal production has increased sharply; environmental protection funds have been lacking; relevant regulations have lagged behind; effective unified supervision mechanism of environmental protection in coal mining area has been lacking. During the "12th Five-Year Plan" period, the Chinese government should change the development mode, establish effective ecological compensation mechanism, prepare environmental protection standards for underground mining, surface mining, construction period and operation period and unified and organized environmental protection supervision system, broaden the financing channels, issue supporting laws, regulations, and policies, and enhance environmental protection level.
(6) Achieve sustainable development of circular economy. Establish the scientific outlook on development and the idea of coordinated development of economy, environment, and resources, realize the reduction, reclaiming, and reusing of pollutants in mining areas to maximize resource value and comprehensive benefit, and form the development mode of virtuous cyclic utilization. Specific measures are as follows: ① Vigorously promote energy conservation and emission reduction. ② Comprehensively promote clean production. ③ Vigorously carry out comprehensive utilization of resources, and maximally realize reclamation of wastes and recycling and reusing of renewable resources. ④ Vigorously develop environmental protection industry, focus on the development of environmental protection technology and equipment, and realize the sustainable development of mining areas. For intensive coal production areas, establish laws and regulations as soon as possible to promote the development of circular

economy, incorporate the comprehensive governance of associated resources and wastes of coal produced in coal production (coal gangue, mine water and coal slime) into legal provisions, and mobilize the whole society to participate in it.

3.2 Coal-Fired Power Generation

3.2.1 Present Situation of Environmental Impacts and Control

Due to the characteristics of China's energy resource endowment, China's power source structure is dominated by coal-fired power. See Fig. 3.1 for main pollution generating links of coal-fired power plants.

3.2.1.1 Smoke and Dust

1. Main environmental impacts

The smoke and dust pollution of the coal-fired power plant mainly refers to the ash content in coal that is discharged into the air in the form of flying ash, leading to air pollution in the coal combustion process. The smoke and dust emission mainly depends on the amount of ash content in coal, boiler combustion mode and dust removal effect of the smoke and dust treatment device. Smoke and dust have many impacts on environment. Through the dust removal of efficient dust removal device (with dust removal efficiency higher than 99%), generally the smoke and dust particles discharged into the air are particulate matters (PM2.5) and smoke particles usually do harm to the respiratory system. Due to the combined effect of primary particulate matters (smoke and dust) and secondary particulate matters generated from gaseous pollutants, there emerges smog and haze which affect the visibility of the atmosphere, leading to environmental pollution.

2. Main control technology

(1) Technology progress. China's coal-fired power plants have witnessed the development of flue gas dust removal technology. In terms of the application of precipitator, at the very beginning cyclone precipitator, multi-tube precipitator, and water film precipitator were used; in the 1980s, electrostatic precipitator was widely used; in recent years as the pollution discharge standards have becoming increasingly stringent, more and more bag-type precipitator and electric-bag-type precipitator have been used and new dust removal technologies and processes have been further developed and utilized. The smoke and dust control technology of coal-fired power plants has developed into the stage

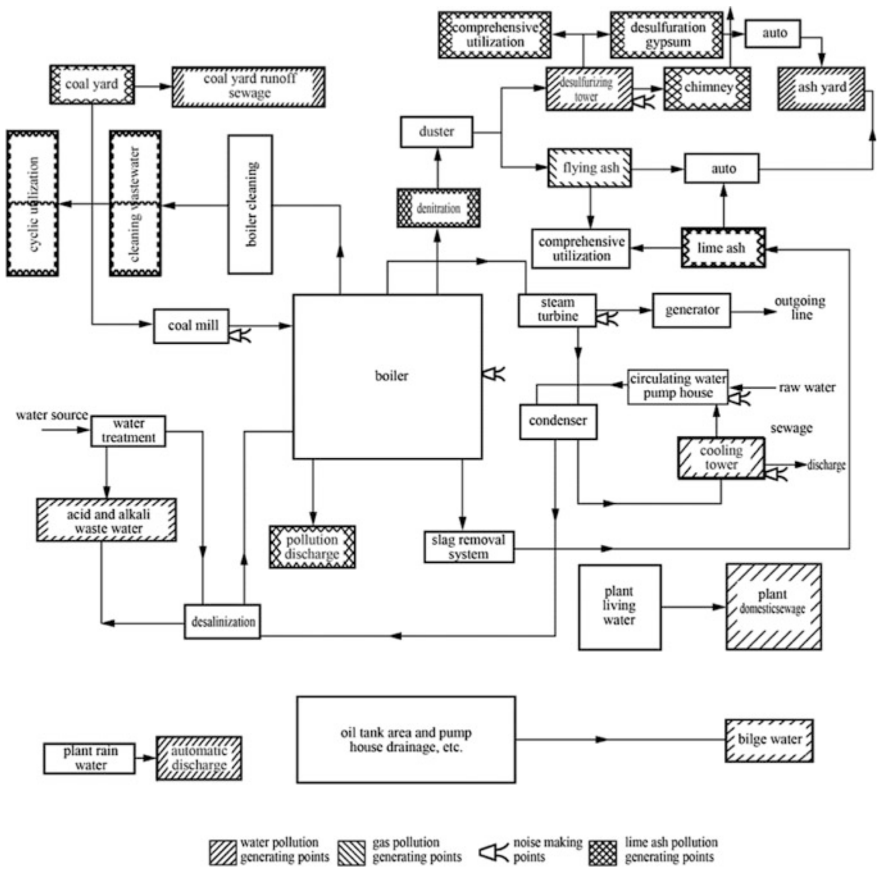

Fig. 3.1 Main pollution generating points of coal-fired power plants

of using best available techniques (BAT). By the end of 2013, the proportion of the electric precipitator, bag-type precipitator, and electrostatic-fabric integrated precipitator in all precipitators used by coal-fired power plants are 79.5, 9, and 11.5%, respectively. See Fig. 3.2 for the change of dust removal technology of China's coal-fired power plants in various stages.

BAT is defined as the latest development stage of all production activities, processes, and relevant operations. It shows the applicability of a particular technique when it meets the discharge limit or when it cannot meet the discharge limit and no other specified technique is available; this technique can be used to minimize the amount of pollutants discharged into environment. "Techniques" should include the application of techniques and the design, construction, repair, operation, and removal of facilities. "Available techniques" refer to the techniques that have developed based on a certain scale or level and can be applied in relevant industrial fields when economic and process conditions permit and the costs and benefits are

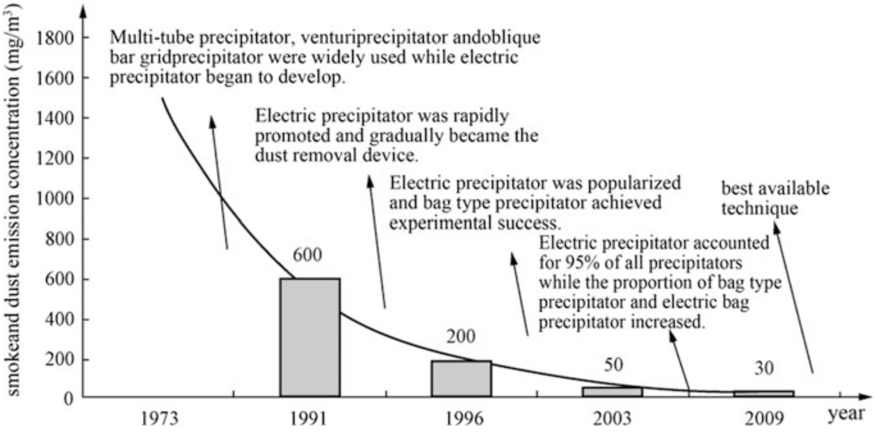

Fig. 3.2 Change of dust removal technology of China's coal-fired power plants in various stages column interpretation best available techniques

taken into consideration. Whether a technique is used and put into production depends on whether it can be reasonably accepted by the operator. "Best" refers to the maximization of effectiveness based on the comprehensive consideration of environmental protection.

(2) Main existing problems

(1) Electric dust removal technology. As the mainstream dust removal technology in the electric power industry, with the decrease of the limit of the smoke and dust emission concentration, electric dust removal technology is facing some problems to be solved urgently. For example, most of China's coal-fired power plants do not have fixed coal sources, burn coals mixed with inferior, and have poor flue gas working conditions. Electric precipitator is sensitive to smoke and dust, and coal quality changes will reduce the efficiency of dust removal. As the corona wire of conventional electric precipitator largely uses barbed electrode and the matched power supply generally uses the low-power frequency equipment, conventional electric precipitator has high energy consumption; conventional electric precipitator has installation and debugging defects. According to the requirements for the special discharge limit in "key areas" (20 mg/m^3), most electric dust removal devices of coal-fired power plants should be upgraded.
(2) Bag-type dust removal technology. Main problems found in the operation of the bag-type precipitator include: ① Generally speaking, due to the short application time, bag-type precipitator used by China's coal-fired power plants needs to be improved in design, manufacturing, and operation. ② Filtering bag has a short service life. The service life of most filtering bags is less than 30,000 h, while the filtering bags used by a few power plants need to be changed every year and even every few months. ③ Dust removal efficiency is

unstable. At the initial stage of the operation, bag-type precipitator has high dust removal efficiency, but some time later, the holes in the bag cannot be easily identified and it is hard to change the bag on the production line. As a result, the actual smoke and dust emission concentration will increase. ④ There are a lot of factors that affect the dust removal effect, and bag-type precipitator has high requirements for design, manufacturing, installation, debugging, maintenance, and operation management. ⑤ Bag-type precipitator has large workload, high operation cost and poor examination and repair work environment.

(3) Electric-bag dust removal technology. Main problems found in the operation of the electrostatic-fabric integrated precipitator are as follows. Electrostatic-fabric integrated precipitator has certain advantages in technical indicators and economical efficiency, but due to its short application time some key technical problems remain to be solved, for example, structure arrangement, impact of cathode discharge on the filtering bag, filtering bag replacement, extremely short service life, low reclamation rate of old bags, and large equipment pressure loss.

3. Present situation of emissions and emission control

With the smoke and dust control technology progress, the dust removal efficiency of China's coal-fired power plants has increasingly improved. Although the installed power capacity and generating capacity have continued to grow rapidly, the annual smoke and dust emissions have been effectively controlled. In 2013, China's annual emissions of electric smoke and dust were about 1.42 million t and smoke and dust emissions per unit thermal power generating capacity were 0.34 g/kWh. See Fig. 3.3 for smoke and dust emissions of China's thermal power plants between 2001 and 2013.

Column Interpretation

Analysis of Control of Particulate Matters Emissions from Thermal Power Plants

I. Emission Characteristics

Particulate matters emitted by coal-fired power plants can be divided into two categories, primary particulate matters directly emitted from power plants and secondary particulate matters that are generated from particulate matters emitted into the air in the form of gas (such as SO_2, NO_x, SO_3 and VOC) through complex atmospheric physical and chemical processes. Primary particulate matters can be categorized into particulate matters directly emitted from power plants in the form of solid (or liquid) and primary condensed particulate matters that are emitted from power plants in the form of gas or vapor at the temperature of flue gas and condensed into solid (or liquid) in the process of dilution and cooling of smoke plume.

II. Impact Estimation

1. Analysis of emissions of primary particulate matters

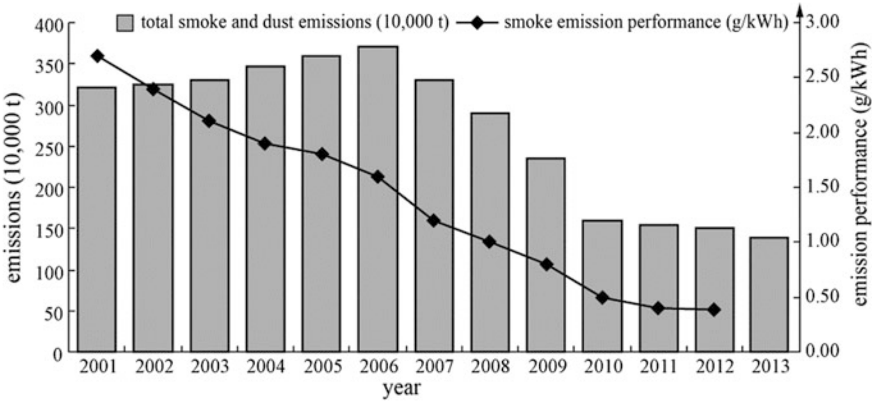

Fig. 3.3 Smoke and dust emissions of China's thermal power plants between 2001 and 2013

In recent years, coal-fired power plants generally use highly efficient dust removal and desulfurization facilities and the smoke and dust removal efficiency of precipitators has reached 99.6% and even higher. More than 90% of the power plants have used the wet limestone–gypsum flue gas desulfurization technology, and the smoke and dust removal efficiency has also reached 50%. The measured results show that more than 90% of the particulate matters in the flue gas emitted from coal-fired power plants are PM10 in which PM2.5 accounts for a large proportion. For example, State Power Environmental Protection Research Institute measured the smoke and dust, PM10 and PM2.5 emitted from six representative coal-fired power plants in the Yangtze River Delta region, and the results show that after the six coal-fired power plants used electrostatic precipitators and wet limestone–gypsum flue gas desulfurization technology, the proportion of PM10 and PM2.5 in the smoke and dust emitted from these power plants were 87.54–95.90% and 41.22–50.31%, respectively, averaging 91.57 and 46.14%, respectively. In a breakdown, the proportion of PM2.5 in PM10 was 42.99–55.14%, averaging 50.45%. Accordingly, conservative estimation was made on the emissions of primary particulate matters emitted from coal-fired power plants. Suppose all the particulate matters in the smoke and dust emitted from these power plants were PM2.5, the annual emissions of primary particulate matters of China's electric power industry in 2012 would not exceed 1.5 million t.

2. Analysis of emissions of secondary particulate matters

Water soluble ion aerosol formed by sulfate, nitrate, and ammonia ion generated from the homogeneous or heterogeneous oxidation reaction of SO_2 and NO_x emitted into the air from thermal power plants is an important source of secondary particulate matters emitted from thermal power plants. In recent years, thermal power plants have installed desulfurization and denitration device on a large scale, significantly improving desulfurization and denitrification efficiency. Total emissions and emissions per unit generating capacity of SO_2 and NO_x of the electric power industry have constantly reduced. In the future with technology progress and management innovation, their emissions will further decline; emissions of secondary particulate matters and the proportion of their impact on environment will reduce accordingly. Due to the complexity of the transformation process, the emissions of secondary particulate matters from thermal power plants cannot be estimated accurately.

III. Impact level analysis

According to relevant requirements, thermal power plants should be scattered and located far away from the city in the upwind position steering clear of the dominant wind direction. As thermal power plants are sources of elevated emissions, generally the stacks in thermal power plants are 240 m high. With the flue gas lifting height taken into consideration, the effective emission height is above 500 m, having a small impact on the near-surface environment.

In terms of the impact of the emissions of pollutants from power plants on environment, with environmental protection requirements becoming increasingly strict, the coal-fired power plants in cities mainly use large-scale combined heat and power boilers and take efficient dust removal measures to meet the emission requirement of the new standard, 30 mg/m^3. According to *Technical Guidelines for Environmental Impact Assessment*, we used the atmospheric steady plume dispersion model recommended by the Ministry of Environmental Protection of the People's Republic of China to predict and analyze the impact of PM2.5 emitted from coal-fired boilers. The maximum daily average concentration of particulate matters emitted from one 1025 t/h boiler in a seaside city was 0.0018 mg/m^3; the maximum daily average concentration of particulate matters emitted from one 2060 t/h boiler in a seaside city was 0.0014 mg/m^3; the maximum daily average concentration of particulate matters emitted from one 2060 t/h boiler in a hilly city was 0.0011 mg/m^3. Through analysis we can make the conclusion that when strict measures are taken to meet the new standard, the concentration of particulate matters emitted from large coal-fired power plants in cities is less than 0.002 mg/m^3 and the concentration of PM2.5 is lower, less than 2.6% of the 0.075 mg/m^3, the daily average value of the Class 2 standard specified in *Ambient Air Quality Standard* (GB 3095—2012). Therefore, after the implementation of the *Standard for Emissions of Air Pollutants from Thermal Power Plants* (GB 13223—2011), particulate matters emitted from the high altitude point sources of urban coal-fired power plants have a small impact on the PM2.5 in the air.

3.2.1.2 Sulfur Dioxide

1. Major environmental impacts

The atmospheric emissions of SO_2 in a small range of spatial scales are an important factor affecting China's air and environment quality. However, as it is also an important factor in the formation of acid rain, its sulfur deposition in a wide range of spatial scales basically shows a linear relationship. In addition, minute particles formed through physical and chemical reactions lead to secondary environmental pollution.

Coal combustion produces a large amount of SO_2. The SO_2 emissions from low and short surface sources have the greatest impact on environment. The SO_2 emissions from low and short surface sources account for 20–30% of total SO_2 emissions, but the rate of its contribution to the ambient SO_2 concentration is 60–70%. As power plants use high stacks to emit flue gases, the rate of the contribution of SO_2 emissions from power plants to the impact on environment quality is 1/4 to 1/3 of the proportion of its emissions.

2. Main control technology

At present, the desulfurization methods widely used in China and foreign countries can be divided into three categories: pre-combustion desulfurization, desulfurization in combustion, and flue gas desulfurization.

(1) Pre-combustion desulfurization includes coal washing, coal gasification, liquefaction and the use of mechanical, electromagnetic, and other physical technologies for desulfurization of coal. This method can only remove some of the sulfur (mainly inorganic sulfur) in coal, which cannot solve the problem of sulfur dioxide pollution.
(2) Desulfurization in combustion mainly includes injection of calcium into furnace and the addition of limestone to fluidized bed (i.e., circulating fluidized bed boiler combustion technology) and so on.
(3) Flue gas desulfurization technologies can be divided into three categories, wet, semi-dry, and dry flue gas desulfurization. The desulfurization technology in which both the desulfurization agent and desulfurization products are in the form of aqueous solution or serous fluids is wet flue gas desulfurization; the desulfurization technology in which desulfurization agent is in the form of aqueous solution or serous fluid and desulfurization products are in the dry state or desulfurization agent is in the dry state and desulfurization products are in the form of aqueous solutions or serous fluid is the semi-dry flue gas desulfurization; the desulfurization technology in which both desulfurization agent and desulfurization products are in the dry state is the dry flue gas desulfurization.

