China – policies, HELE technologies and CO_2 reductions

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Preface

This report has been produced by IEA Clean Coal Centre and is based on a survey and analysis of published literature, and on information gathered in discussions with interested organisations and individuals. Their assistance is gratefully acknowledged. It should be understood that the views expressed in this report are our own, and are not necessarily shared by those who supplied the information, nor by our member countries.

IEA Clean Coal Centre is an organisation set up under the auspices of the International Energy Agency (IEA) which was itself founded in 1974 by member countries of the Organisation for Economic Co-operation and Development (OECD). The purpose of the IEA is to explore means by which countries interested in minimising their dependence on imported oil can co-operate. In the field of Research, Development and Demonstration over fifty individual projects have been established in partnership between member countries of the IEA.

IEA Clean Coal Centre began in 1975 and has contracting parties and sponsors from: Australia, China, the European Commission, Germany, India, Italy, Japan, Poland, Russia, South Africa, Thailand, the UK and the USA. The Centre provides information and assessments on all aspects of coal from supply and transport, through markets and end-use technologies, to environmental issues and waste utilisation.

Abstract

As the world's largest consumer of coal and leading CO_2 emitter, China's role in the international effort to combat climate change can hardly be overstated. The challenges China faces to control emission and pollution levels while meeting the country's increasing energy demand are enormous. Over the years, China has made considerable efforts to reduce CO_2 emissions and control pollution levels, and notable progress has been made through the implementation of ambitious programmes aimed at improving energy efficiency across a number of industrial sectors and a rapid development of renewable energy. This study reviews China's policy and regulatory initiatives, in particular those aimed at improving energy efficiency of and reducing emissions from coal power generation, HELE upgrade of coal power plants, as well as the progress to date in reaching a series of ambitious goals. China's rapid expansion of non-fossil energy which affects the structural change of the power sector and coal use in electricity generation, and therefore, CO_2 emissions from coal-fired power generation is discussed.

China has also provided strong financing and policy support for the R&D of HELE technologies. China now possesses a range of HELE technologies that are applicable to new coal-fired power plants and to retrofitting the existing ones. They are described in this report. Finally, peak coal consumption and CO_2 emissions from power generation from coal, in light of China's economic and policy trends affecting the structure of the economy and coal consumption, are assessed.

Acronyms and abbreviations

AAQS	Ambient Air Quality Standards
Bt	billion tonnes (10^{12})
CCS	carbon capture and storage
CCT	clean coal technology
CFB	circulating fluidised bed
CHP	combined heat and power
ELV	emission limit value
ESP	electrostatic precipitator
FGD	flue gas desulphurisation
FYP	FiveYear Plan
GHG	greenhouse gas
Gt	gigatonne (10^9)
GWe	gigawatts electricity
HELE	high efficiency, low emission
IEA	International Energy Agency
IGCC	integrated gasification combined cycle
kWh	kilowatt hour
LSS	large substituting small
MEP	Ministry of Environmental Protection (China)
MOST	Ministry of Science and Technology (China)
Mt	million tonnes
NBSC	National Bureau of Statistics of China
NDRC	National Development and Reform Commission (China)
NEA	the National Energy Administration
NPC	National People's Congress
O&M	operation and maintenance
R&D	research and development
PM	particulate matter
SASAC	State-owned Assets Supervision and Administration Commission of the State Council
SC	supercritical
SCE	standard coal equivalent
SCR	selective catalytic reduction
SPC	spin exchange coupling
SPE	solid particle erosion
S&T	science and technology
TEC	total emission control
USC	ultra-supercritical

Note: The Chinese characters in the text are a reference for the policies and regulations cited. The documents can only be found in official Chinese websites using these characters, not a translated version.