Due to the high desulfurization efficiency and mature technology, wet limestone–gypsum flue gas desulfurization technology has become the mainstream technology both in China and foreign countries. By the end of 2013, the proportion of wet limestone–gypsum flue gas desulfurization technology (including carbide slag method, etc.), sea water desulfurization technology, flue gas circulating fluidized bed desulfurization technology, ammonia desulfurization technology, and other desulfurization technologies in all desulfurization technologies is 92.3, 2.8, 2.0, 1.9, and 1.0% respectively. See Table 3.4 for main characteristics of typical flue gas desulfurization technologies.

Table 3.4 Main characteristics of typical flue gas desulfurization technologies

Item	Wet limestone–gypsum flue gas desulfurization	Seawater desulfurization	Flue gas circulating fluidized bed desulfurization	Ammonia desulfurization
Sulfur content of applicable coal (%)	A wide range of applications	<1.5	<1.5	A wide range of applications
Desulfurization efficiency (%)	>90	>85	About 90	>90
Proportion of electricity consumption in total generating capacity (%)	1.5–2	About 1	Relatively small	About 1
Equipment floor area	Large	Large	Relatively small	Relatively large
Scaling and blocking	Yes	No	No	Yes
Slag state	Wet	–	Dry	Dry
Operating cost	High	Relatively low	Relatively low	Relatively high
Desulfurization by product	Gypsum	None	Mixtures of dust, $CaSO_4$, $CaSO_3$, and CaO	Ammonium sulfate
Technology maturity	Large-scale application in China and foreign countries	Large-scale application in China and foreign countries	Large-scale application in China and foreign countries	Application in China

Since 2005, China's coal-fired power plants have begun to implement large-scale flue gas desulfurization. By the end of 2013, total capacity of flue gas desulfurization units in thermal power plants that have been put into operation was 720k MW, accounting for 91.6% of the capacity of the in-service coal-fired generating units in China. If the circulating fluidized bed boilers with the function of desulfurization are taken into consideration and the units planned to be shut down are deducted, the proportion of desulfurization units to coal-fired generating units was close to 100%. See Fig. 3.4 for application of flue gas desulfurization units in China's coal-fired power plants between 2005 and 2013.

3. Present situation of emissions and emission control

In 2013, China's sulfur dioxide emissions were 20.439 million tons, down 3.48% over 2012. According to the statistical analysis of China Electricity Council,

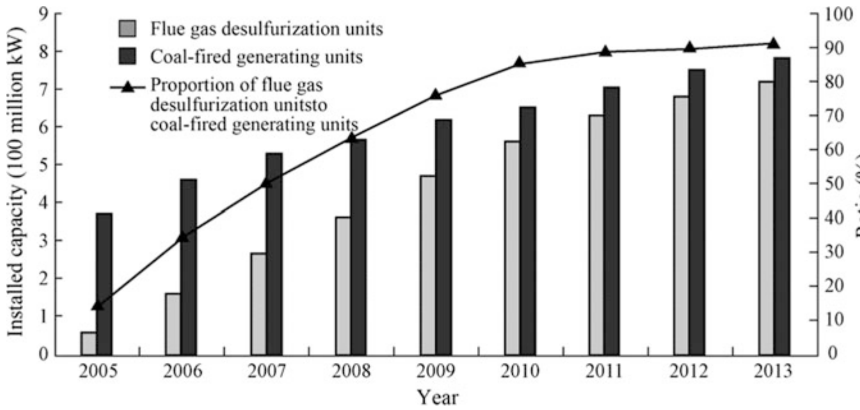

Fig. 3.4 Application of flue gas desulfurization units in China's coal-fired power plants between 2005 and 2013

in 2013 China's sulfur dioxide emissions from electric power generation were 7.8 million tons, down 11.7% over 2012, equivalent to sulfur dioxide emissions from electric power generation in 1999 and sulfur dioxide emissions from electric power generation accounted for 38.2% of China's total sulfur dioxide emissions. In 2013, China's sulfur dioxide emissions per kilowatt hour of thermal power were 1.86 g, reducing by 0.39 g as compared with 2012, lower than America's (in 2012, America's sulfur dioxide emission performance per unit coal-fired generating capacity was 2.44 g/kWh). See Fig. 3.5 for China's sulfur dioxide emissions and sulfur dioxide emissions from electric power generation between 2001 and 2013.

3.2.1.3 Nitrogen Oxide

1. Major environmental impacts

NO_x is an important factor in the formation of acid rain, precursor of photochemical smog that contains pollutants, mainly ozone and one of the important sources of nutrient nitrogen element in lakes and other water bodies. In addition, the ultrafine particles in secondary pollutants NO_x forms are an important source of smog and haze in city clusters and regions. More than 95% of NO_x emitted from coal-fired power generation are NO, but NO can be easily oxidized by oxidizing substances in the atmosphere into NO_2.

2. Main control technology

Methods for controlling nitrogen oxide emissions from thermal power plants can be categorized into two categories, low NO_x combustion technology which is used to control the generation of NO_x in the combustion process and flue gas denitration technology which is used remove the generated NO_x from the flue gas.

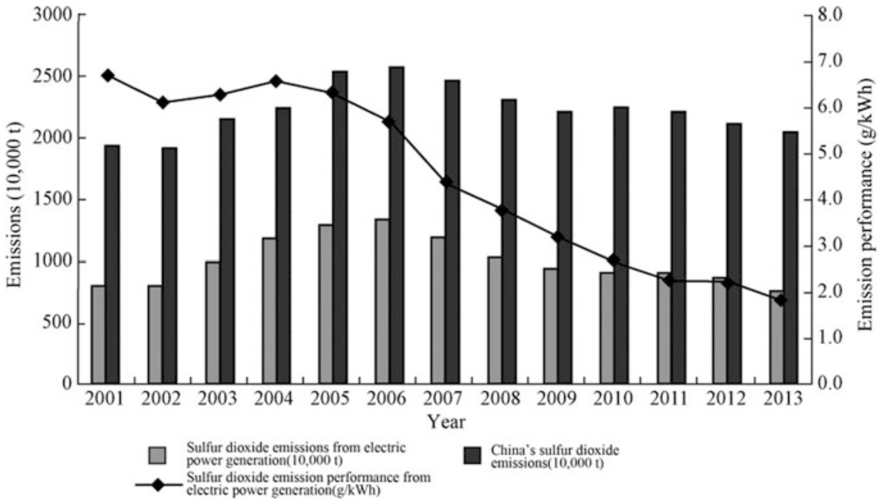

Fig. 3.5 China's sulfur dioxide emissions and sulfur dioxide emissions from electric power generation between 2001 and 2013. *Notes* China's sulfur dioxide emissions are based on Report on the State of environment of China, while China's sulfur dioxide emission performance from electric power generation is based on the statistical analysis of the electric power industry

Low NO_x combustion technology is the main method widely used to control the formation and emissions of nitrogen oxides from thermal power plant and mainly includes the low NO_x burner (LNB), air classification technology, and fuel-staged combustion (re-combustion).

The flue gas denitration technology widely used by thermal power plants mainly includes selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and SNCR/SCR combined denitration technology. SCR technology is currently the most widely used commercial application of flue gas denitration technology. See Table 3.5 for main control technologies for nitrogen oxide emissions from thermal power plants.

Since the "10th Five-Year Plan" period, all the newly built coal-fired generating units use the low NO_x combustion mode as required. A number of existing units are also equipped with low NO_x burners through technical reconstruction. According to statistics of China Electricity Council, by the end of 2013 the capacity of flue gas denitration units that had been put into operation in thermal power plants was 430k MW, accounting for 50% of the capacity of in-service thermal power generating units in China; the proportion of the capacity of denitration units to the capacity of coal-fired generating units reached 55, 5% higher than that in America; most thermal power plants used the SCR technology. See Fig. 3.6 for application of flue gas denitration units in China's thermal power plants between 2005 and 2013.

3. Present situation of emissions and emission control

Since the "12th Five-Year Plan" period, China's electric power industry has constantly strengthened the control of nitrogen oxide emissions. In 2013, China's

Table 3.5 Main control technologies for nitrogen oxide emissions from thermal power plants

Technology	Control effect of nitrogen oxides	Advantages	Disadvantages
Air-staged combustion (OFA)	Reducing nitrogen oxide emissions by 30%	Low investment and rich operating experience	It is not applicable to all furnaces, and it is possible to cause furnace corrosion and slagging and reduce the combustion efficiency
Reducing the number of burners put into operation	Reducing nitrogen oxide emissions by 15–30%	Low investment, conducive to boiler reconstruction, rich operating experience	It is possible to cause furnace corrosion and slagging and increase carbon content in the fly ash
Fuel-staged combustion	Reducing nitrogen oxide emissions by 50–60%	It is applicable to newly built boilers and existing boiler retrofitting; it can reduce the formed nitrogen oxides; it requires medium investment	It might require secondary fuels, may be required, and increases carbon content in fly ash
Low oxygen combustion	Reducing nitrogen oxide emissions by 20%	Minimum investment and rich operating experience	It increases carbon content in fly ash
Flue gas recirculation (FGR)	Reducing nitrogen oxide emissions by 20%	It can improve mixed combustion and requires medium investment	Unstable flame; increasing the number of recycling fans; not widely used
Low NO_x burner (LNB)	When it is combined with air-staged combustion, it can reduce nitrogen oxide emissions by 60%	Suitable for newly built boilers and existing boiler reconstruction; medium investment; rich operating experience	Its structure is more complex than the conventional burner; it is possible to cause the furnace slagging and corrosion and reduce the combustion efficiency
Selective non-catalytic reduction (SNCR)	Large units can reduce nitrogen oxide emissions by 25–40%; small units can reduce nitrogen oxide emissions by 80% when it is combined with LNB and OFA	Occupying a small area; not affected by the fuel; medium investment; having a small impact on the air preheater	NH_3 escape rate is high, and denitration efficiency is affected by the flue gas flow rate, temperature distribution, and the distribution of nitrogen oxides in the furnace, which is not easy to control
Selective catalytic reduction (SCR)	Reducing nitrogen oxide emissions by 95%	High denitrification efficiency	Occupying a large area; high investment and operation cost; the system pressure loss is large; easy to lead to SO_2 oxidation
SCR/SNCR	Reducing nitrogen oxide emissions by 95%	Moderate investment and high denitration efficiency	Large units are yet to pass industrial tests, and the flow field is not easy to control

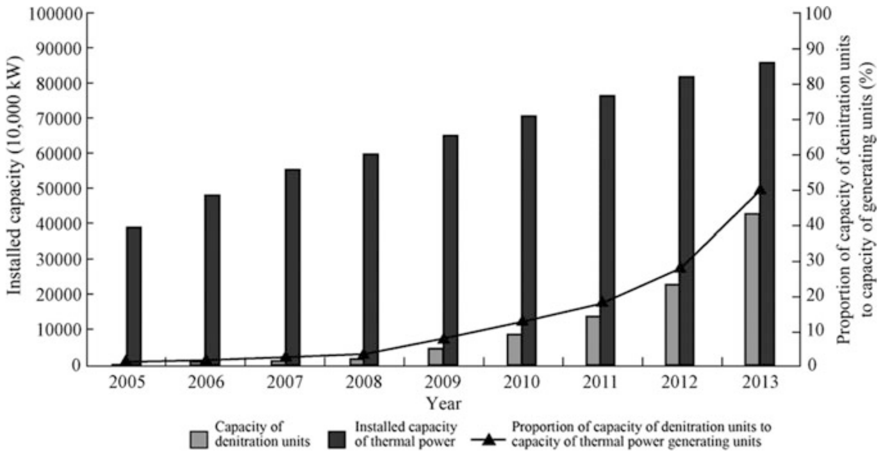

Fig. 3.6 Application of flue gas denitration units in China's thermal power plants between 2005 and 2013

nitrogen oxide emissions were 22.273 million tons, down 4.72% over 2012. According to the statistical analysis of China Electricity Council, in 2013 China's nitrogen oxide emissions from electric power generation was 8.34 million tons, down 11.7% over 2012 and accounting for about 37.4% of China's total emissions of nitrogen oxides. In 2013, nitrogen oxides emissions per kilowatt hour of thermal power was 1.99 g, reducing by 0.43 g or 17.8% as compared with 2012. See

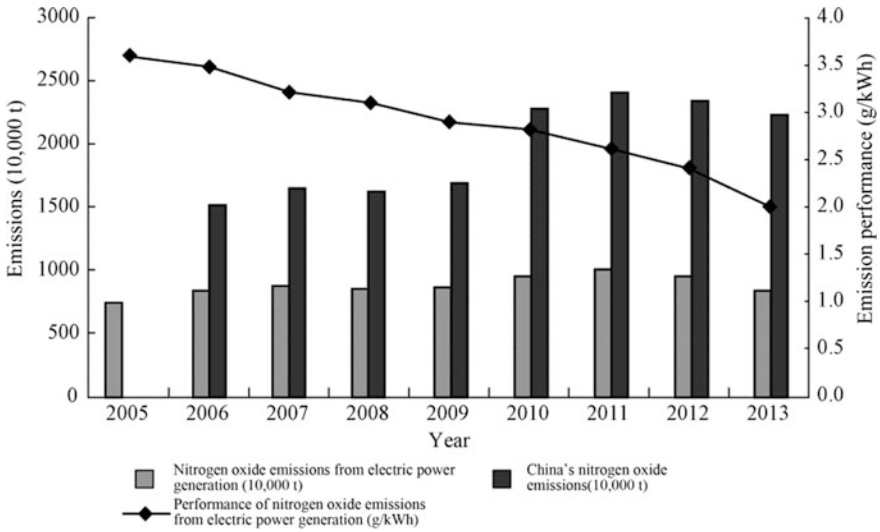

Fig. 3.7 China's nitrogen oxide emissions and nitrogen oxide emissions from electric power generation between 2005 and 2013

Fig. 3.7 for China's nitrogen oxide emissions and nitrogen oxide emissions from electric power generation between 2005 and 2013.

3.2.1.4 Heavy Metals in Flue Gas

1. Major environmental impacts

Coal contains traces of heavy metal elements. When coal is burned at a high temperature, some of these heavy metal elements will volatilize and change into metal vapor which, in the lower part of the flue pipe, gathers on the surface of submicron particles through nucleation, coagulation, and condensation as the temperature falls and is discharged into the air or polluted water resources, doing great harm to environment and human health. According to the current statistics, China has detected 47 kinds of trace elements and those that have attracted the most attention are mercury, cadmium, and chromium. Especially mercury, even at a very low concentration, is extremely toxic to human beings and wildlife. Emissions of mercury from human activities, mainly from coal-fired power plants, account for 10–30% of total mercury emissions.

2. Main control technology

The methods for controlling mercury emissions from coal combustion can be divided into three categories: pre-combustion control, control in combustion, and post-combustion control. Pre-combustion control mainly includes coal washing technology and chemical desulfurization process; combustion control is mainly achieved through the change of combustion conditions and the injection of the solid adsorbent into the furnace; post-combustion control is mainly achieved through the use of activated carbon, fly ash, calcium-based absorbents, and some new absorbents to reduce mercury emissions. See Table 3.6 for the average demercuration efficiency of existing flue gas pollution control methods.

3. Present situation of emissions and emission control

At present, special technology for removing mercury has not been used in China, but the widely used electrostatic precipitators and wet flue gas desulfurization devices and the rapidly developing flue gas denitration devices can effectively reduce the mercury emissions from coal-fired power plants and are the main means used by China's coal-fired power plants to control mercury pollution. Some

Table 3.6 Average demercuration efficiency of existing flue gas pollution control methods

Control measures	Mercury removal rate (%)
Electrostatic precipitator (ESP)	10–30
Fabric filter (FF)	20–40
ESP/FF + wet flue gas desulfurization (WFGD)	65–85
SCR + ESP/FF + WFGD	70–95

scholars and research institutes have estimated the mercury emissions from coal combustion in China:

(1) According to estimates made by Tsinghua University, in 2000 China's atmospheric mercury emissions from coal combustion were 219.5 t of which 76.8 t, or 35%, were from electricity production and China's mercury emissions from coal combustion exceeded the USA.
(2) According to the estimates made by Chinese Research Academy of Environmental Sciences in 2006, in 2003 China's atmospheric mercury emissions from coal-fired power plants were 89.4 t of which 18.5 t were Hg0, 1.9 t, particulate mercury (Hgp) and 69.0 t, Hg2.

3.2.1.5 Wastewater

1. Major environmental impacts

Wastewater from power plants mainly includes industrial wastewater, domestic sewage, and ash flushing wastewater. In addition, it also includes non-normal drainage from regular maintenance of power plants, for example, cleaning water for dust collectors and air preheaters and wastewater from boiler pickling. If power plants use the DC cooling system, there will be warm water discharge. The industrial wastewater from power plants and domestic sewage usually can meet the discharge standards through treatment or are recycled and reused, making a small impact on environment.

2. Present situation of discharge and discharge control

In recent years, electric power enterprises have actively adopted dry slag removal technology and direct air cooling technology while most newly built power plants have used the wastewater "zero discharge" technology. Through the use of water-saving technology, water-saving technical reconstruction and water management, the improvement of water reuse rate and external drainage discharge, wastewater discharge per unit generating capacity has reduced year by year. In 2013, water consumption per kilowatt hour of electricity of China's thermal power plants was 2.0 g, reducing by 0.15 g as compared with 2012 and wastewater discharge per kilowatt hour of electricity was 0.10 kg, equivalent to that in 2012. See Fig. 3.8 for water consumption and wastewater discharge per kilowatt hour of electricity of China's thermal power plants between 2001 and 2013.

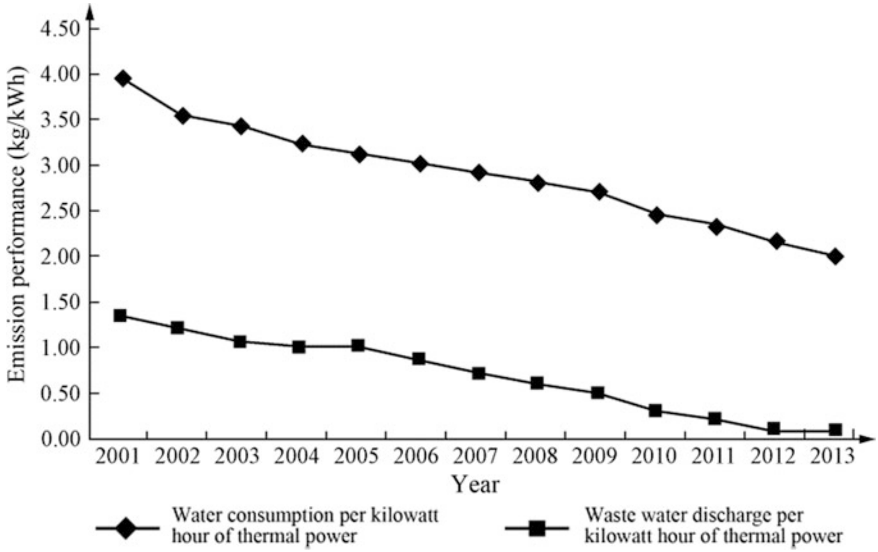

Fig. 3.8 Water consumption and wastewater discharge per kilowatt hour of electricity of China's thermal power plants between 2001 and 2013

3.2.1.6 Solid Waste

1. Fly ash

Fly ash is the main solid waste discharged from coal-fired power plants and one of the industrial solid wastes with the largest discharge capacity in China. If fly ash is not used properly, it will produce dust and other sources of environmental pollution; if used properly, it is a resource. Therefore, proper disposal and comprehensive utilization of fly ash are one of the important tasks of environmental protection for thermal power plants.

Methods for comprehensive utilization of fly ash mainly include production of building materials (cement, brick, block, ceramicite), construction works (concrete, mortar), road building (embankment, road base, pavement), backfilling (structure backfilling, building backfilling, filling of mines, sea beach), agriculture (soil improvement, compound fertilizer production, land reclamation), fly ash filling materials and recycling useful materials and products in fly ash.

According to the statistics of China Electricity Council, in 2013 China's coal-fired power plants produced about 550 million tons of fly ash, up 20% over 2012; fly ash comprehensive utilization rate was about 69%, up 2% over 2012. See Fig. 3.9 for China's fly ash comprehensive utilization rate between 2005 and 2013.

2. Desulfuration gypsum

More and more China's coal-fired power plants have had flue gas desulfurization units installed, producing a large amount of desulfurization gypsum. Desulfurization

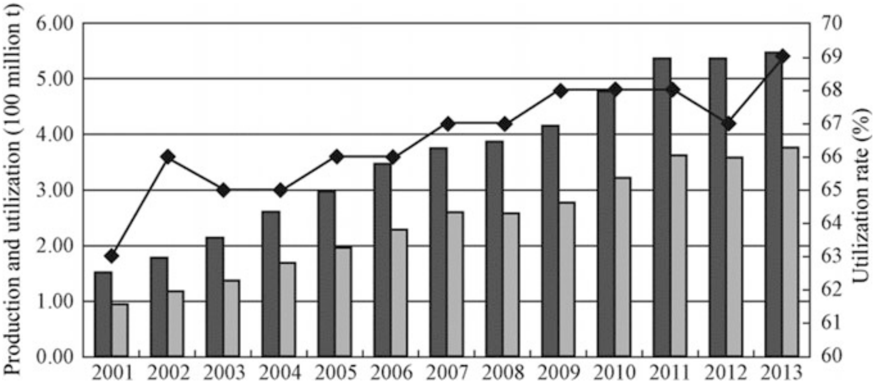

Fig. 3.9 China's fly ash comprehensive utilization rate between 2005 and 2013

gypsum has a very short history in China, and its comprehensive utilization has just started. China's utilization of desulfurization gypsum can be divided into two categories: ① direct use of desulfurization gypsum, mainly used as cement retarding agent and saline alkali soil improvement. ② Roasting desulfurization gypsum calcination into building gypsum which can be used to produce paperbacked gypsum board, gypsum block, stucco gypsum, gypsum plank, and other gypsum products. At present, desulfurization gypsum produced by China's coal-fired power plants is mainly used in the cement and gypsum board industry; in addition, it is also used in the fields such as stucco gypsum, gypsum powder, gypsum binder, agriculture, mine mortar filling, and highway subgrade materials, but does not form industrial scale. Desulfurization gypsum has been in Europe and Japan for more than 20 years ago. In Japan in 1997, utilization rate of desulfurization gypsum reached 98% and it is mainly used for producing paperbacked gypsum and cement; in Europe, it is mainly used for producing paperbacked gypsum board, gypsum block, and self-leveling floor; in the USA, it is mainly used for producing cement, gypsum plaster for building purposes, and various gypsum boards.

According to statistics, in 2013 China's electric power industry produced about 75.5 million tons of desulfurization gypsum, up 11% over 2012 and the comprehensive utilization rate of desulfurization gypsum was about 72%, equivalent to that in 2012. See Fig. 3.10 for comprehensive utilization of desulfurization gypsum in China between 2005 and 2013.

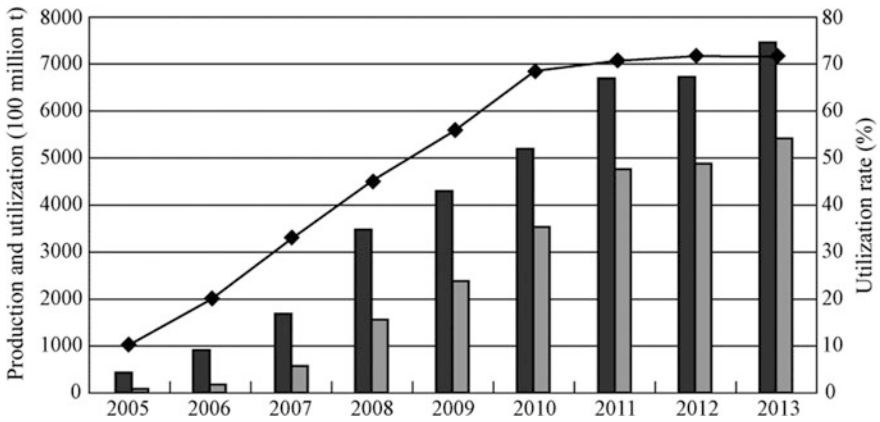

Fig. 3.10 Comprehensive utilization of desulfurization gypsum in China between 2005 and 2013

3.2.2 Analysis of Major Environmental Protection Constraints

3.2.2.1 Analysis of Laws, Regulations, and Policies

1. Requirements of existing laws, regulations, and policies

According to China's current environmental protection regulations and administrative requirements, the emissions of pollutants from electric power (industry) enterprises are measured in three ways. ① Standards for emissions of pollutants from all thermal power plants, for example, *Standard for Emissions of Air Pollutants from Thermal Power Plants* (GB 13223—2011) and *Integrated Wastewater Discharge Standard* (GB8978—2002). ② Requirements for the control of total emissions in a certain region, for example, control of total sulfur dioxide emissions. ③ Environment quality standard for environmental impact assessment of construction projects, for example, *Atmospheric Environment Quality Standard*, *Environment Quality Standard* (GB 3095—2012) and *Environment Quality Standards for Surface Water* (GB 3838—2002). In addition, long-distance transport of cross-border pollutants (mainly heavy metals discharged from power plants) should conform to relevant international conventions, for example, *Helsinki Convention* and *Rotterdam Convention*.

2. Analysis of laws, regulations, and policies made during the "12th Five-Year Plan" period

In terms of laws, environmental *Protection Law of the People's Republic of China* revised and adopted at the Eighth Session of the Standing Committee of the 12th National People's Congress on April 24, 2014, will come into force on January 1, 2015. The revision of environment*al Protection Law of the People's Republic of*

China mainly includes strengthening environmental protection publicity, raising public awareness of environmental protection, drawing the red line of ecological protection, governance of smog and haze pollution, define the legal status of environmental monitoring agencies, improving administrative coercive measures, encouragement and organization of the research into the impact of environment quality on the public health, changing of pollution discharge fee into environmental protection tax, improving the regional restricted approval system and pollution discharge license system, protection of relevant informants, expansion of the main body of environmental public interest lawsuit and increasing environmental violations. The revised *Environmental Protection Law* further defines the responsibilities of the government for environmental protection supervision and management, improves basic environmental protection systems such as the red line of ecological protection, control of total emissions of pollutants, environmental and health monitoring and impact assessment, cross-administrative region joint prevention, strengthens corporate responsibility for pollution prevention and control, increases legal sanctions against environmental violations, and makes systematic regulations on environmental information disclosure by the government and enterprises and the public participation in and supervision of environmental protection. The original 47 provisions are increased to 70, enhancing the law's performability and operability. The revised law is of great significance to protecting and improving environment, preventing pollution and other public hazards, ensuring human health and promoting the construction of ecological civilization and the sustainable development of economy and society. In addition, relevant departments of the Chinese government are arranging to amend the *Law on Prevention and Control of Atmospheric Pollution* and will further increase the strength of pollution prevention and control and strengthen legal liability.

In terms of regulations and policies, the Chinese central government and relevant ministries and commissions have formulated and issued a number of energy conservation and emission reduction plans and notices and put forward specific environmental protection requirements for the electric power industry during the "12th Five-Year Plan" period. For example, the State Council issued the *Action Plan on Prevention and Control of Air Pollution* (Document No. 37, 2013 issued by General Office of the State Council) to carry out comprehensive prevention and control of smog and haze and issued the *12th Five-Year Plan for Energy Development* (Document No. 2, 2013 issued by General Office of the State Council) in which goals for 2015 such as total energy consumption and efficiency, energy production and supply, energy structure optimization, national comprehensive energy base construction, ecological and environmental protection, energy consumption of urban and rural residents and energy system reform and goals for reduction of emissions from electricity production, namely reducing the emissions of sulfur dioxide and nitrogen oxide by 8 million tons and 7.5 million tons, respectively, are set. The Ministry of Environmental Protection issued the *Notice on the Implementation of Special Emission Limits of Air pollutants* (No. 14, 2013) in which the coal-fired generating units in key control regions (47 cities in 19 provinces) are required to, on April 1, 2013, start implementing the special emission limits, namely 20, 50, and 100 mg/m^3 for smoke and dust emissions, sulfur dioxide emissions and nitrogen oxide emissions, respectively; for in-service generating units, those in downtown of these key control regions are required to start implementing the special emission limits on July 1, 2014 and those in non-downtown areas of the key control regions are required to implement the special emission limits during the "13th Five-Year Plan" period. In the *12th Five-Year Plan for Energy Conservation and Emission Reduction* (Document No. 40, 2012 issued by General Office of the State Council), the indicators of the goals of reducing emissions from electricity production are also specified. For example, sulfur dioxide emissions should be reduced from 9.56 million tons in 2010 to 8 million tons in 2015, and a decrease of 16% while nitrogen oxide emissions should be reduced from 10.55 tons in 2010 to 7.5 million tons in 2015, a decrease of 29%. In the *Responsibility Agreement on Goals of Reducing Emissions of Major Pollutants during the "12th Five-Year Plan" Period*, the Ministry of Environmental Protection makes public the *Responsibility Agreement on Sulfur Dioxide and Nitrogen Oxide Governance Projects* signed with State Grid Corporation of China, China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, State Power Investment Corporation, and other major electric power enterprises. In addition, the Ministry of Environmental Protection requires the governance projects listed in the Responsibility Agreement should be completed by the end of 2012 and strengthens the supervision and inspection.

In terms of standard revision, the more stringent version of *Standard for Emissions of Air Pollutants from Thermal Power Plants* (GB 13223—2011) has been officially implemented since January 1, 2012. The new standard tightens the limits of emissions of air pollutants from thermal power plants and becomes the strictest operation regulation for the thermal power enterprises as it is more stringent than all existing laws, regulations, and administrative requirements including the requirements for the control goal of total sulfur dioxide and nitrogen oxide emissions during the "12th Five-Year Plan" period. The latest revised version of *Environment Quality Standard* (GB 3095—2012) has been implemented since January 1, 2012. Compared with the original one, the revised version is stricter and adds the average concentration limit of PM2.5 and the average 8 h ozone concentration limit. It tightens the annual average PM10 concentration limit of the Class 2 standard to 0.07 mg/m^3 and tightens the annual, daily and 1 h average NO_2 concentration limits of the Class 2 standard to 0.04, 0.08 and 0.20 mg/m^3, respectively. National Energy Administration issued No. 4 Announcement of 2012 and approved the release of the 56 standards of the electric power industry. Among these standards, 20 ones are for thermal power generation, 6 ones, for hydropower generation, 2 ones, for new energy power generation, and 28 ones, for power transmission distribution. The approval of standards for resource conservation and clean production including *Technical Specification for Evaluation of Energy Consumption of Coal-fired Power Plants*, *Guidelines for Online Calculation of Coal Consumption of Thermal Power Generating Units*, *Performance of Flue Gas Denitration Devices Used by Coal-fired Power Plants* and *Guidelines for Energy Efficiency, Technical and Economic Evaluation of Distribution Transformers* has promoted the standardization of environmental protection in China's electric power industry.

The revision and issuing of the above regulations, policies, and standards shows that China will further strengthen the control the power of sulfur dioxide, nitrogen oxide and smoke and dust emissions from electricity production and implement more stringent standards for concentration and concentration control during the "12th Five-Year Plan" period.

(1) Analysis of environmental protection constraints. In terms of the impact on environment quality, with the national and industry environmental protection requirements becoming increasingly stringent, coal-fired power plants have high-level dust removal technologies and the comprehensive dust removal efficiency has reached 99% and even higher. The layout of coal-fired power plants has undergone great changes. Except for heat and power plants, new coal-fired power plants are no longer built in cities. In-service power plants have taken measures such as control of pollutant emissions, shutting down of small thermal power generating units and building of large generating units and wet flue gas desulfurization and dust removal to further improve the smoke and dust emission control level of coal-fired power plants. The causes of fine particulate matters are very complicated. In addition to natural factors, pollutant emissions from coal combustion and motor vehicles and construction dust are also important causes. However, through further analysis we find that, as one of the causes of generating smog and haze, pollutant emissions are not resulted from coal combustion of power plants. Instead, a large number of low and short surface sources in cities including industrial small boilers, domestic stoves and scattered coal burning directly emit pollutants into the atmospheric surface layer, contributing more to the concentrations of PM2.5, TSP, SO_2, and NO_x. We cannot use the proportion of the smoke and dust emissions to measure its impact on environment quality.

In terms of compliance of emission standards, the emission limits for new generating units specified in the *Standard for Emissions of Air Pollutants from Thermal Power Plants* (GB 13223—2011) are more stringent than the standards of the same class made by other countries and regions, becoming the most stringent standard in the world. See Figs. 3.11 and 3.12 for comparison of smoke and dust emission standard limits for new and in-service generating units between major countries in the world.

Now, we are going to analyze the technical feasibility of smoke and dust emission control. First, from the analysis of coal ash content, we know that in China ash content in coal reaches 28%, one time or two times higher than that in Europe and America, with ash content in coal in Europe averaging 14.4% and ash content in coal in America averaging below 10%. In addition, as in China the calorific value of coal is lower than that in Europe and America, the difference in ash content in coal between China and Europe and America is even larger. Therefore, in order to meet the same emission standard, China's comprehensive dust removal efficiency

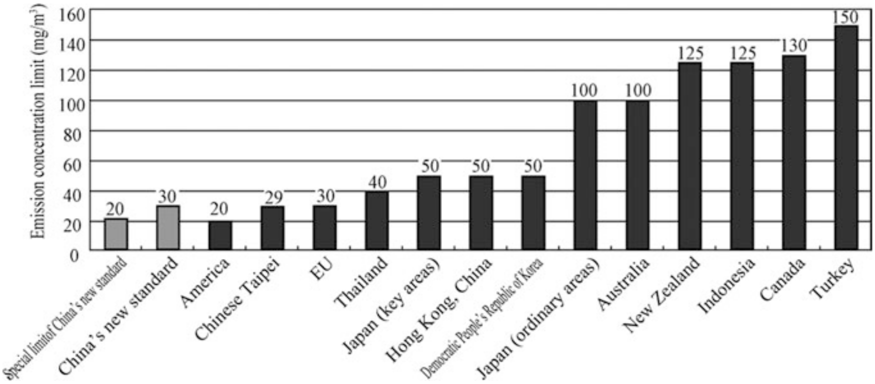

Fig. 3.11 Comparison of smoke and dust emission concentration limits for new large coal-fired power plants between major countries and regions in the world. *Notes* America's and EU's limits are the daily average over a several-day period

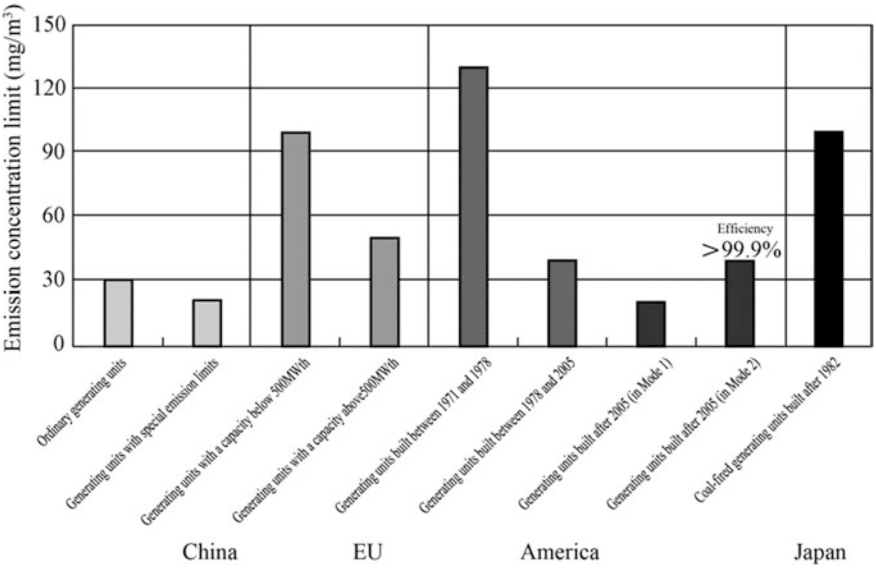

Fig. 3.12 Comparison of smoke and dust emission standard limits for in-service generating units between major countries in the world. *Notes* America's and EU's limits are the daily average over a several-day period

must be higher than Europe and America, which requires China to pay a higher economic cost. Second, from the analysis of the existing dust removal technology, we know that suppose in China the average ash content in coal is 25%, the dust removal efficiency of precipitators must be higher than 99.9% in order to meet the required emission limit of 20–30 mg/m^3. As a result, 73.7% of China's existing generating units must be reconstructed. The capacity of existing electrostatic precipitators must be increased by one to two electric fields or existing electrostatic precipitators must be subject to technology improvement, for example, replacing electrostatic precipitators with fabric filters or electrostatic-fabric integrated precipitator.