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1 Introduction

Coal plays an important role in the world energy supply, particularly for power generation. In 2013, 68% of primary coal was used for the generation of electricity and commercial heat (IEA, 2015a). Currently, coal-fired power plants with a total capacity of about 1700 gigawatts (GWe) produce over 41% of the world's electricity (Burnard and others, 2014). Coal's share in electricity generation mix is significantly higher than the global average in countries such as South Africa, Poland, China and India. Coal is a carbon intensive fuel and remains the largest source of anthropogenic carbon dioxide (CO_2) emissions. The combustion of coal adds a significant amount of CO_2 to the atmosphere per unit of heat energy, more than does the combustion of other fossil fuels. Currently, the global average efficiency of coal-fired power plants in operation is around 33%, much lower than the 47% efficiency possible with today's state of the art, ultra-supercritical (USC) coal-fired power plants. Figure 1 shows the CO_2 emission levels in relation to power plant efficiency or coal consumption rate for power supply. In 2012, coal related CO_2 emissions were 13.9 gigatonnes (Gt), accounting for 43.9% of global CO_2 emissions (IEA, 2014). Because of a growing international concern over the possible consequences of global warming, related to increases in atmospheric CO_2 the need to improve the efficiency of coal-fired power plants is clear.

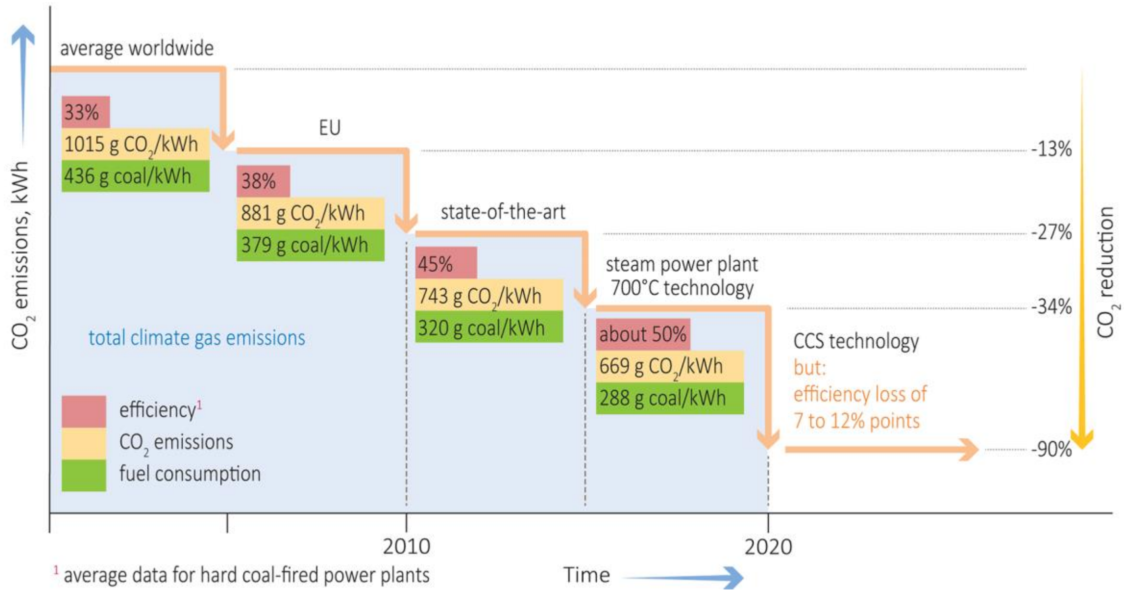

Figure 1 CO_2 emission level in relation to coal consumption rate/plant efficiency (VGB, 2015)

In the latest 'Energy Technology Perspectives', the International Energy Agency (IEA, 2015b) claims that in order to have at least a 50% chance of limiting average global temperature increase to 2°C towards the end of this century, energy- and process-related CO_2 emissions will need to be cut by almost 60% by 2050 (compared with 2012) and they should continue to decline thereafter. The IEA concludes that, although a wide range of technologies will be necessary to substantially reduce CO_2 emissions from coal-fired power plants, carbon capture and storage (CCS) will have a major role to play. However, as the introduction of CCS is not progressing as quickly as anticipated, the need to improve the efficiency of coal-fired power plants in the short to medium term is urgent. CO_2 mitigation by means of power plant efficiency improvement can be achieved through closing older, less efficient generating units and replacing them with new, larger and efficient units where it is practical to do so, and by equipment refurbishing and upgrading, and by optimising operation and maintenance (O&M) schedules to improve the energy efficiency of existing plants. According to the IEA's (2012) analyses, modern coal-fired power plants using high efficiency, low emission (HELE) technologies are the most suitable for economic CCS retrofit but currently this would only be possible on around 29% of the existing total installed global coal-fired power plant fleet. Recently, Barnes (2014) examined the prospect for the role of HELE technologies in CO_2 abatement in selected major coal user countries. His work for the IEA Clean Coal Centre indicates that HELE plant upgrades are generally applicable to most of these countries whilst those with a prolonged growing demand for electricity and with aging, inefficient coal-fired power plant fleet will have the greatest benefit from HELE technology.