From the above analysis, we know that China's control level of smoke and dust emissions from electricity production has reached the international advanced level. What is more, as a result of power plants' optimized layout, smoke and dust emissions from electricity production have made an increasingly small impact on environment and air quality in cities and the smoke and dust emissions from coal-fired power plants are no longer the main cause of environmental pollution. However, as China has made increasingly stringent control requirements for smoke and dust emissions from thermal power plants, most coal-fired power plants have to upgrade and reconstruct precipitators. Specifically, they have to choose from different dust removal technologies, invest heavily in technical reconstruction and make proper arrangements for production and reconstruction in a short period of time.

(2) Analysis of obligatory emission limits in the "12th Five-Year Plan" period. On the one hand, China has tightened requirements for environmental protection. On the other hand, China's dust removal technologies have further developed. Take electrostatic dust removal as an example: The increasingly mature efficient dust removal technologies (system with low-low temperature ESP, electromechanical multi-mode and double-zone ESP, SO_3 flue gas conditioning technology, and moving electrode electrostatic precipitator) have been widely used in China; dust condensation technology has become mature in foreign countries, while some countries in China have mastered its core technology; the filter bag technologies, including high pressure spunlace nondestructive filtering technology, new technology of cleaning filtering materials, surface nanocoating technology, and high temperature hot press laminating technology, are being developed and improved.

In China, the ash content in coal is higher than that in other developed countries, averaging 28%. For example, the annual average ash content in coal of a power generation group between 2010 and 2012 was 28.5, 28.4 and 26.5%, respectively. With the changes in the coal market in recent years, the ash content in coal has also reduced. Suppose the average ash content coal is 28% and the precipitator inlet smoke and dust concentration is 30 g/m^3, in order to meet the emission limit of 30 g/m^3 the comprehensive dust removal efficiency must be higher than 99.9%. However, judging from the actual situation, it is impossible for China's all in-service generating units to completely meet the emission standard. Suppose the comprehensive dust removal efficiency is 99.9%, the smoke and dust emissions from existing generating units will reach 430,000 tons. If the fact that in the key regions the special emission limit of 20 mg/m^3 implemented are taken into consideration, the emissions of in-service generating units are even lower, being about 400,000 tons.

It is predicted that in 2015 due to the higher dust removal efficiency of new generating units and reconstructed existing units, the average dust removal efficiency of coal-fired generating units will increase to 99.75–99.8% and smoke and dust emissions will be about 1.1 million tons; in 2020, the average dust removal efficiency of coal-fired generating units will increase to 99.9–99.95% and smoke and dust emissions will be 0.5–0.6 million tons.

2. Sulfur dioxide

(1) Analysis of environmental protection constraints. China has made specific control requirements for sulfur dioxide emissions from electricity production. Among all the requirements, the new emission standard, namely the revised *Standard for Emissions of Air Pollutants from Thermal Power Plants* and the *Notice on the Implementation of Special Emission Limits for Air pollutants,* are the most stringent. As long as the new standard and requirements for special emission limits are met, all other environmental protection requirements will pose no problem. See Figs. 3.13 and 3.14 for comparison of sulfur dioxide emission standard limits for new generating units and in-service generating units between major countries in the world.

Now, we are going to analyze the technical feasibility of sulfur dioxide emission control. First, in China the sulfur content in coal for electricity production is high and unstable. According to the power environment protection statistics over the years, in 2005 the weighted average sulfur content in coal of above-scale power generation groups was about 0.89% and it increased to 1.02% in 2010. The actual average sulfur content in coal was higher than the designed sulfur content, which might affect the stable sulfur dioxide emissions from power plants that meet the standard. Second, as China's emission standard is the most stringent in the world, in terms of desulfurization technology, except for wet limestone–gypsum flue gas desulfurization technology, all other desulfurization technologies (including dry flue gas desulfurization and sea water desulfurization technology) cannot be used to achieve the stable sulfur dioxide emissions from generating units burning high-sulfur coal that meet the standard. According to the experimental results of Electric Power Research Institute (EPRI) and past experience in engineering practice, it is easy to increase the desulfurization efficiency from 85 to 95%, but the increase from 95 to 99% will cost a high price.

(2) Analysis of environmental protection constraints on thermal power installed capacity. The constraints of sulfur dioxide on thermal power installed capacity fundamentally depend on environment quality requirements mainly including the requirement that the concentration of sulfur dioxide in environment should meet the required quality standard and that the acid deposition caused by sulfur dioxide should meet environmental critical load requirement. Therefore, environment quality requirements are the basis for making requirements for total emissions. However, in the actual operation due to the following reasons,

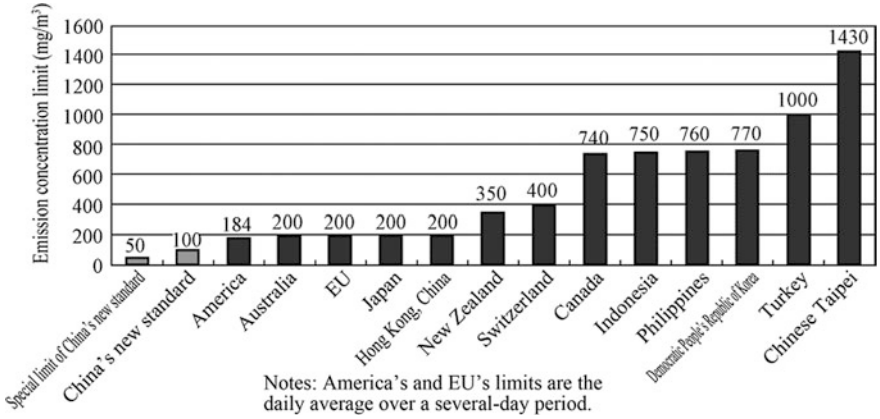

Fig. 3.13 Comparison of sulfur dioxide emission concentration limits for new large coal-fired power plants between major countries and regions in the world

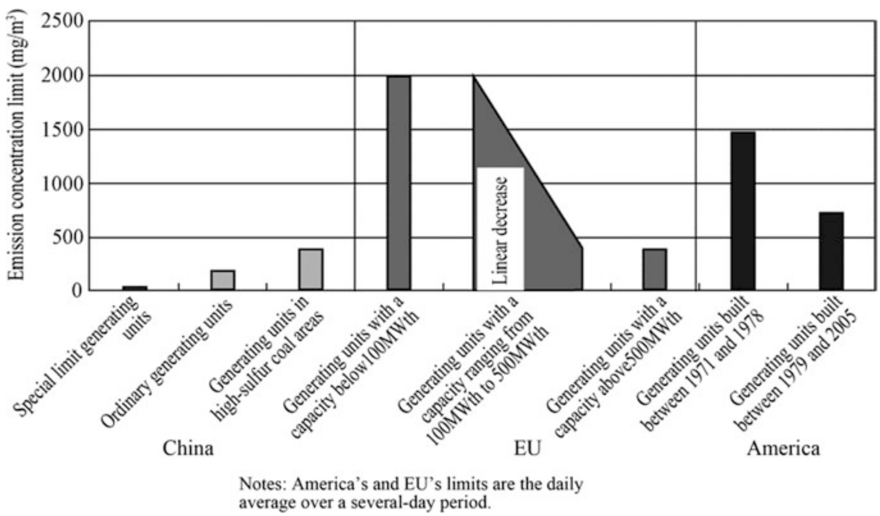

Fig. 3.14 Comparison of sulfur dioxide emission standard limits for in-service generating units between different countries in the world

it is difficult to make control requirements for sulfur dioxide emissions from electricity production from the perspective of environmental quality. ① The impact of sulfur dioxide on environment quality not only depends on sulfur dioxide emissions, but also various factors such as the layout of emission sources, pollutant emission mode (number and height of stacks and flue gas temperature, etc.), terrain conditions of areas where pollution sources are located and atmospheric physical conditions (such as flow field and dispersion parameters) and atmospheric chemical conditions. The relationship between sulfur dioxide emissions and environmental impact is very complicated non-linear relationship. In other words, with the same environment quality requirement, due to a variety of different conditions, allowed sulfur dioxide emissions might vary. ② The impact of sulfur dioxide on environment quality depends on environmental conditions and other conditions in the affected area. For example, in some areas due to the high background concentration, a small amount of new emissions can be accommodated; some areas are sensitive to acid rain while others are not. ③ Acid deposition mainly results from the combined effect of sulfur dioxide and nitrogen oxides. As a result, the limits of sulfur dioxide emissions cannot be made based on the requirement for acid deposition. What is more, China has not set the legal requirement for critical load. ④ Sulfur dioxide emissions from electricity production account for less than 50% of China's total sulfur dioxide emissions. As sulfur dioxide generated in the electricity production process is mainly emitted outside cities and belongs to elevated emissions, the impact of sulfur dioxide emissions from electricity production on the air and environment quality is smaller than other emission sources. Therefore, when all the above-mentioned boundary conditions are uncertain, it is impossible to set the limit for China's total sulfur dioxide emissions. Even if the boundary conditions are identified, theoretically speaking, we can only roughly predict the impact of sulfur dioxide emissions on environment quality through a large number of complicated forecasting tools. In practical application, such forecasting tools can be used to evaluate the pollution situation and optimize the industrial layout, instead of calculating total permitted emissions. Moreover, from the perspective of environment quality requirements, it is unscientific and unrealistic to set the limit of sulfur dioxide emissions from electricity production without considering the emissions of other sources.

However, it does not mean that China cannot set a limit of sulfur dioxide emissions. In both the *Law on Prevention and Control of Atmospheric Pollution* and *12th Five-Year Plan for National Economic and Social Development of the People's Republic of China*, the sulfur dioxide emission control requirement is made. However, it is an administrative requirement made by the Chinese government or relevant departments based on the overall environmental evaluation as well as technical and economic conditions instead of environment quality. During the "12fth Five-Year Plan" period, sulfur dioxide emissions from electricity production can be controlled through technical measures so as to meet the air and environment quality standard requirement. What is more, sulfur dioxide emissions from non-electric power sectors have a greater impact on environment quality. Therefore, from the "12fth Five-Year Plan" period on control of sulfur dioxide emissions from electricity production will still be based on reducing acid deposition and the "administrative" distribution of sulfur dioxide emissions adopted during the "11fth Five-Year Plan" period will continue to be used. The distribution of total emissions will still be based on technical and economic conditions.

Column Interpretation

Environment Quality, Environmental Critical Load, and Acid Deposition

Environment quality: It generally refers to the suitability of the overall environment within a certain range or some environmental elements for the survival, life, and development of human beings.

Environmental critical load: It is the maximum amount of acid deposition that does not lead to the chemical changes in ecological system that have long-term harmful effects.

Acid deposition: It is the process in which acids in the atmosphere drop to the surfaces in the form of precipitation or under the action of airflow. Acids are deposited via two processes, “wet” and “dry deposition”. Wet precipitation generally refers to the process by which acids with a pH normally below 5.6 are removed from the atmosphere in rain, snow, sleet, or hail. Acid rain is the most common form of wet precipitation. Dry deposition is the process by which acids are deposited on the surfaces under the action of airflow. At present, acid rain is most thoroughly studied and acid deposition is usually equated with acid rain.

(3) Analysis of environment protection constraints on the distribution of thermal power installed capacity. Environmental space for the development of coal power in China is affected by many factors. In terms of layout, China’s coal power is mainly distributed in economically developed areas in Central and East China. Due to dense population and industrial concentration, concentrated sulfur dioxide emissions (including emissions from electric power sector and other sectors such as industry and transportation), large amount of sulfur deposition and acid rain, these areas usually have serious environmental pollution problems. By contrast, West and North China abound in resources, but due to backward economic development have relatively a small thermal power installed capacity, though thermal power is developing at a fast speed. In addition, in the mode of balancing power development on the spot, more and more coal has been transferred to the resource-deficient areas in Central and East China and shortage of coal power in these areas has been constantly intensified. In the future with the increase of energy consumption and demand in Central and East China as well as external energy dependence, the electric power safety in these areas will become increasingly prominent.

If the local coal resources, regional economic and social development demand, ecological environment carrying capacity, comprehensive energy transportation capacity, and many other factors are taken into consideration, in the “12th Five-Year Plan” period, coal power development should adjust the traditional balance-focused coal power layout mode in order to adapt to the inevitable development trend of “replacing coal and oil with power and long-distance power transmission”. The major coal production bases in West China are the key areas for the future new coal power development, while the eastern coastal areas with poor energy resources and limited environmental protection space will be the areas with controlled new coal power development.

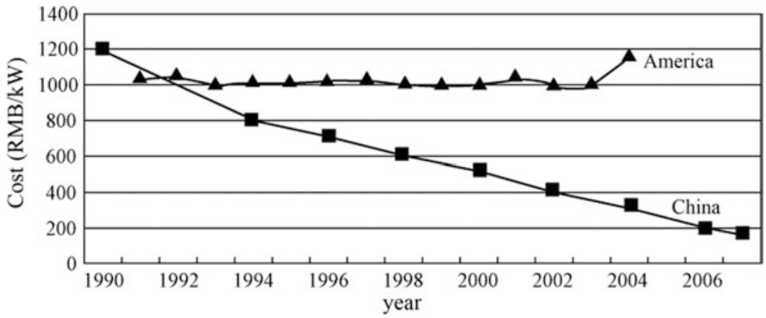

Fig. 3.15 Comparison of average installation cost of flue gas desulfurization device between China and America

(4) Analysis of economic constraints on desulfurization technology

(1) Cost-level analysis. Judging from the cost of the desulfurization project, as China has vigorously promoted the localization and marketization of flue gas desulfurization equipment, the localization rate of desulfurization equipment and materials has reached 90% and even more than 95%. The cost of the desulfurization project has significantly reduced. The cost of flue gas desulfurization per kW of newly built large coal-fired generating units has reduced from RMB 1200 at the end of the "8th Five-Year Plan" period to RMB 500 at the end of the "9th Five-Year Plan" period and then to the current below RMB 200 which is about one-fifth of the cost of America's flue gas desulfurization device. See Fig. 3.15 for comparison of average installation cost of flue gas desulfurization device between China and America.

(2) Analysis of the sensitivity of the change of sulfur content in coal to the cost of removing one kilogram of sulfur dioxide. When the cost of removing one kilogram of sulfur dioxide is used to measure economic cost, sulfur content in coal is most sensitive to economical efficiency of desulfurization, presenting the negative exponential relationship. See Fig. 3.16 for details. For example, if we take 1% as the benchmark of the sulfur content in coal, when the sulfur content in coal increases by one time, the cost of removing one kilogram of sulfur dioxide will reduce by 42%; when the sulfur content in coal reduces by 50% (namely, when sulfur content in coal is 0.5%), the cost of removing one kilogram of sulfur dioxide will increase by 85%.

(3) Analysis of sensitivity of the change of sulfur content in coal to electricity price increment. When the desulfurization efficiency is certain, with the increase of the sulfur content in coal, total amount of removed sulfur dioxide increases accordingly and so does total cost and electricity price. There is a linear relationship between the increase of the sulfur content in coal and the increase of electricity price. When the sulfur content in coal is 1%, desulfurization will increase the electricity price by RMB 0.0151/kWh. If we take 1% as the benchmark of sulfur content in coal, when the sulfur content in coal

increases to 2%, the electricity price will increase by 13%; when sulfur content in coal reduces to 0.5%, the electricity price will reduce by only 4%. It further demonstrates that when total amount of emission reduction is certain, the generating units burning coal with a higher sulfur content have higher economical efficiency of desulfurization.

(4) Analysis of the impact of cost on desulfurization electricity price. The special studies conducted by China Electricity Council show that in addition to the impact of sulfur content on desulfurization electricity price, the impact of change of other cost elements on desulfurization electricity price is as follows. ① The installation of gas heater (GGH) will increase desulfurization investment and electricity consumption, and the desulfurization electricity price of generating units equipped with GGH will be higher than those not equipped with GGH. For example, the difference in desulfurization electricity price between 300 MW generating units equipped with GGH and those not equipped with GGH is RMB 0.003/kWh and the difference between 600 MW generating units equipped with GGH and those not equipped with GGH is RMB 0.002/kWh. ② The annual utilization hours are most sensitive to desulfurization electricity price, followed by investment, electricity price, and unit price of limestone. The following estimates are made based on different sulfur contents in coal and generating units equipped with or not equipped with GGH: When the annual utilization hours change within a range of 20%, the change of desulfurization electricity price ranges from 8.5 to 15.2%; when the investment changes within a range of 20%, the change of desulfurization electricity price ranges from 6.4 to 11.7%; when the auxiliary electricity price changes within a range of 20%, the change of desulfurization electricity price ranges from 5.4 to 7.5%; when the average load changes within a range of 20%, the change of desulfurization electricity price ranges from 3.3 to 5.6%; when the unit price of limestone changes within a range of 20%, the change of desulfurization electricity price ranges from 1.2 to 5.7%. ③ When power plants' sulfur content in coal as received basis is low, investment, auxiliary electricity price, and repair cost are the three major factors affecting the desulfurization electricity price. With the increase of sulfur content in coal as received basis, the proportion of depreciation cost and desulfurization electricity power cost will reduce while the proportion of cost of limestone and other desulfurizing agents will increase and become the fourth major factor affecting the desulfurization electricity price.