China is the world's most populous country (1.37 billion people in 2015) and has the world's second largest economy, which has driven the country's high overall energy demand. China's fossil fuel resources are mainly coal; there is a relative lack of oil and natural gas. As of 2013, China's coal reserve was 236 billion tonnes, while its oil reserve was 3.37 billion tonnes (1.1% of the world's total) and natural gas reserve was 4640 billion cubic meters (1.8% of the world's total) (Li and Sun, 2015). As a result, coal is the dominant form of energy used in China. The vast coal resources enable the fuel to remain the mainstay of China's energy industry and have supported the country's rapid economic growth over the past three decades. Currently, China is the largest producer, consumer and importer of coal, globally. Figure 2 compares China's energy consumption in 2014 with the world's average. It clearly shows that coal's share in total energy consumption in China (66%) is much higher (35.9% points higher) than the world average of 30.1% (Li and Sun, 2015). In fact, China consumes more coal in a year than the rest of the world put together.

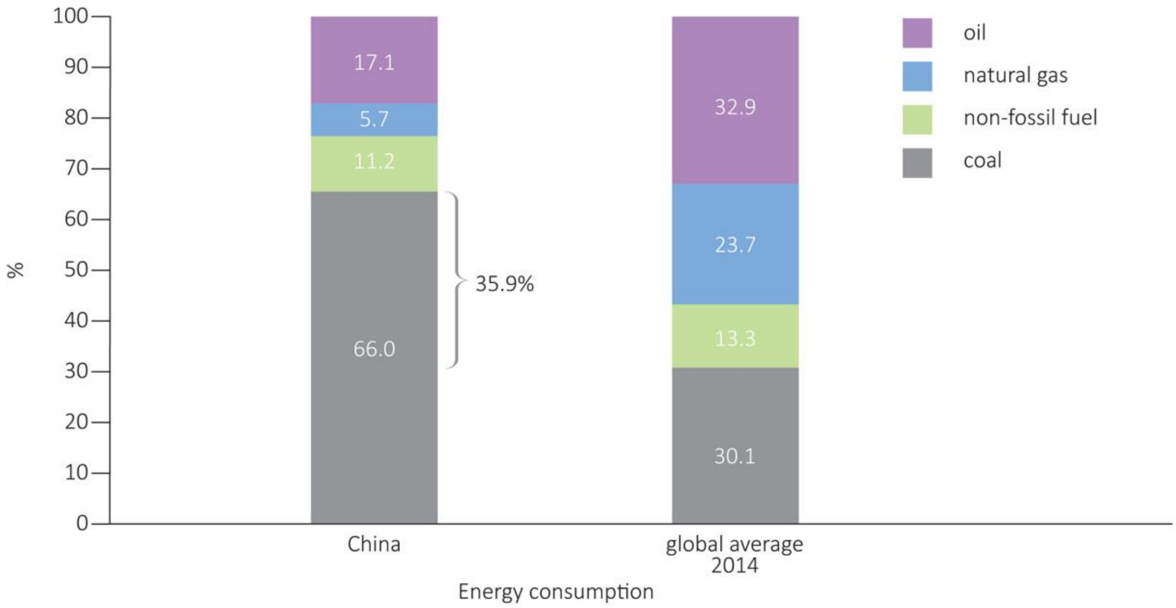

Figure 2 Comparison of China's energy consumption with the global average in 2014 (Li and Sun, 2015)

As a result of high coal consumption, China is also the world's leading CO_2 emitter, releasing 8.25 Gt of CO_2 (26% of global total) in 2012 (IEA, 2014). Coal is the country's largest source of CO_2 emissions accounting for over 60% of total emissions. As the world's largest consumer of coal and biggest CO_2 emitter, China's role in the international effort to combat climate change can hardly be overstated. The challenges China faces to control emission and pollution levels while meeting the country's increasing energy demand are enormous. China is making great efforts to promote green, low-carbon, climate resilient and sustainable development through accelerating institutional innovation and enhancing policies and actions. Over the years China has unleashed laws, standards, regulations, action plans, and other policies at national and regional levels that are directly related to even broader policy measures, including for energy development, energy conservation, efficiency improvement, emissions control and technology promotion. In November 2014, China and the USA made a historic joint announcement pledging to curb greenhouse gas (GHG) emissions within the next decades. Through this statement, China committed to making its GHG emissions peak by 2030 and to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030 (www.whitehouse.gov/the-press-office/2014/11/11/us-china-joint-announcement-climate-change). In September 2015, China and the USA made another Joint Presidential Statement on Climate Change through which China reconfirmed its commitments to reduce GHG emissions through promoting sustainable development and the transition to a green, low-carbon and climate-resilient economy and to strive to lower CO_2 emissions per unit of GDP by 40 to 45% from the 2005 level by 2020 (www.whitehouse.gov/the-press-office/2015/09/25/us-china-joint-presidential-statement-climate-change). To date, China has already made considerable progress through the implementation of ambitious programmes aimed at improving energy efficiency of power generation as well as across a number of industrial sectors and a rapid scaling up of renewable energy.

This study reviews China's policy and regulatory initiatives, in particular those aimed at improving energy efficiency and encouraging the deployment of HELE technologies to reduce CO_2 emissions from coal-fired power generation and the progress to date in reaching these goals. The main focus of the report is to review China's policy and regulatory initiatives aimed at energy efficiency targets and measures for the coal power sector, HELE technology upgrades, limits on coal use, and the expansion of non-fossil energy which affect the structural change of the power sector and coal use in electricity generation, and therefore, CO_2 emissions from coal-fired power generation. The recent advances in Chinese HELE coal power generation technologies are discussed. The peak of coal consumption and CO_2 emissions from power generation from coal, in light of China's economic and policy trends affecting the structure of the economy and the coal consumption, are projected.

2 Overview of China's legal framework and administrative implementation structure

2.1 Legal framework

China's energy, climate change and air pollution prevention and control policies are made up of a range of different measures including laws, standards, regulations, action plans and others. The legal framework has several levels. Laws are decided by the National People's Congress. Other policies at the national level such as regulations and standards are issued by the State Council and ministries. The last level includes policies and regulations by provincial and local governments. The following sections review China's legal framework and administrative implementation structure, focusing on the policy and regulatory initiatives related to energy development, air pollution prevention/control and CO_2 emission reduction from the coal power sector.

2.1.1 Laws

Laws that apply to electric power regulation are in three categories:

1) specific laws for industrial regulation such as the 'Energy Law' (1997), the 'Electric Power Law' (1996);

2) general regulatory laws such as anti-illegitimate competition law, anti-trust law and law on the protection of rights and interests of consumers;

3) related laws for regulation such as company law, price law and contract law.

Relevant environmental laws include the 'Environmental Protection Law' which established the framework for protecting the environment, including setting standards, assessing and limiting environmental impacts, fines for pollution, and bans on polluting technologies and facilities, and the 'Law on the Prevention and Control of Atmospheric Pollutants'.

China's climate related laws are dominated by a focus on saving energy, reflecting the need to improve energy efficiency to enable the country to keep pace with energy demand as the economy grows strongly. The 'Energy conservation law' of 1997 (amended in 2007) and the 'Renewable energy law' passed in 2005, are designed to help reduce the country's energy and carbon intensity and protect the environment.