(5) Analysis of obligatory emission limits in the "12th Five-Year Plan" period. At present, the average sulfur content in coal for electricity production in China is 1.0–1.1% (for example, the average sulfur content in coal in environmental accounting of an electric power group between 2010 and 2012 was 1.11, 1.08 and 1.15%, respectively). If the average SO_2 concentration at the inlet of desulfurization equipment and the SO_2 emissions of in-service generating units are 2200 and 200 mg/m^3, respectively, and the average desulfurization efficiency is 92%, especially when the flue gas bypass is removed, the operation rate of desulfurization equipment will reach 100% (without considering

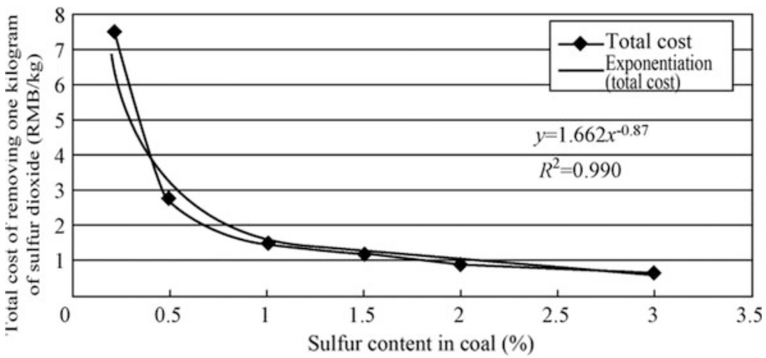

Fig. 3.16 Analysis of sensitivity of change of sulfur content in coal to cost of removing 1 kg of sulfur dioxide

safety factors). If all the emission standards are met (without considering high-sulfur coal and special emission limits), as the high SO_2 emission concentration in high-sulfur coal areas is offset by the low SO_2 emission concentration in key areas, the SO_2 emissions of in-service generating units that meet the standard will be 3.97 million tons. According to the present total emissions accounting mode and the maximum desulfurization efficiency after removal of bypass being 85%, it is predicted that in 2015 the SO_2 emissions from electricity production will be about 6.5 million tons; in 2020, the average desulfurization efficiency will be increased to 90–95% and the SO_2 emissions will be 4 million to 4.5 million tons.

3. Nitrogen oxides

(1) Analysis of environment protection constraints. Similar to requirements for SO_2 emissions, among all the national requirements for nitrogen oxide emissions from electricity production, the new emission standard, the new emission standard, namely the revised *Standard for Emissions of Air Pollutants from Thermal Power Plants* and the *Notice on the Implementation of Special Emission Limits of Air pollutants,* are the most stringent. See Figs. 3.17 and 3.18 for comparison of nitrogen oxide emission standard limits for new generating units and in-service generating units between major countries and regions in the world.

Now, we are going to analyze the technical feasibility of nitrogen oxide emission control. First, due to poor and variable quality of China's coal as well as unstable coal supply, denitration devices have very bad operating conditions and the parameters of flue gas at the inlet of denitration devices are complicated and variable, which makes a negative impact on the design, construction, and operation of denitration devices. Second, in-service generating units, especially coal-fired generating units built after 2000, are generally equipped with low NO_x burners. However, as the existing low NO_x combustion technology cannot meet the requirement of the new standard, the flue gas denitration technology must be used.

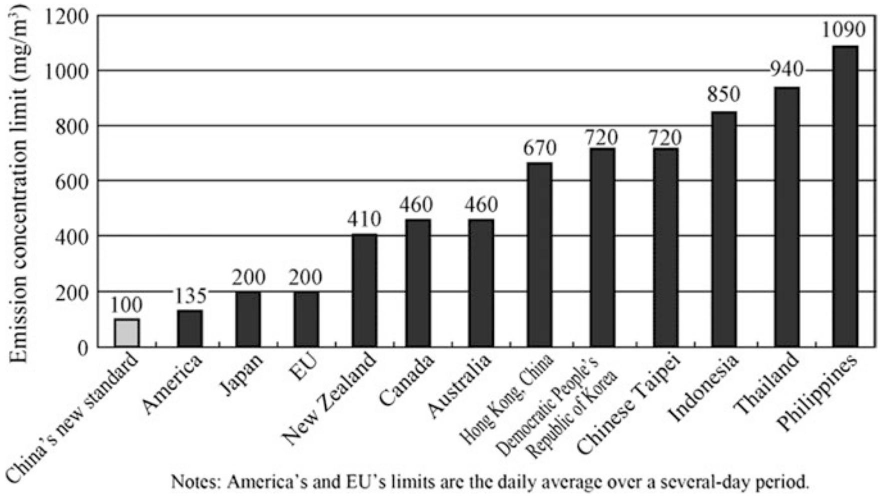

Fig. 3.17 Comparison of nitrogen oxide emission concentration limits for new large coal-fired power plants between major countries and regions in the world

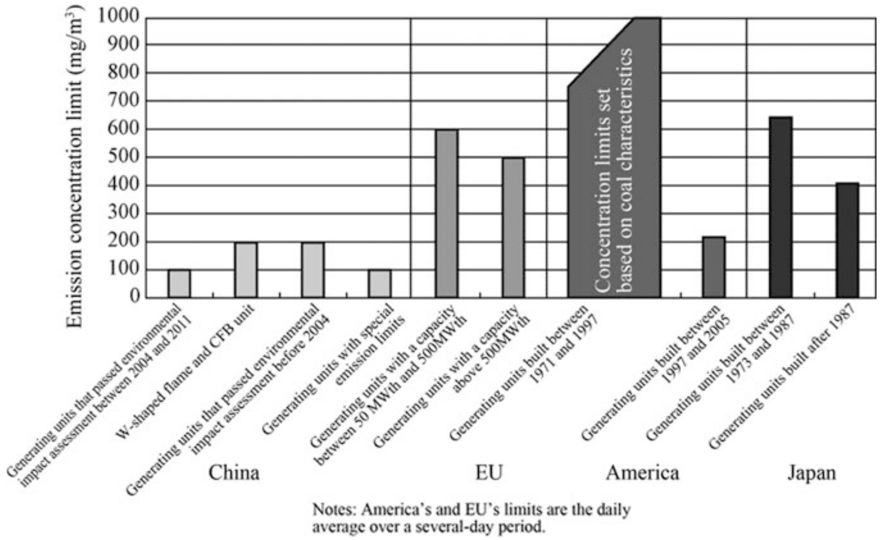

Fig. 3.18 Comparison of nitrogen oxide emission standard limits for in-service generating units between different countries in the world

As double arch flame furnaces produce a large amount of NO_x which even exceeds the processing limit of SCR technology. When using SCR technology alone cannot make nitrogen oxide emissions meet the standard and technical and economic conditions are feasible, the SNCR+SCR method can be considered. If the nitrogen oxide emissions of existing CFB generating units exceed the emission standard of 200 mg/m^3, priority should be given to the SNCR technology.

(2) Analysis of environmental protection indicator limits in the “12th Five-Year Plan” period. In-service generating units, especially coal-fired generating units built after 2000, are generally equipped with low NO_x burners. However, in spite of the use of the low NO_x burner, the concentration of the generated NO_x is closely related to the type of boiler. China’s coal-fired power plants mainly use “four-corner tangentially boiler” and “wall-type (cyclone)” boiler and use the W-shaped flame and CFB boiler as supplement. The four-corner tangentially boiler accounts for 50% of generating units of 100,000 kW and above. The NO_x emissions of various boilers are as follows: four-corner tangentially boiler: 250–800 mg/m^3; wall-type boiler: 350–1200 mg/m^3; W-shaped flame boiler: 800–2000 mg/m^3; CFB boiler: <200 mg/m^3. For four-corner tangentially boilers and wall-type boilers, very mature low NO_x combustion technologies are available, but as the existing low NO_x combustion technologies cannot meet the requirement of the new standard revised in 2011, the flue gas denitration technology must be used. The W-shaped flame boiler is not applicable to low NO_x combustion technologies, so efficient denitration facilities must be adopted.

According to the current situation of denitration reconstruction, it is expected in 2015, in addition to part of the planned shutdown group, 300 MW (including some 200 MW) or more units to complete the whole denitration. In addition, considering the unit load (denitrification doesn’t work under certain unit load) and other factors, is expected to 2015, the power industry emissions of nitrogen oxides fell to about 600 million tons; by 2020, power nitrogen oxide emissions fell to 400 million to 450 million tons.

3.2.3 Solutions and Policy Suggestions

3.2.3.1 Solutions and Policy Suggestions for Fine Particulate Matter

(1) Change the pollution control idea of focusing on major emission sources. The generation of smog and haze and PM2.5 cannot be attributed to major emitters such as electric power enterprises. Instead, it results from the combined effect of hundreds of millions of uncontrolled small pollution sources. Therefore, we should focus on controlling pollution sources that emit a small amount of pollutants, but cover a wide range of areas and change the focus of environmental supervision from the “point sources” of overhead power supply of power plants to crisscrossing “line sources” (motor vehicles) and “surface sources” of numerous small emission sources.

(2) Give full play to the important role of the electric power industry in smog and haze governance from the overall and systematic perspective. With the continuous development of the electric power industry, the electric power industry has made more and more contributions to the improvement of environment quality and the scientific development of the electric power industry will provide powerful material basis and technical means for solving the problem of smog and haze and PM2.5. ① Accelerate the construction and application of smart grids to provide strong basic support for the prevention of smog and haze. ② Increase the proportion of renewable energy power generation, further improve the proportion of electricity in the final energy consumption, actively and effectively promote replacing heat and power plants with small coal-fired heat producers in cities, using electricity instead of coal and development of electric vehicles in cities in a scientific, reasonable, economical, and effective way. ③ In economically feasible areas with adequate gas supply, establish gas-fired power stations; in areas with inadequate gas supply, instead of immediately replacing coal-fired heat and power plants, continue to keep clean and efficient coal-fired heat and power plants in order to supply limited gas to urban or rural residents, and reduce scattered burning of coal and restrain power plants from competing with small and medium energy users. ④ Improve the proportion of converting coal into electricity and the proportion of pollutant emissions from electricity production in total pollutant emissions. Both theory and foreign practice have proved that the higher the proportion of air pollutant emissions from electricity production, the better the energy structure and the less environmental pollution. ⑤ Encourage coal-fired power plants to use and import low sulfur, low ash, and high-quality steam coal for power generation; restrain and even prohibit scattered small combustion equipment, kilns, and residents from using high sulfur and high ash coal inefficiently or without proper pollution control measures; meanwhile if it is difficult to change coal sources and coal quality, convert inferior coal to electricity, strengthen the classification and use of coal for power generation and prevent power plant from scrambling for high-quality coal and imposing inferior coal on residents and small-sized combustion equipment so as to optimize coal utilization at the social level, reduce pollutant emissions and improve the overall environmental and economic benefits. ⑥ For power plants located in areas with large environmental capacity, equip them with proper environmental protection facilities and make reasonable emission standards for them and draw up a reasonable schedule for the construction of pollution control equipment in thermal power plants; avoid constructing environmental protection facilities in large quantities and then reconstructing them before they are put into operation due to the declined quality.

3.2.3.2 Solutions and Policy Suggestions for Sulfur Dioxide

(1) Change the mode of controlling total sulfur dioxide emissions with administrative requirements as the control target; develop the *Standard for Emissions of Air Pollutants from Thermal Power Plants* (GB 13223—2011) in a scientific way with improving environment quality as the goal, the BAT as the means and technical and economic conditions as constraints, and allocate the sulfur dioxide emission indicator to each sector in a scientific way.
(2) Strengthen law-based control, clean up, rectify, and improve the existing sulfur dioxide emission control laws, regulations, and policies to implement sulfur dioxide emission control in compliance with laws and regulations and promote the implementation of emission reduction by enterprises and supervision of it by governments according to law.
(3) Strengthen environmental protection supervision and at the same time ensure the full and timely implementation of the desulfurization electricity price and speed up the introduction of the electricity price formation mechanism with environmental costs taken into consideration.
(4) Find out the problem of poor-quality desulfurization equipment caused by lack of experience and vicious low-price competition in the explosive development of flue gas desulfurization equipment construction in recent years, carry out research on improving the reliability of desulfurization devices, and formulate relevant technical regulations to provide technical basis for law-based administration and technical supervision.
(5) Speed up the development of the resource-saving desulfurization industrialization which can change sulfur dioxide emissions into useful materials, and facilitate the development of circular economy.
(6) Really give enterprises the right to choose pollution control means and manage emission reduction, reduce unnecessary administrative intervention, and at the same time strengthen industrial self-discipline and public supervision.

3.2.3.3 Solutions and Policy Suggestions for Nitrogen Oxides

(1) The Chinese central government should carry out an in-depth investigation into the nitrogen oxide emissions from environmental pollution sources all over the country and strengthen the research into NO_x emissions and its distribution characteristics. ① Study the NO_x emission forecasting and statistical methods. ② Study automatic monitoring-based technologies and methods. ③ Study the industrial and geographical distribution of China's total NO_x emissions, and predict the future NO_x emissions based on it to provide data basis for the control of NO_x emissions.
(2) Revise nitrogen oxide emission standards for thermal power plants in a scientific way. Comprehensively, consider environmental, technical, and

economic conditions, region, time (period of time), characteristics of generating units, and characteristics of fuel. On the principle of distinction, govern the nitrogen oxide emissions from newly established power plants according to more stringent standards than those for the governance of nitrogen oxide emissions from existing power plants and those in-service power plants from which nitrogen oxide emissions have to be governed in a strict and prompt way should be compensated, which is international practice and in line with China's national characteristics and the principle of *Administrative License Law of The People's Republic of China*.

(3) Identify the technical route for control of nitrogen oxide emissions from electricity production.

  (1) The technical route should be determined according to the principle of economy, efficiency, safety, reliability, resource conservation, and comprehensive utilization.
  (2) All power plants including newly established power plants, existing power plants, and power plants using all kinds of coal should give priority to low NO_x combustion technologies to maximally reduce the generation of nitrogen oxides in the combustion process of the boiler.
  (3) If the nitrogen oxide emissions from newly established and in-service generating units burning anthracite and meager (low volatile component) coal cannot meet the emission standard after the low NO_x combustion technologies are used, the SCR denitration technology should be used. If the SCR device cannot be installed due to the constraints of conditions such as space and boiler structure, the SNCR technology or combine the SCR-SNCR combined denitration technology. Small-sized power plants with small changes of load and unstable fuel quality should choose the SNCR technology.
  (4) If the nitrogen oxide emissions from generating units cannot meet the emission standard after the low NO_x combustion technologies are used or generating units located in sensitive areas burn bituminous coal and lignitous coal, the SCR denitration technology should be the first choice.
  (5) Encourage and promote power plants to integrate desulfurization, denitration, and dust removal technologies, and carry out collaborative control research and development and engineering demonstration.
  (6) Identify the reducing agent system suitable for the local technical and economic conditions. In using the liquid ammonia system, security requirements should be fully considered and preventive measures should be taken in accordance with legal provisions for safe production.

(4) Strengthen the nitrogen oxide emission control operation management of coal-fired power plants. Coal-fired power plants should use the low NO_x combustion technologies to give full play to the functions of the low NO_x combustion devices; establish and improve the daily management system of flue gas denitration facilities; set up operation and maintenance procedures, and work out nitrogen oxide emission control operation management measures

such as the ledger system. Environmental protection administrative departments at all levels should strengthen the operation supervision of nitrogen oxide emission control technology and equipment. Nitrogen oxide online continuous monitoring devices that have been constructed should be connected with the management information system of environmental protection administrative departments. Formulation and experimental work of technical specifications for flue gas denitration project construction should be further improved.

(5) Accelerate the flue gas denitration environmental protection industrialization.

(1) Promote the industrialization of environmental protection with the law as the criterion, the market as the orientation, science and technology as the guide, benefits as the center, and enterprises as the main body.

(2) Speed up the development of denitration technologies suitable for China's national conditions and with independent intellectual property rights. ① Provide financial support and tax preferences. ② Strictly restrict repeated introduction of denitration technologies. ③ Actively support the construction of demonstration projects to give full play to denitrification technologies with independent intellectual property rights, and continuously improve and optimize denitration technologies so as to make them reach the international advanced level.

(3) Accelerate the localization of catalysts. Localization of catalysts is the key to flue gas denitration industrialization. Government departments or relevant industrial organizations commissioned by government departments should conduct an in-depth investigation into the development, raw material, production, use, test, recycling, and disposal of flue gas denitration catalysts to collect detailed information of the catalyst production and supply market, grasp the trend of changes, assess the impact of catalyst failure disposal on environment, and put forward relevant standards and management regulations for catalysts as well as suggestions for accelerating localization of catalysts. As there are several catalyst manufacturers in China, government departments should arrange for experts to carry out investigations to find out the situation, release relevant information, and guide the correct development of the industry in order to avoid redundant construction of catalyst manufacturers and reduce blind technical import and blind investment.