Climate change was first officially referred to in legislation or regulations in China's National Climate Change Programme of 2007, and repeated in China's Policies and Actions for Addressing Climate Change issued in 2008. In August 2009, the National People's Congress passed a comprehensive Climate Change Resolution. This is the first resolution of its kind adopted by the top legislature of China to deal with climate change. Technically these are not laws but policy documents guiding legislation.

2.1.2 Five-Year Plan

The most important policy documents in China are the Five-Year Plan (FYP) that is composed of a master plan and many sub-plans, and even sub-sub plans. China develops a Master Plan for Economic and Social Development every five years. The master plan coordinates public policy priorities and lays down the main national development objectives. Several sub-plans for various sectors and different levels of government are developed according to the master plan. With a comprehensive decision making mechanism engaged by all the Chinese government agencies in five-year cycles, the FYPs structure the nation's planning system. The FYP lays out China's development strategies, clarifies the government's working focus, provides guidance and sets specific economic and environmental goals and targets for the activities of major market actors. Some FYPs mandate overall directions for the revision of laws, regulations, standards, and other measures and instruments, for instance, for energy and environmental performance. Some geographical factors and technological capacity building are also incorporated in the development of various FYPs relating to emissions control and other goals. It should be noted that the FYP is not one large integrated plan. It is composed of a master plan with many sub-plans that are not developed all at one time to start at the beginning of the period, but rather their development is an ongoing process continuing throughout the plan period.

The FYPs are not mandated by China's constitution, and they do not have the status of law or regulations. They are enforced through a target responsibility system established by a State Council Order. Moreover, regarding policy implementation, the Master Plan is considered to be a State Council Order or Decision. Implementation of the State Council's Orders is mandatory for local governments and therefore, the implementation of the Master Plan is regarded as an obligation of local governments (Lin and Elder, 2014).

2.1.3 Standards, pollution levies and total emission control

In addition to administrative law, China has a series of regulations relating to emissions of specific pollutants. They are in the form of ambient air quality standards, specific standards on pollution discharge and administrative regulations.

Emission Standards for air pollutants are divided into two categories. One category is for a particular industry and/or particular type of pollution. The other category is a general standard specified in the 'Integrated emission standard of air pollutants', which includes those industries and pollutants not currently covered by any specific emission standards. The 'Emission standard of air pollutants for thermal power plants' sets the limiting values for emissions of major air pollutants from coal-, oil- and gas-fired power plants, whilst the air pollutant emissions from small industrial and heating boilers are regulated by 'Emission standard of air pollutants for boiler'.

The ***'Ambient air quality standards'*** (AAQS) stipulate the total amount of pollutants in the air, in order to safeguard human health, conditions for normal life, and the ecological environment. The ambient standards set up the basic criteria for the management and evaluation of ambient air quality, related air pollution prevention and control planning, as well as the standards for other emissions. The latest developments in

China's emission standards for air pollutant emissions from coal combustion and AAQS have been recently reviewed in detail by Zhang (2016).

Pollution levies were initiated in 1979 with the 'Environmental Protection Law' (1979 trial), which established the 'polluter pays' principle, and have been revised several times since then. In January 2003, the State Council promulgated the 'Management Regulation for Collecting Pollution Charge Fees' (State Council Order No. 369) that introduced significant changes into the pollution levy system. The changes were made mainly in four areas: 1) the air pollution fees which previously only levied for above-standard discharges were converted to levies on the total amount of discharges; 2) the levies were applied to the concentration and the total quantity of pollutant discharge rather than the concentration only as before; 3) the number of targeted pollutants that the levies applied to was increased; and 4) the previously low rate of the levies was increased in order to compensate for the management costs. To implement the strengthened regulations, several corresponding regulations and measures were subsequently issued. The 'Standard management measures for collecting pollution charge fees' (Order No. 31) and the 'Management measures for collecting and using pollution charge fees' (Order No. 17) were issued in 2003. An information communication management system for the pollution levy was established at the same time (http://jgs.ndrc.gov.cn/zttp/zyhjjg/200704/t20070409_127834.html).