(4) Introduce economic policies to encourage the thermal power plant to implement flue gas denitration. ① We should comprehensively use various economic means to promote the control of NO_x emissions from power plants to achieve maximum environmental benefits at a minimal cost, for example, making the emissions trading policy. ② Reflect environmental protection cost of denitration in the electricity price in a scientific and reasonable way to make the electricity production cost really reflect resource and environmental costs. ③ All the NO_x sewage charges should be used for NO_x emission control, especially the reconstruction of

low NO_x burners and flue gas denitrification technologies of old power plants. ④ For denitrification devices that cannot be localized for the time being, tax exemption or reduction policies should be developed. ⑤ The flue gas denitration device construction of in-service power plants should be subsidized by Central Financial Special Fund of Environmental Protection or investment fund from the central budget.

(5) Strengthen supervision and industrial self-discipline, and standardize and rectify the denitration market. ① Establish the market access system to avoid vicious competition, ensure project quality, and improve the reliability and stability of the operation. ② Establish denitration (desulfurization) facilities operation monitoring and verification system, and strengthen the supervision and inspection of the facilities operation. ③ Establish the directory of denitration technologies and devices encouraged by the Chinese central government to guide the sound development of the denitration industry and technologies. ④ Suggest the national industrialization management department should join hands with relevant government departments to arrange for the research on thermal power plant flue gas denitration standard system, and make relevant standards in accordance with the priorities. ⑤ Improve the communication and cooperation mechanism, and carry out denitration industrialization information statistics, analysis, and release. Organize and carry out the on-the-job training of the denitration operation management personal, and guide the denitration industry to continuously improve quality.

3.2.4 Summary of Environmental Protection Constraints on Coal-Fired Power Generation

(1) Smoke and dust. As environmental protection requirements have become increasingly stringent, the layout of coal-fired power plants has undergone great changes. Except for heat and power plants, new coal-fired power plants are no longer built in cities. For in-service generating units, measures such as control of pollutant emissions, shutting down of small thermal power generating units, and building of large generating units and wet flue gas desulfurization and dust removal have been taken to further improve the smoke and dust emission control level of coal-fired power plants. The smoke and dust emissions from coal-fired power plants during the "12th Five-Year Plan" period are not the main cause of environmental pollution. However, as China has made increasingly stringent control requirements for smoke and dust emissions from thermal power plants, most coal-fired power plants have to upgrade and reconstruct precipitators. Specifically, they have to choose from different dust removal technologies, invest heavily in technical reconstruction,

and make proper arrangements for production and reconstruction in a short period of time.

(2) Sulfur dioxide. By the end of the "12th Five-Year Plan" period, flue gas desulfurization devices will be installed and operated in all coal-fired generating units. In the 12th Five-Year Plan, it is required that in 2015 sulfur dioxide emissions from electricity production should be controlled within 6.5 million to 7.5 million tons and the emission performance should be 1.4–1.7 g/kWh. During the "12th Five-Year Plan" period, sulfur dioxide emission control will still be one of the major environmental constraints on electric power development. In this book, we mainly put forward the following solutions to it. ① Determine the limits of the air pollutant emissions from thermal power plants during the "12th Five-Year Plan" period with environmental protection requirements (instead of administrative requirements) as the goal, the BAT as the means and technical and economic conditions as constraints. ② Strengthen law-based control, clean up, rectify, and improve the existing sulfur dioxide emission control laws, regulations, and policies, really give enterprises the right to choose pollution control means and manage emission reduction and reduce unnecessary administrative intervention. ③ Strengthen environmental protection supervision, ensure the full and timely implementation of the desulfurization electricity price, and speed up the introduction of the electricity price formation mechanism with environmental costs taken into consideration. ④ Carry out research on improving the reliability of desulfurization devices, and formulate relevant technical regulations to provide technical basis for law-based administration and technical supervision. ⑤ Speed up the development of the resource-saving desulfurization industrialization which can change sulfur dioxide emissions into useful materials, and facilitate the development of circular economy. ⑥ Strengthen industrial self-discipline and public supervision.

(3) Nitrogen oxides. Comprehensively, consider optimal operation, low NO_x combustion technologies, flue gas denitration, and other nitrogen oxide emission control measures and it is predicted that by 2015 NO_x emissions from electricity production will be controlled within 6 million to 7 million tons. The nitrogen oxide emission control will be one of the major environmental constraints on electric power development. In this book, we mainly put forward the following solutions to it. ① The Chinese central government should carry out an in-depth investigation into the nitrogen oxide emissions from environmental pollution sources all over the country and strengthen the research into NO_x emissions and its distribution characteristics. ② Determine limits of nitrogen oxide emissions from thermal power plants based on the comprehensive consideration of environmental, technical, and economic conditions, region, time (period of time), characteristics of generating units, and characteristics of fuel. ③ Priority should be given to low NO_x combustion technologies. If the nitrogen oxide emissions still cannot meet the emission standard after the low NO_x combustion technologies are used, the SCR technology, SNCR technology, or SCR-SNCR combined denitration

technology should be used. Identify the reducing agent system through comparison of technical and economic conditions. ④ Speed up the development of denitration technologies suitable for China's national conditions and with independent intellectual property rights. Accelerate the localization of catalysts. Encourage and promote power plants to integrate desulfurization, denitration, and dust removal technologies, and carry out collaborative control research and development and engineering demonstration. ⑤ Introduce economic policies to encourage the thermal power plant to implement flue gas denitration. ⑥ Strengthen supervision, industrial self-discipline, and standardize and rectify the denitration market.

3.3 Hydropower Development

3.3.1 Current Situation of Environmental Impacts and Mitigation

China's hydropower development has gone through four stages, technical constraints, investment constraints, market constraints, and ecological constraints. Nowadays, ecological constraints and the social problems caused by resettlement of affected residents of hydropower projects have become the key constraints on the hydropower development in China.

1. Ecological constraints

China's hydropower potential is mainly concentrated in the western, the upper reaches of China's major rivers. Western China is the ecological screen and "source" of ecological balance of the middle and lower reaches of the rivers. The environmental quality and ecosystem level in the upper region will have a direct impact on these in the middle and lower reaches of the rivers. Western China has an ecological environment characterized by fragility, vulnerability, and difficult recovery because of located in the inland plateau. Under the integration of natural and human factors, ecological and environmental problems such as land desertification, decline of water conservation function of soils, destruction of biodiversity, and frequent disasters have become increasingly prominent, which exacerbated the adverse effects of the development of hydropower resources on the ecological environment and threatened the ecological safety in the middle and lower reaches of the Yangtze River and the Yellow River and other major rivers.

Important ecological and environmental constraints include:

(1) Hydropower construction and operation change the hydrological process and river channel characteristics of the lower reaches, and then impact downstream important aquatic and terrestrial habitats and sensitive protection targets of the reservoir area.

(2) Water temperature stratification in the reservoir area leads to low temperature water released, water eutrophication in reservoirs, and the dam water discharge, which may cause supersaturation of dissolved gas or dissolved oxygen deficiency in water in the downstream channels.
(3) Flooding, impeding, and runoff regulation of a reservoir will destroy river connectivity and impact the quality, quantity, and accessibility of the habitat of aquatic organisms, especially for fishes. Migration and other activities of fishes therefore might be terminated or postponed. Mitigation of ecological and environmental constraints is the major issue of hydropower development, which requires both ecological protection technology and environmental management policies.

2. Social problems caused by resettlement

The social problems caused by resettlement are another important constraint on hydropower development. Although China's current policy on resettlement of water conservancy and hydropower projects has increased the compensation standards, the existing "agriculture-based" resettlement mode and disposable compensation method cannot get rid of chronic poverty or share the benefits of hydropower development. Reservoir inundation and resettlement problems are still very prominent to restrict the hydropower development.

Meanwhile, hydropower bases in Western China are mainly located in regions populated by ethnic minorities. Due to inconvenient transportation and underdeveloped economy in these regions, hydropower enterprises have to shoulder more social responsibilities for promoting the local social and economic development. In addition, resettlement involves the issue of religious beliefs, which will have a far-reaching impact on the future hydropower development.

Column Interpretation

Ecological and environmental impact of Xiluodu Hydropower Station on Jinshajiang River and corresponding mitigation measures during its construction period

Located in the Xiluodu Gorge contiguous to Leibo County, Sichuan Province and Yongshan County, Yunnan Province and as the third cascade in the development planning for the lower reaches of Jinsha River, Xiluodu Hydropower Station has a total installed capacity of 12.6 million kW and an annual generation of 57.12 billion kWh. Ranked the third in the world, it is the second largest hydropower station in China. The Xiluodu Gorge hydropower project focuses on hydropower generation and additional comprehensive benefits such as flood control, sediment retention, and improving downstream shipping conditions. In addition, it can provide cascade compensation for downstream hydropower projects. The concrete double curvature arch dam of the key project is 278 m high and has a normal impounded water level of 600 m, a total reservoir capacity of 11.57 billion m^3, and a total investment of RMB 79.234 billion.

After the construction of the Xiluodu hydropower project, the reservoir will inundate the main spawning ground of Chinese paddlefish, coreius guichenoti, and other rare and specific fishes; impeding of the dam will split a complete living environment of aquatics into two sections of the reservoir and downstream, specifically reduce the living environment of fishes; the low temperature water discharged from the reservoir in spring and summer will postpone the spawning period of Chinese paddlefish and other fishes; the changes in hydrological and sediment conditions will change the water level, flow velocity, and channel morphology of natural river.

Main mitigation measures taken during the construction period include: the adjustment scheme of natural reserve area, Chinese paddlefish artificial culture research and artificial propagation, artificial reproduction and releasing of river sturgeon and mullet, coreius guichenoti artificial reproduction research, and artificial reproduction and strengthening monitoring and management.

On the morning of December 7, 2008, China Three Gorges Corporation held the "first releasing of rare and specific fishes in Xiluodu Xiangjiaba Hydropower Station on Jinsha River" and altogether 20,000 rare and specific fishes including river sturgeon, mullet, Procypris rabaudi, Leptobotia elongata, and Megalobrama pellegrini were released to the Yangtze River.

3.3.2 Analysis of Major Environmental Constraints

3.3.2.1 Analysis of Laws, Regulations, and Policies

1. Analysis of existing laws, regulations, and policies

Since the founding of People's Republic of China more than 60 years ago, China implements the principle of "actively developing hydropower." As an important electric energy, hydroelectricity has been closely related to the power sector development. The Communist Party of China and the Chinese central government have stuck to the policy of actively developing hydropower resources. In 1982, the editorial entitled *Paying Special Attention to Hydropower Development* published in the *People's Daily* pointed out that hydropower was a renewable energy; the construction of hydropower stations was a kind of project in which the development of primary energy and conversion of secondary energy could be completed at the same time; we should develop and utilize more hydropower to gradually replace some coal-fired power. At the National Electric Power Work Meeting held in 1997, it was proposed the slogans of "vigorously developing hydropower" and "increasing the proportion of hydropower to 30% by 2010." The goal of developing hydropower was further defined in the *11th Five-Year Plan for Renewable Energy Development* and the *Medium and Long-Term Development Plan for Renewable Energy in China*. At the National Electric Power Work Meeting held in August 2009, the role of hydropower in the renewable energy development and its future development goal were reiterated. The goal of "steady and rapid development of hydropower construction" was clearly defined in the *12th Five-Year Plan for*

Table 3.7 China's current hydropower development promotion policies

Policy	Time	Main content
Renewable energy law of the People's Republic of China	2005	Hydropower is a renewable energy source. Financial institutions will provide financial discount preferential loans for projects being included in the national renewable energy industry guidance catalogue and meeting credit terms. Meanwhile, the government will provide tax preferences for these hydropower projects
11th Five-Year Plan for national economic and social development of the People's Republic of China (2006–2010)	2006	Orderly developing hydropower on the basis of protecting the eco-environment, actively developing renewable energy (including hydropower), implementing preferential fiscal and tax policy and investment policy and mandatory market share policy, encouraging the production and consumption of renewable energy, and increasing the proportion of renewable energy consumption in primary energy consumption
11th Five-Year Plan for renewable energy development	2006	Actively developing hydropower on the premise of ensuring environmental protection and resettlement
Medium- and long-term development plan for renewable energy in China	2007	China has made to international communities to increase its non-fossil fuel energy to 15% of its total primary energy consumption by 2020. Installed capacity of hydropower will reach 190 and 300 GW in 2010 and 2020, respectively
12th Five-Year Plan for renewable energy development 12th Five-Year Plan for hydropower development	2012	In the period of 12th FTP, new conventional hydropower installed capacity under construction will reach 1.2, and 40 GW for pumped storage hydropower; total hydropower installed capacity will reach 290 GW with an annual generating of 910 billion kWh by 2015; total hydropower installed capacity will reach 420 GW with an annual generation of 1200 billion kWh by 2020

Hydropower Development released by National Energy Administration in 2012. See Table 3.7 for China's current hydropower development promotion policies.

See Table 3.8 for China's existing laws, regulations, and policies for hydropower development. All of them divide into two kinds of constraints: ① ecological and environmental protection, including conservation of fish-focused aquatics and terrestrials, soil conservation, and protection of important protected areas, such as

Table 3.8 China's existing laws, regulations, and policies for hydropower development

Category	Law/regulation/policy	Time	Content
Main laws	*Water Law of the People's Republic of China*	2002	It stipulates in Article 26 that the government encourages the development and utilization of water resources. On rivers rich in hydropower, multi-purpose and cascade development shall be promoted in a planned manner. In construction of hydropower stations, attention shall be paid to protection of the ecological environment, and consideration shall, at the same time, be given to the need of flood control, water supply, irrigation, navigation, bamboo and log rafting, fishery, etc.
	Environmental Protection Law of the People's Republic of China	1989	It stipulates in Article 17 that the people's governments at various levels shall take measures to protect regions representing various types of natural ecological systems and regions. Damage to the above shall be strictly forbidden. It stipulates in Article 18 that within the scenic spots or historic sites, nature reserves and other zones that need special protection, as designated by the State Council, the relevant competent department under the State Council, and the people's governments of provinces, autonomous regions and municipalities directly under the Central Government, no industrial production installations that cause environmental pollution shall be built
	Law of Land Administration of the People's Republic of China	2004	It stipulates in Article 31 that the government protects the cultivated land and strictly controls the conversion of cultivated land into non-cultivated land. The states foster the system of compensations to cultivated land to be occupied. Land in rural areas shall be collectively owned by farmers. In addition, the standards for compensation and subsidy and legal procedures for requisition of land are also stipulated
International treaties	*World Heritage Convention*		It gives greater freedom to sovereign nations in the protection and development of resources. The sovereign nations recognize this kind of heritage is part of the world heritage when the property right under the national legislation is not damaged

(continued)

Table 3.8 (continued)

Category	Law/regulation/policy	Time	Content
Special laws and regulations	*Fisheries Law of the People's Republic of China*	2004	It stipulates in Article 32 that when building sluices and dams which will have serious effects on fishery resources on the migration routes of fish, shrimp, and crabs, the construction units must build fish passages or adopt other mitigation measures
	Law of the People's Republic of China on the Protection of Wildlife	2004	It stipulates in Article 20 that in nature reserves and areas closed to hunting, and during seasons closed to hunting, the hunting and catching of wildlife and other activities which are harmful to the living and breeding of wildlife shall be prohibited
	Regulations of the People's Republic of China on Wild Plants Protection	1997	It stipulates in Article 9 that the government shall protect wild plants and the environment for their survival. All units and individuals shall be forbidden to illegally collect wild plants or damage the environment for their survival
	Interim Regulations of the People's Republic of China on the National Scenic and Historic Areas		It stipulates in Article 26 that activities of destroying landscape, vegetation, and landform shall be prohibited in scenic and historic areas. It stipulates in Article 27 that it is forbidden to build various types of development zones in scenic and historic areas and build other buildings irrelevant to protection of scenic resources in the core scenic areas in violation of the scenic and historic area planning
	Regulations of the People's Republic of China on Nature Reserves	1994	It stipulates in Article 18 that nature reserves may be divided into three parts: the core area, buffer zone, and experimental zone. The integral natural ecosystems and the areas where the rare and endangered animals or plants are concentrated within nature reserves shall be included in the core area into which no units or individuals are allowed to enter. Scientific research activities are generally prohibited in the core area except for those approved according to Article 27 of the Regulations
	Measures for the Administration of National Forest Parks	1994	It stipulates in Article 11 that in the precious scenery, important scenic areas, and core scenic areas, except for necessary protection and ancillary facilities, the construction of hotels, guest houses, nursing homes, and other engineering facilities shall be forbidden

(continued)

Table 3.8 (continued)

Category	Law/regulation/policy	Time	Content
	Regulations on the Protection and Management of Geological Relics	1995	It stipulates in Article 11 that categorization of protection: Protection of geological relics in protected areas can be categorized into first-grade protection, second-grade protection, and third-grade protection. First-grade protection: First-grade protection shall be provided for geological relics which are extremely rare and of important scientific value in the world or in China and without approval access shall be prohibited. Second-grade protection: Second-grade protection shall be provided for geological relics in the large area—Scientific research, teaching, academic exchange, and appropriate tourism activities can be organized in these geological relics. Third-grade protection: Third-grade protection shall be provided for geological relics which are of a certain value—tourism activities can be organized in these geological relics
	Law of the People's Republic of China on Land Contract in Rural Areas		Land can be contracted to individual villagers for operation and management, and villagers' land contract rights and related circulation rights are protected by law
	Regulations on the Protection of Basic Farmland	1998	It stipulates in Article 15 that once a protected area of basic farmland is designated, no plant/institution or individual may alter or occupy the said land without authorization. When selecting sites for important national construction projects related to energy, communications and water conservancy, military facilities, etc., and there is no way to avoid in fact a need to occupy cultivated land in protected areas of basic farmland, it shall be approved by the State Council
	Regulations on Land Requisition Compensation and Resettlement for Construction of Large and Medium-sized Water Conservancy and Hydropower Projects	2006	Applicable in the whole China, it is made based on the characteristics of hydropower engineering and summary of the historical experience and lessons learned in resettlement. It makes corresponding provisions for standards for land requisition compensation and principle of resettlement. These provisions are one of the major legal bases for implementation of resettlement in recent years

(continued)

Table 3.8 (continued)

Category	Law/regulation/policy	Time	Content
Special plans	Comprehensive utilization plan for water resources in China and sub-basins, national water resources protection plan, river basin comprehensive utilization plan, river hydropower development plan, national and regional water function zoning, etc.		Take river basin comprehensive utilization plan as an example: Revise and implement water resources comprehensive utilization plan, combine hydropower development and comprehensive utilization of water resources, ecological engineering construction, and regional economy organically, realize the comprehensive development of water resources in the river basin, and give full play to the guidance role of water resources comprehensive utilization in hydropower design, construction, and management
	Outline of National Ecological Environmental Protection of the People's Republic of China, national and regional ecological function zoning, etc.		Take the Outline of National Ecological Environmental Protection of the People's Republic of China as an example: All development activities that lead to the continuous degeneration of ecological functions and other human sabotage activities shall be stopped; the construction of all engineering projects that produce serious environmental pollution shall be stopped

natural reserves, scenic spots, forest parks, geological relics, and world natural heritage. ② Resettlement.