The ***Total Emission Control*** (TEC) policy was introduced in 1988 at the Third National Conference for Environmental Protection. TEC is a total mass emissions control policy at the national, provincial, and municipal/city levels. In TEC policy planning, the central government first lays down the total mass emission target, prepares a national air pollutant emission control plan, and allocates the plan's tasks to local governments. TEC plans are made and implemented at each level, the central government then assesses implementation. After many trials in pilot cities, TEC was first implemented in 1996 in the 9th FYP, replacing the previous policy focusing on the total concentration of emissions. Despite some deficiencies which have emerged in its implementation so far, it is generally agreed that TEC has made a significant contribution to China's environmental protection and provided a solid policy foundation for many other environmental policy instruments (Lin and Elder, 2014).

2.1.4 Other policy measures and instruments

Action plans set mandatory targets and outline a number of strengthened governance measures and approaches in order to achieve these targets. Action plans provide overall strategy guidance for development in certain sectors or areas in the near future and the programme of action. The two important action plans released in 2014 concerning China's energy development and coal power generation are the 'Energy Development Strategy Action Plan (2014-2020)' (issued by China's State Council) and the 'Action Plan on Upgrading and Reconstruction of Coal-Fired Power Plants for Energy Conservation and Emission Reduction (2014-2020)' issued by the National Development and Reform Commission (NDRC), the Ministry of Environmental Protection (MEP), and the National Energy Administration (NEA). These two action plans are discussed in more detail in Section 3.3.

In response to the severe air pollution, the State Council unveiled the 'Air Pollution Prevention and Control Action Plan' in 2013 containing a mixture of general aspirations/directions, concrete measures, and targets. One of the areas for action is the energy sector where measures are outlined to cap coal consumption, to renovate small coal-fired boilers and to increase clean energy supply (*see* Sections 3.3 and 3.4).

The legal status of the action plans is not the same as a law or regulation, since some of them were issued by the State Council, and not approved by the National People's Congress and some were issued by a ministry or multiple ministries.

In 2013, China launched ***Carbon emission trading pilot programmes*** in five cities (Beijing, Chongqing, Shanghai, Shenzhen, and Tianjin) and two provinces (Guangdong and Hubei). Each one explores a different carbon trading mechanism in order to inform the development of a future national carbon emissions trading market. The key features of each pilot programme are summarised in Table 1. Taken together, the programmes substantially expand the portion of emissions covered by carbon markets, bringing global coverage from less than 8% to more than 11% of the world's total carbon emissions. Moreover, the allowance prices in some programmes such as Beijing and Guangdong are comparable or greater than those in other markets (Munnings and others, 2014). More detailed description and analysis of the pilot programmes and their performances can be found in a recent review by Qi and Cheng (2015). In the U.S.-China Joint Presidential Statement on Climate Change made in September 2015, the Chinese leader Xi Jinping announced that China would '*start in 2017 its national emission trading system, covering key industry sectors such as iron and steel, power generation, chemicals, building materials, paper-making, and nonferrous metals*' (White House, 2015).

Table 1 Key Features of China's carbon emission trading pilot programmes (Munnings and others, 2014)

Pilot scheme	Start date	Emissions coverage (Mt)	Covered entities	Allowance price (2014 US dollar)
Beijing	November 2013	50	~490	9.28
Chongqing	June 2014	125	242	4.92
Guangdong	December 2013	408	211	9.31
Hubei	April 2014	324	138	3.76
Shanghai	November 2013	160	~200	7.68
Shenzhen	June 2013	33	~635	8.96
Tianjin	December 2013	160	197	3.79

2.2 Institutional structure

Like many countries, China's formal governmental structure is divided into legislative and administrative branches, and these branches are further divided into national and subnational levels. The national legislative power is exercised by the National People's Congress (NPC) and the Standing Committee of the National People's Congress. The NPC is the highest law-making body and there is no division of legislative power between the central government and the provincial governments in China. The State Council is the highest administrative body and it supervises the national ministries. The State Council decides the contents of the Master Plan, and examines and approves the sub-plans and regulations that are to be implemented by multiple ministries, which require the State Council's coordination.