2. Trends of regulations and policies

The *Energy Law of the People's Republic of China* and *Renewable Energy Law of the People's Republic of China* are being revised, and it is expected that the role of renewable energy of large hydropower will be further defined. It is clearly put forward by the State Council in approving *Notice on Opinions of Deepening Economic Restructuring in 2009* made by the National Development and Reform Commission (NDRC) for release that we should vigorously promote the resource product price and energy conservation and environmental protection system reform. On November 20, 2009, the NDRC published the on-grid tariff adjustment. Up-regulation of hydropower on-grid price was larger than that of benchmark thermal coal-fired power price. The gap between hydropower on-grid price and thermal coal-fired power on-grid price was further narrowed. Benchmark hydropower price, i.e., the hydropower on-grid pricing mechanism, was suspended temporarily. Instead, the interim hydropower price was implemented. In recent years, the "same grid and same price" has been vigorously proposed. In addition, in order to promote economic and social development of the hydropower reservoir area and resettlement area, and to solve the problem of lack of reconstruction funds, the NDRC will further raise the hydropower on-grid price during the "12th Five-Year Plan" period and make relevant policies to promote the ecological protection and resettlement of affected residents in hydropower development.

At the end of 2009, the revised or newly revised comprehensive plannings for all major river basins were released. The revised or newly revised comprehensive plans for all major river basins put more emphasis on multi-purpose development of resources and strengthened the ecological protection of river basins. In addition, the hydropower development plan was revised, laying a foundation for the orderly development of hydropower.

3.3.2.2 Analysis of Major Ecological and Environmental Constraints

1. Rare and specific fishes

(1) The upper reaches of the Yangtze River. The upper reaches of the Yangtze River are a concentrated distribution area of rare fishes including Chinese paddlefish, river sturgeon, mullet, and 117 fishes specific to the upper reaches of the Yangtze River. In April 2005, general office of the State Council approved the plan for changing *Rare Fish Species National Nature Reserve at Hejiang-Leibo Section of Yangtze River* to *Rare and Specific Fish Species National Nature Reserve in the Upper Reaches of Yangtze River* proposed by the Ministry of Agriculture. The scope of the reserve changed from the 420 km Leibo-Hejiang river section to the 1162.6 km river section which starts from the estuary of the Hejiang River, 1.8 km down Xiangjiaba Dam to

Masang Stream, Chongqing, including the main stream and tributaries of Chishui River, lower reaches of Minjiang River, tributaries of Yuexi River and estuaries of Nanguang River, Changning River, Tuojiang River, and Yongning River. The adjusted reserve crosses Sichuan, Guizhou, Yunnan, and Chongqing and has total river area of the 331.7 km^2. The following three kinds of fishes are protected: ① rare and endangered fish species in the upper reaches of the Yangtze River such as national first-grade and second-grade key protected aquatic wildlife including river sturgeon, Chinese paddlefish, and mullet; ② 117 fish species specific to the upper reaches of the Yangtze River; ③ the aquatic environment rare and endangered species and specific fishes in the upper reaches of the Yangtze River rely on for survival.

(2) Yalong River. The Yalong River is the largest first-grade tributary on the left bank of Jinsha River. According to the relevant river basin comprehensive planning results, in the middle reaches of the river there are no national protected rare fishes, but there are two Sichuan provincial key protected fishes *Schizothorax dolichonema* Herzenstein and Euchiloglanis david and one specific fish Diptychus kaznakovi. All the above-mentioned three fishes are fishes living in running water. *Diptychus kaznakovi* only exists in the upper reaches of Jinsha River and Yalong River and has been listed in *China Red Data Book of Endangered Animals: Fishes*.

(3) Jinsha River. Hutiao Gorge is the natural divide between fish faunas in the Jinsha River. Living in the channel segment up the entrance to the gorge are mainly cold water fishes typical of the Qinghai–Tibet Plateau including about 20 Schizothoracinae species and 10 loach species. Down the entrance to the gorge is the lower reaches of the Jinsha River (transition section between the lower reaches of the Jinsha River and the upper reaches of the Yangtze River) which is the transition distribution waters between river plain fishes and Qinghai–Tibet Plateau fishes and the staggered distribution area of 160 fish species, mainly river plain fishes, of which 133 ones are the same as those in the middle reaches of the Jinsha River and 151 ones are the same as those in the Rare Fish Species National Nature Reserve in the Upper Reaches of Yangtze River.

According to the research findings of the *Research Report on the Environmental Impacts of Cascade Hydropower Development in the Lower Reaches of the Jinsha River and Countermeasures*, in the lower reaches of the Jinsha River there are three national key protected rare fish species, Chinese paddlefish, river sturgeon, and mullet (Chinese paddlefish and river sturgeon are the first-grade national key protected rare fish species, while mullet is the national second-grade key protected rare fish species); there are 56 fishes specific to the upper reaches of the Yangtze River of which two ones, *Anabarilius songmingensis* and *Anabarilius brevianalis*, are specific to the lower reaches of the Jinsha River; there are 54 other specific fishes of which 16 ones including *Schizothorax prenanti*, *Schizothorax wangchiachii*, *Schizothorax dolichonema Herzenstein*, *Schizothorax kozlovi Nikolsky*, *Schizothorax chongi*, *P. anteanalis*, *Onychostoma angustistomata*, *Leptobotia elongata*, *Coreius guichenoti*, *Rhinogobio ventralis*, *Xenophysogobio nudicorpa*, *Percocypris pingi,* and *Procypris rabaudi* should be taken as national key protected species according to the characteristics of the distribution of fishes in this section and the environmental impacts of cascade hydropower development.

(4) Dadu River. According to the research on the special investigation of the aquatic organisms in Dadu River and the literature, in the Dadu River basin there are 111 fish species of which 2 ones, Sichuan faimen and mullet, are the national second-grade protected fishes, 11 ones, provincial protected fishes, and 38 ones, specific to the upper reaches of the Yangtze River. These fishes are basically living in running water, for example, *Sichuan faimen*, *Varicorhinus daduensis*, *Percocypris pingi*, *Procypris rabaudi*, *Schizothorax longibarbus*, *Schizothorax davidi*, *Schizothorax prenanti,* and Euchiloglanis david.

(5) Lancang River. According to relevant river basin comprehensive planning results, in the Lancang River the fish faunas mainly include 105 species, 67 genera, and 3 families of the Cypriniformes. The largest genus of the indigenous fishes is Schistura, of which there are eight species. At present no long-distance migratory fishes that migrate between oceans and rivers are found, but most fishes have the habit of spawning migration. There are four typical long-distance spawning migratory fishes, namely giant pangasius, *Pangasius micronemus*, Pseudopangasius, and *Pangasius beani*.
No fishes in Lancang River are listed in the national first-grade or second-grade protected fishes or in the Appendix of CITES. Listed in the Yunnan provincial second-grade protected fishes are biforated carp, *Macrochirichthys macrochiriu,* and giant pangasius which are mainly distributed in the lower reaches of the Lancang River. With the three provincial protected fishes included, a total of ten fishes in the Lancang River basin are listed in *China Red Data Book of Endangered Animals: Fishes*. The other seven ones are grooved isthmus barbell, *Cosmochilus cardinalis*, *Puntioplites proctozysron*, *Kryptopterus moorei*, *Akysis brachybarbatus*, yellow sisorid-catfish, and *Trichogaster trichopterus*. All these ten fishes are distributed in the middle and lower reaches of Lancang River.

(6) Nujiang River. At present, there are 7 kinds of 72 fish species, including 58 indigenous fish species which belong to 32 genera, 8 families, and 5 orders. Among the 58 indigenous species, there are 40 rare fishes, accounting for 68.97% of the indigenous fish species, 6 endangered species, accounting for 10.34%, and one national second-grade protected fish species. The *Anguilla nebulosa*, *Epalzeorhynchos bicornis*, *Schizothorax griseus Pellegrin*, *Schizothorax lantsangensis*, *P. myzostoma,* and *P. gracilicaudata* are listed in *China Red Data Book of Endangered Animals: Fishes*. *Anguilla nebulosa* (commonly known as Monopterus alba) is one of the national second-grade protected fish species. *Epalzeorhynchos bicornis* (commonly known as

bihorned barb) is a specific fish species. *Placocheilus cryptonemus* is a rare fish species and listed in the Vulnerable Animal Catalogue. *Bagarius yarrelli* is a provincial protected fish species and distributed in Gaoligongshan Mountains National Nature Reserve. Acrossocheilus (Lissochilichthys) hemispinus is a rare fish species and only found in underground swallet stream flowing into Nujiang River near Liuku Town and is not found outside Gaoligongshan Mountains National Nature Reserve.

(7) Wujiang River. Wujiang River is a first-grade tributary on the right bank in the upper reaches of the Yangtze River. A total of 123 fish species are distributed in it including 9 Chongqing municipal key protected aquatic wild fishes and more than 30 fishes specific to the upper reaches of the Yangtze River. According to *Overall Planning for Wujiang River-Changxi River Fish Nature Reserve*, there are 12 rare fish species in Wujiang River basin mainly including Chinese paddlefish, river sturgeon, mullet, *Leptobotia elongata*, *Leptobotia rubrilabris*, *Luciobrama microcephalus*, *Ochetobius elongatus* Kner, *Percocypris pingi*, *Procypris rabaudi*, *Jinshaia sinensis*, *Sinogastromyzon szechuanensis* and *Metahomaloptera omeiensis*.

Among all the above-mentioned protected fish species, there have been no exact distribution records for Chinese paddlefish and river sturgeon for years. As the two fish species are mainly distributed in the main stream of the Yangtze River, in the newly built "Rare and Specific Fish Species National Nature Reserve in the Upper Reaches of the Yangtze River" they can be well protected. Similarly, Leptobotia elongata, *Leptobotia rubrilabris*, *Luciobrama microcephalus*, *Ochetobius elongatus* Kner, *Percocypris pingi*, *Procypris rabaudi,* and *Jinshaia sinensis* are also widely distributed in this reserve. In addition, the amphibious animal *Andrias davidianus* appearing in the river basin is a second-grade national protected animal and should also be protected. Therefore, the core protected rare and specific fishes in the Wujiang River section include two second-grade national key protected animals, mullet and *Andrias davidianus* and *Sinogastromyzon szechuanensis* and *Metahomaloptera omeiensis*. Particularly, mullet is mainly distributed in the lower reaches of the Wujiang River.

(8) The upper reaches of the Yellow River. Yellow River is relatively poor in aquatic species. The biomass is low, and there are only a small number of fish species. Due to the special geographical environment and climate characteristics in the upper reaches of the Yellow River, there have formed the indigenous fishes specific to the Yellow River that adapt to the plateau ecological environment. These fishes are concentrated in the channel segment up Longyang Gorge, and the fish fauna in the upper reaches mainly includes central Asia mountain complex fishes. According to relevant river basin comprehensive planning results, in the upper reaches of the Yellow River, three national aquatic germplasm resources conservation areas including Zhaling Lake and Eling Lake Gymnocypris eckloni Herzensten and Platypharodon extremus National Aquatic Germplasm Resources

Conservation Area, Specific Fish Species National Aquatic Germplasm Resources Conservation Area at Upper Reaches of Yellow River and *Silurus lanzhouensis* National Aquatic Germplasm Resources Conservation Area at Liujia Gorge at Yellow River. Key protected fish species include plateau cold water fish such as *Triplophysa siluroides*, *Chuanchia labiosa*, *Platypharodon extremus*, *Gymnocypris eckloni*, *Schizopygopsis pylzovi* and *Triplophysa pappenheimi* and *Silurus lanzhouensis* and *Cyprinus carpio*.
According to the survey of the former State Bureau of Aquatic Products, at present in the upper reaches of the Yellow River there are a total of 47 fish species including 3 endangered fish species and 15 indigenous fish species, but no long-distance migratory fishes or national key protected fishes. *Triplophysa siluroides*, *Chuanchia labiosa,* and *Platypharodon extremus* are listed in *China Red Data Book of Endangered Animals: Fishes*. Compared with the 1980s, the fish species in the Yellow River have declined sharply and the rare endangered and indigenous fish species have reduced. In the channel segments where hydropower resources are developed in a concentrated way, the fish habitat has undergone great changes and indigenous fish species resources have declined dramatically.

(9) North main stream of the Yellow River. The channel segment between Ketou Town in the middle reaches of the Yellow River and Yumenkou is known as the north main stream of the Yellow River and the longest continuous canyon in the main stream of the Yellow River. The fish fauna in the north main stream of the Yellow River mainly includes a great variety of river plain complex fishes. Most of these fishes are widely distributed. In order to protect aquatic germplasm resources and their living environment, the Ministry of Agriculture has built three national aquatic germplasm resources conservation areas including Silurus Lanzhouensis National Aquatic Germplasm Resources Conservation Area at Weining Section of Yellow River, Rhinogobio Nasutus National Aquatic Germplasm Resources Conservation Area at Qingshi Section of Yellow River, and Yellow River Catfish National Aquatic Germplasm Resources Conservation Area at Ordos Section of Yellow River in the channel segment between Liujia Gorge and Toudaoguai. Key protected fish species include *Silurus lanzhouensis*, *Cyprinus carpio*, *Rhinogobio nasutus,* and *Coreius septentrionalis*. At present in the north main stream of the Yellow River, there are no long-distance migratory fishes or national key protected fishes. The *Coreius septentrionalis* distributed in the channel segment between Qingtong Gorge and Shizuishan is first-grade endangered animal and listed in *China Red Data Book of Endangered Animals: Fishes*.

(10) Nanpanjiang River–Hongshui River. According to relevant river basin comprehensive utilization planning results, the channel segment between the middle and lower reaches of Nanpanjiang River and the upper reaches of Hongshui River are concentrated spawning and reproduction areas of fishes. In this channel segment, there are 90 indigenous fish species which belong to 65 genera, 16 families, and 6 orders and most of which are cypriniformes. In this

Table 3.9 Standard for fish constraint indicator evaluation in important hydropower bases

Score	Ecological implications
5	National protected long-distance migratory fishes
4	First-grade national protected fishes
3	Second-grade national protected fishes
2	Short-distance migratory fishes and China Red Data Book of Endangered Animals: Fishes
1	Provincial protected fishes, specific fishes, national aquatic germplasm resources conservation areas
0	None

channel segment, there are a total of 11 specific species including *Acrossocheilus iridescens*, *Paraspinibarbus hekouensis*, Sparulo justo quatuor requiruntur caldwelli, *Abbottina yunnanensis*, *Schistura macrotaenia*, *Glyptothorax honghensis*, *Microphysogobio yunnanensis*, *Triplophysa gejiuensis*, *Ctenogobius hongheensis*, *Schistura callichromus,* and *Schistura laterivittata*. Listed in the *China Red Data Book of Endangered Animals: Fishes* are *Anguilla marmorata*, *Paraspinibarbus alloiopleurus*, *Semilabeo obscurus* Lin, *Triplophysa gejiuensis,* and *Parazacco spilurus* of which the migratory fish *Anguilla marmorata* is second-grade national protected fish species.

(11) Fish constraint indicators evaluation standards and results. Dam building will change the original water habitat of the river course, while fish channel impeding will have an adverse impact on the fishes living in running water, especially for migratory fishes. According to the national requirements for biodiversity and fish resources protection, the fish constraint indicator evaluation standard (see Table 3.9) is defined based on the indigenous significance, peculiarity, economic value, and endangered degree of rare and specific fishes in the hydropower bases combined with the results of the present situation survey. At the same level, the river basins with a large number of fish species are further categorized. See Table 3.10 for constraint indicatory evaluation results.

2. Biodiversity Conservation

National ecological function zoning is to analyze the spatial distribution regularities and determine the ecological functions of different regions based on ecological status investigation, ecological sensitivity, and ecological service function evaluation. The national terrestrial ecosystem is divided into three ecological areas: eastern monsoon ecological region, western arid ecological region, and Qinghai–Tibet alpine ecological region, and the national ecologically functional zones are divided into the following three grades:

Table 3.10 Fish constraint level in China's main hydropower stations

River basin	Score	Notes
Upper reaches of Yangtze River	5	Rare and Specific Fish Species National Nature Reserve in the upper reaches of the Yangtze River; 3 first- and second-grade national key protected fish species (Chinese paddlefish, river sturgeon, mullet); 117 fish species specific to the upper reaches of Yangtze River
Main stream of Jinsha River	5	Three first- and second-grade national key protected fish species (Chinese paddlefish, river sturgeon, mullet); 4 provincial key protected fish species; 54 fish species specific to the upper reaches of Yangtze River; 2 fish species specific to the lower reaches of Jinsha River
Main stream of Yalong River	2	No long-distance migratory fish species or national key protected fish species; provincial key protected fish species; one specific fish species; one fish species listed in *China Red Data Book of Endangered Animals: Fishes*
Main stream of Lancang River	2.5	No long-distance migratory fish species or national key protected fish species; there exist anadromous and migratory fish species in Mekong River; three provincial key protected fish species; ten fish species listed in *China Red Data Book of Endangered Animals: Fishes*
Main stream of Dadu River	5	Second-grade national key protected fish species (Sichuan faimen and mullet); 11 provincial key protected fish species; 38 fish species specific to the upper reaches of the Yangtze River
Main stream of Nujiang River	5	1 s grade national key protected fish species (Anguilla nebulosa); 40 specific fish species; 6 fish species listed in *China Red Data Book of Endangered Animals: Fishes*
Nanpanjiang River-Hongshui River	5	First-grade national key protected fish species (Anguilla marmorata); 11 specific fish species; five fish species listed in *China Red Data Book of Endangered Animals: Fishes*
Wujiang River	5	Second-grade national key protected fish species (mullet and Andrias davidianus); 9 Chongqing municipal key protected fish species; 30 fish species specific to the upper reaches of the Yangtze River
Upper reaches of Yellow River	2.3	Two national aquatic germplasm resources conservation areas; no long-distance migratory fish species or national key protected fish species; three fish species listed in *China Red Data Book of Endangered Animals: Fishes*
North main stream of Yellow River	2.1	Three national aquatic germplasm resources conservation areas; no long-distance migratory fish species or national key protected fish species; one fish species listed in *China Red Data Book of Endangered Animals: Fishes*

(1) According to the natural properties of the ecosystem and dominant service function types, China is divided into three first-grade ecologically functional zones, ecological regulation, product supply, and human habitat security.

(2) The first-grade ecologically functional zones are further divided into second-grade ecologically functional zones based on the importance of ecological functions. The ecological regulation functions include water conservation, soil conservation, windbreak and sand fixation, biodiversity conservation, flood regulation and storage, and other functions; product supply functions include agricultural products, livestock products, aquatic products, and forest products; human habitat security functions include densely populated and economy-intensive metropolitan groups and key town groups. The value of protecting the biodiversity of different regions depends on the distribution of endangered rare animals and plants as well as typical ecological system distribution.

(3) The second-grade ecologically functional zones are divided into the third-grade ecologically functional zones according to the ecological system, spatial differentiation characteristics of ecological functions, topographic differences, and land use.

Based on the plan for dividing ecologically functional zones into three grades, this book uses the ratio of the sum of biodiversity conservation areas to the total area of hydropower development base, to measure the constraint of biodiversity conservation on the hydropower base development. The results show that the Dadu River hydropower base and Wujiang River hydropower base are 100% within the third-grade biodiversity conservation zones, while Jinsha River hydropower base and Lancang River main stream hydropower base occupy a relatively smaller area in the third-grade biodiversity conservation zones.

3. Ecological conservation priority area

According to relevant river basin comprehensive planning reports, environmental impact assessment documents, *Overall Construction Planning for Rare Fish Species National Nature Reserve at Hejiang-Leibo Section of Yangtze River*, *Overall Planning for Wujiang River-Changxi River Fish Species Nature Reserve* and literature review (Zhou Jianping, and others 2011), we review the world natural and cultural heritage, national scenic and historic interest areas, national nature reserves, and national forest parks that might get involved in cascade development of all river basins and hydropower bases. See Table 3.11 for details. Our obtained results indicate that it needs to further demonstrate dam site selection of Hutiao Gorge on Jinsha River, identify the relationship between ecological protection priority areas and important hydropower stations in the upper reaches of Yalong River, Dadu River, and Yellow River, recalculate the hydropower station size, and further increase environmental protection investment.

4. Technical and economic analysis

In addition to the benefits brought by power generation, development of hydropower resources has comprehensive utilization benefits such as flood control, irrigation, water supply, shipping, and tourism. The technical and economic analysis we make in this book of major hydropower bases to be promoted during the “12th

Table 3.11 Important ecological and environmental protection priority areas of China's major hydropower bases

Hydropower base	Cascade hydropower station	Protection scope	Name of reserve
Jinsha River	Longpan Hydropower Station	From Judian to Daju	Landscape resources such as first bend of the Yangtze River and Tiger Leaping Gorge Grand Canyon; Yulong Snow Mountain and Haba Snow Mountain Provincial Nature Reserve
	Liangjiaren Hydropower Station; Liyuan Hydropower Station	Four areas: Hongshan Mountain, Haba Snow Mountain, Laojun Mountain, Baima-Meri Snow Mountain	World Heritage Sites located in these eight areas; Three Parallel Rivers of Yunnan National Key Scenic and Historic Interest Area
	Xiangjiaba Hydropower Station	The channel segment from 1.8 km down the dam axis of Xiangjiaba Dam to Yibin City	Rare and Specific Fish Species National Nature Reserve in the Upper Reaches of Yangtze River
Yangtze River	Xiaonanhai Hydropower Station, etc.	From Yibin City to Nanxi Town	River sturgeon, Chinese paddlefish, mullet, and other rare and specific fish resources in the Yangtze River basin and their living environment; typical river wetland; Rare and Specific Fish Species National Nature Reserve in the upper reaches of Yangtze River
		From Nanxi Town to Shatuozi	
		From Tuojiang River mouth to Mituo Town	
		From Mituo Town to Songji Town	
		From Songji Town to Luohuang Town	
Lancang River	Huangdeng Hydropower Station, Tuoba Hydropower Station, Lidi Hydropower Station, Wunonglong Hydropower Station, Guonian Hydropower Station, Gushui Hydropower Station	Eight areas: Gaoligong Mountain (North), Baima-Meri Snow Mountain, Laowo Mountain, Yunling Mountain, Julong Lake, Laojun Mountain, Haba Snow Mountain, Qianhu Mountain, and Hongshan Mountain	World Heritage Sites located in these eight areas; Three Parallel Rivers of Yunnan National Key Scenic and Historic Interest Area
	Jinghong Hydropower Station, Ganlanba Hydropower Station, Mengsong Hydropower Station	From Jinghong to Mengla	Xishuangbanna National Scenic and Historic Interest Area and National Nature Reserve
Dadu River	Shenxigou Hydropower Station, Zhentouba Hydropower Station	Northwestern area of Jinkouhe District, Leshan City, eastern area of Hanyuan County, Ya'an City, northern area of	Dadu River Grand Canyon National Geopark

(continued)

Table 3.11 (continued)

Hydropower base	Cascade hydropower station	Protection scope	Name of reserve
		Ganluo County, Liangshan Yi Autonomous Prefecture	
	Luding Hydropower Station, Yinliangbao Hydropower Station, Dagangshan Hydropower Station, Longshitou Hydropower Station, Laoyingyan Hydropower Station	Kangding County, Luding County, Jiulong County, and Daofu County, Ganzi Tibetan Autonomous Prefecture and Shimian County, Ya'an City	Gongga Mountain National Scenic and Historic Interest Area
Yalong River	Lianghekou Hydropower Station	26 km north of Yajiang County town	Qingdagou Second-Grade Forest Park
Nanpanjiang River; Hongshui River	Longtan Hydropower Station	Leye County in Northwest Guangxi Province	Guangxi Yalong National Nature Reserve
Wujiang River	Pengshui Hydropower Station	Areas along the rivers in Guizhou Province and Wuchuan County	Mayang River National Nature Reserve
Nujiang River	Liuku Hydropower Station, Hushui Hydropower Station, Yabiluo Hydropower Station, Bijiang Hydropower Station, Fugong Hydropower Station, Lumadeng Hydropower Station, Maji Hydropower Station, Bingzhongluo Hydropower Station, Songta Hydropower Station	Gaogongli Mountain area	Three Parallel Rivers of Yunnan National Key Scenic and Historic Interest Area
Upper reaches of Yellow River	Guancang Hydropower Station, Mentang Hydropower Station, Tajike Hydropower Station	From Xiarihu Temple to Mentang	Sanjiangyuan National Nature Reserve
	Xiaoguanyin Hydropower Station	Jingtai County, Gansu Province	Yellow River Stone Forest National Geopark

Table 3.12 Technical and economic analysis of hydropower resources development of China's major hydropower bases

River basin	Installed capacity (10,000 kW)	Annual electricity generation (100 million kWh)	Operation scale in 2010 (10,000 kW)	New construction scale during "12th Five-Year Plan" period	New operation scale during "12th Five-Year Plan" period	Flood control capacity	Total static investment (RMB 100 million)
Upper reaches of Yangtze River	3400	1280	2431	170	420	231.5	1602
Jinsha River	7700	2908	0	4640	2390	221.4	2775
Lancang River	3140	1400	885	2030	750	32	1350
Yalong River	2600	1360	330	850	1080	40	1228
Dadu River	2640	1010	641	1180	540	11.7	1390
Wujiang River	1140	418	933	40	170	11.7	526
Upper reaches of Yellow River	2530	1275	1457	650	40	116.7	689
Nanpanjiang River; Hongshui River	1570	504	1208	140	60	100.2	766
Nujiang River	3600	1029	0	1120	0	52.3	897
Total	28,320	11,184	7885	10,820	5450	817.5	11,223

Notes The data of annual generating capacity are based on *Planning for China's 13 Hydropower Bases*; the data of flood control capacity and total static investment are as of 2010; other data are based on the *12th Five-Year Plan for Hydropower Development*

Five-Year Plan" period is mainly based on the construction scale in 2010, started construction scale and new production scale during the 12th FYP period, total static investment and flood control capacity. See Table 3.12 for details.

3.3.3 Solutions and Policy Suggestions

3.3.3.1 Solutions

1. Coordinate overall planning goals and promote hydropower development

China developed the *Planning for National Principal Functional Regions* and officially released in June 2011. It is a strategy and the basis of the overall plan for national economic and social development, regional planning, and urban planning. In addition, we give more consideration to comprehensive river basin requirements. At the end of 2009, China completed the revision or formulation of comprehensive plans for all major river basins, which will make arrangements for river basin development planning and become important basis for river basin development, utilization, water resources conservation and prevention, and control of water disasters. Hydropower development planning should follow the overall goals and principles of watershed planning to accelerate the rapid and good hydropower development.

2. Integrating ecological protection into the process management of hydropower development

The issue of ecological protection in hydropower development has received extensive attention. In reviewing China's hydropower development progress since reform and opening up 30 years ago, we find we have made major progresses in environmental protection for a hydropower plants in the planning and construction stage. However, the ecological environmental constraint to hydropower development is still a hard nut to crack. First, it should optimize hydropower layout and scale and balance development and ecological protection in the planning period. Hydropower development should meet the overall demands of the comprehensive watershed planning. Second, the mitigation measures should be implemented in the hydropower project design and construction period. Hydropower project design should focus on more environmental protection technologies, put forward countermeasures for preventing or mitigating the adverse effects on the environment to ensure that the ecological environment protection measures construct earlier than the construction of hydropower projects. Finally, the ecological operational scheme should be identified in hydropower project operation. Hydropower project operational dispatch management will become the core of ecological protection for the hydropower sector in China. Dispatch scheme of a hydropower should meet the requirements of regional ecological protection goals. We suggest that it should improve the dispatch scheme of a reservoir by learning from the international idea and mechanism of "adaptive management."

3. Establish social wealth sharing mechanism

Hydropower development is a process of converting natural resources into social wealth. China's central government, local governments, enterprises, and citizens should establish the idea of development resources and sharing wealth. Most hydropower bases are located in poor and undeveloped areas. Without the support of hydropower enterprises, hydropower might never become social wealth only by local finance and techniques. Practice experiences shows that we should establish a wealth sharing mechanism to achieve the regional social and economic benefits driving by hydropower development, and thus promote the common prosperity of the whole society; we should recognize the rights of the affected groups to use resources and improve the current mode that local residents and the governments in the reservoir areas fail to share social wealth in a reasonable way; we should actively explore the innovative resettlement mode, reform the existing the distribution mode of benefits and profit from resources, raise the funds for resettlement, and define resettlement compensation standards according to law.

4. Establish guarantee institutions

Reservoir migrants have a characteristic of involuntary. In China, involuntary migrants caused by project construction is not limited to the water conservancy and hydropower sectors. The compensation standard for migrants varies among different sectors and areas. Therefore, we suggest resettlement compensation should be legally standardized to ensure the stable implementation of resettlement.

We suggest "equal electricity with equal price in a grid." It should establish a long-term institution to ensure put funds in resettlement compensation and ecological protection in the hydropower sector projects. We also suggest establishing the watershed compensation mechanism as soon as possible. It should reasonably evaluate the ecological loss and benefits of a hydropower project and establish a cost sharing mechanism to promote the implementation of watershed ecological compensation.

3.3.3.2 Policy Suggestions

1. Improve medium- and long-term hydropower development idea and strategy

According to China's energy strategy goals and GHG emission reduction goals in 2020, we suggest establishing China's overall hydropower development strategy, identifying the development goals and adjusting current hydropower station layout, scale, development mode, and time arrangement in comprehensive watershed planning.

The development degree of China's hydropower bases such as Jinsha River hydropower base, Yalong River hydropower base, Lancang River hydropower base, and Dadu River hydropower base will reach 70% and above by 2020. Then, China will still have a surplus of economically exploitable hydropower installed capacity of 50 GW mainly concentrated in river sources and Tibet. Hydroelectricity transmission from Tibet to the whole country will play an important supporting role in achieving China's energy strategy and promoting Tibet's social and economic development. Meanwhile, China will face ecological protection, migrant resettlement, protection of minority culture, and other problems. We suggest making preparations for developing hydropower resources in Tibet as soon as possible.

China has rich transboundary rivers, but the development degree of these international rivers is very low. In which, Nujiang River and Yarlung Zangbo River are basically not developed. Downstream countries of these transboundary rivers are very complicated. We suggest starting the research on establishing the transboundary river water right allocation mechanism, transboundary water pollution conflict coordination mechanism, biodiversity conservation negotiation mechanism, major emergency warning mechanism, and river development rights coordination mechanism. The results can provide useful information for decision-makers and promote the early utilization of water resources and hydropower potential in transboundary rivers.

We should consider how to use cascade reservoir dispatch to improve the quantity and quality of hydroelectricity generation. Meanwhile, it will a long-term task to obtain the sustainable development of river basins, including water supply, flood control, and eco-environment protection goals. We suggest comprehensively considering the relationship between upstream and downstream cascade power stations in basins. It should improve the operational and scheduling level of the cascade hydropower plants by using advanced decision-making theories and methods to achieve efficient utilization of river hydropower potential.

Construction of pumped storage hydropower is an important solution to the grid peak regulation problem with the rapid development of new energy. We suggest as soon as possible to make pumped storage hydropower planning and construction during the 12th FYP period for the grid security.

2. Improve institutions to establish a policy system for promoting hydropower development

   (1) Tax reduction policy. Current hydropower taxes are too high in China. Taxation basically remains unchanged after tax reform in other sectors in China. However, hydropower taxation has been increased by several times in recent years. Take the value-added tax as an example: Before the tax reform, the value-added tax rate in the electric sector was about 10%; while after the tax reform, value-added tax rate for hydropower sector is 17%, about two times that of coal-fired fuel power. We suggest carrying out tax reform in the hydropower industry to reduce its taxation.
   (2) Price policy. Hydropower price is lower than its value. China's electricity price is controlled and approved by the government. China's electricity price system may be the most complex in the world. Although the Electricity Law of the People's Republic of China required "equal electricity with equal price in a grid," however, it does not implement until now. The on-grid hydropower price in China is the lowest in all electricity. We

suggest implementing the policy of "equal electricity with equal price in a grid" and establishing relevant policies to reflect resettlement and ecological protection cost in hydropower projects.

(3) Current submerged compensation policy does not benefit to hydropower development. Since the promulgation and implementation of the revised Land Administration Law of the People's Republic of China and Forestry Law of the People's Republic of China, the submerged compensation policy has failed to reflect the nature of hydropower projects occupying land. All land is regarded as forest land and farmland, which results in the overestimated value of land in remote areas and the failure to reflect the significance of hydropower development. We suggest to further subdivide land types in reservoir inundation for compensation policy-making.

(4) Environment policies. We suggest carrying out strategic environmental impact assessment for energy development projects with the consideration of national energy security and GHG emission reduction goal. It should weight the GHG emissions and the ecosystem protection to identify the short-, medium-, and long-term environmental protection strategy for national energy development.

(5) Hydropower project construction management policy. We suggest improving hydropower project construction management procedures and measures, identifying the requirements for the prophase, approval, construction, and operation, establishing the relative simple approval system according to the investment system reform requirements and actual situation of hydropower construction, establishing the new hydropower preparatory work fund and operation system according to the market rules, and emphasizing the investment in the preparatory work.

3. Increase technical investment to promote innovations in the science and technology system

We find that each leap in hydropower construction sourced from the breakthrough in the key technologies during China's hydropower development history. China's dam construction technology has reached the world leading level, but it does not mean that the technology problem has been solved completely. After the reform of the national electric power system, the investment in the systematic research on the hydropower development science and technology is obviously insufficient. The ecological protection practice for the hydropower sector lacks basic and systematic research and investigation, which results in the absence of the integrated ecological protection goal for many rivers. As an interdisciplinary, the theory and methodologies of ecological protection for the hydropower sector should be better. We suggest increasing investment in hydropower development technology, innovating the industry-academia-research system and promoting application of interdisciplinary approaches to solve key technical problems that affect the dam security and restrict hydropower development.

4. Suggestions for revision of laws and regulations

We suggest that it should revise the *Renewable Energy Law of the People's Republic of China* to define hydropower as a renewable energy, establishing and improving the hydropower development regulations, making Regulations on Administration of Hydropower Development to propose relevant requirements for hydropower development.

We suggest developing a *Project Construction Resettlement Law* to ensure the rights and interests of reservoir migrants, standardize the migrant resettlement in different hydropower projects, and solve the problem of unrealistic comparison of resettlement standards among different sectors.

5. Suggestions for hydropower development and management

China implements multiple administration by different government sections for hydropower development. The NDRC is responsible for the management of large hydropower, the Ministry of Water Resources for the management of reservoirs and small hydropower focusing on public welfare, and transportation departments for the management of navigation hydropower junction. This situation is seriously harmful to watershed integrated management and water resource utilization. We suggest establishing an integrated organization to implement watershed hydropower management.