The National Energy Commission, headed by Premier Li Keqiang, is a high-level deliberative organ responsible for policy decisions and coordination in national energy development strategy, energy security and energy development (http://www.nea.gov.cn/gjnyw/). Regulations and policies regarding energy/energy development are under the jurisdiction of the NDRC and NEA, while those of air pollution issues are mainly under jurisdiction of the NDRC and MEP. The NDRC functions as a macroeconomic management and planning agency which studies and formulates policies for economic and social development and guides the overall restructuring of the economic system. The NDRC acts as a kind of 'super ministry' in charge of overall economic planning as well as energy and climate change. These ministries share responsibility for the management of comprehensive coordination among various government bodies engaged in China's energy development and emissions control at both the national and subnational levels.

At the design stage of energy policy, the NEA (under the jurisdiction of the NDRC) is responsible for industrial regulation concerning coal, oil, natural gas, electricity and renewable energy, which includes energy industry planning, industrial policy and standards generation, relevant energy legislation enactment, energy system reform promotion, renewable energy development and energy conservation motivation (http://www.nea.gov.cn/gjnyj/). For environmental protection polices, NDRC is in charge of planning prevention strategies for emission sources, while MEP is in charge of planning for pollution control strategies. At the policy implementation stage, NDRC assigns tasks to the relevant government departments.

2.2.1 Implementation by ministries

In a broader view of energy and environmental policies related to power generation, there are several other ministries involved in addition to the NDRC, NEA and MEP. These include:

- the Ministry of Finance, Ministry of Commerce and NDRC are responsible for developing finance, taxation, industry, pricing and investment policies conducive to energy development and air pollution control;
- the Ministry of Industry and Information Technology is responsible for promoting technical improvements of enterprises, imposing standards for new industrial projects and factory construction, improving the mechanisms of phasing out outdated production capacity, and strengthening prevention and control of industrial pollution;
- the Ministry of Science and Technology is responsible for supporting R&D of clean coal and HELE technologies, and key technologies for air pollution control and improvement of air quality.

Among them, the NDRC plays the most important role (Lin and Elder, 2014).

2.2.2 Implementation by provincial and local governments

Policy implementation is basically carried out by local governments. Under the coordination of various ministries, guidelines on local targets and measures are approved and distributed by the central government to local governments. Based on these instructions, local governments develop local plans. Competent departments of the local governments at or above the county level are required to conduct unified supervision and management within areas under their jurisdiction to ensure the targets and requirements are met.

As mentioned in Section 2.1.2, the FYPs are enforced through a target responsibility system that establishes the indicators for the evaluation of the performance of local governments. Assessments of the implementation of the Plan and the examination of the performance on, for instance the Total Emission Control programme are conducted. The results are reported to the State Council and made public and serve as an important component for assessing the overall performance of local governments. If a local authority fails to fulfil the local targets and requirements set by the Plan, its head may receive a punishment such as a serious warning, admonishment, demotion, or removal from office, although it is not clear whether this has actually ever happened (Lin and Elder, 2014).

3 Major developments in China's policies

3.1 Background

Since its former leader Deng Xiaoping started 'reform and opening-up' in 1978, China has experienced a period of rapid economic growth, urbanisation, and demographic change, which have lifted hundreds of millions of Chinese people out of poverty. Over the past thirty years, China has grown rapidly, often at double-digit rates. China's growth strategy has been characterised by high investment, strong export orientation, and a focus on manufacturing industry and construction. The high levels of investment in energy intensive heavy industrial sectors such as steel and cement have led to strong growth in energy demand.

There was a continuous shortage of power supply, which started in the 1960s. In 1986, the shortage in power supply was over 20% of the total electricity production in the year (Lin, 2005), severely hindering the country's economic development. The growth rate of installed generation capacity was slow due to a lack of capital investment. Policies issued during the early period (1978-2003) were mainly focused on the reform of the investment system to raise money to build power plants (Wang, 2008). The construction of new power plants started to accelerate and during the 1990s, the average annual addition of generation capacity was over 17 GWe. By 1998, China's total installed generation capacity reached 227 GWe, the world's second largest next to the USA (Zhou, 1999). After 1994, the emphasis on energy production started to shift from quantity to quality while China began a step-by-step restructuring of its power and industrial sectors and improving efficiency across industry. In February 2002, the State Council issued a 'Program for Structural Reform of Power Sector' (国发(2002)5 号) to deepen the reform of the power sector. The main goals were to '*break the monopoly and introduce competition, improve efficiency, reduce costs, improve the price mechanism, optimise resource allocation, promote the development of power sector and national networking (grid), establish under the government supervision separate administration and enterprise, fair competition, as well as an open, orderly and healthy electricity market system*'. In December 2002, the Chinese government reorganised the state-owned power companies into eleven new power enterprise groups including two grid corporations and five power generation corporations. The Chinese government published policies and regulations for the electricity pricing system, and transmission and distribution management. The reform transformed the business model of the power sector from central planning to market-oriented and hence attracted diverse private and foreign investors, which led to profound changes in China's electric power industry.

The vast majority of the power plants built during the 1980s and 1990s are relatively small coal-fired generating units using a subcritical steam cycle. As a result of the rapid expansion of coal-fired power plants, the share of coal used for electricity generation in the total annual coal consumption increased from 20.7% in 1980 to 48% in 2002 (calculation based on data published in China Statistical Yearbook 1996-2005) as shown in Figure 3. The total coal consumption increased from 610 Mt (million tonnes) in 1980 to 1366 Mt in 2002 (NBSC, 2015a).

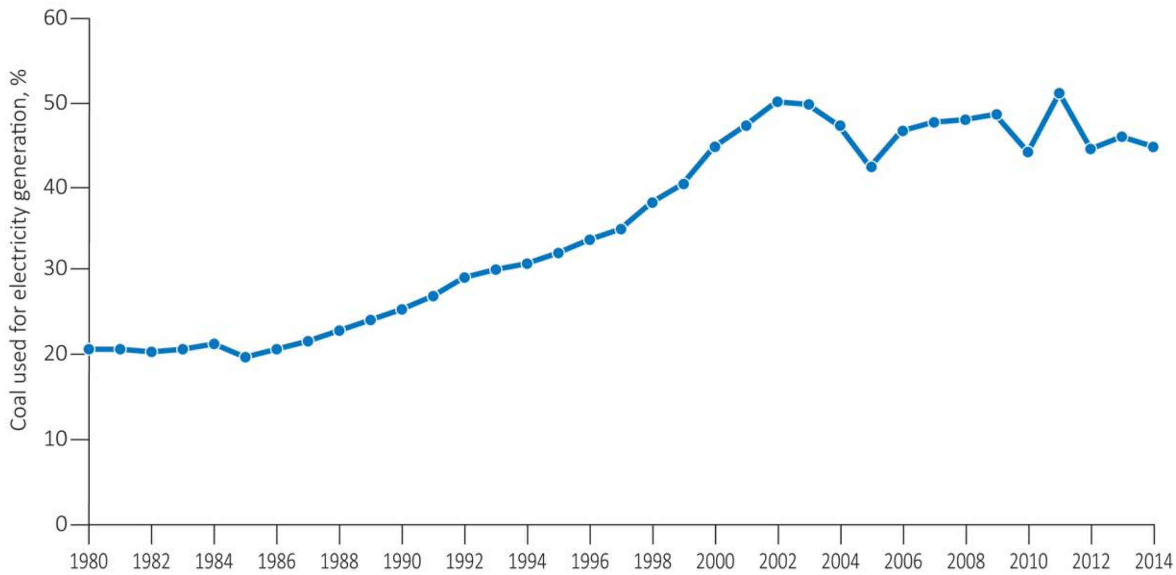

Figure 3 Share of coal used for electricity generation in total coal consumption in China from 1980 to 2014 (Li and Wang, 2015)

Coal-fired power plants are the major source of emissions of CO_2 and air pollutants such as particulate matter (PM), SO_2 and NOx. The emissions of air pollutants intensified as a result of the substantial increase in coal use for power generation since the 1980s and had a huge negative impact on environment. In 1999, SO_2 emissions from thermal power plants accounted for 43% of total SO_2 emissions in China (Wang, 2001) and acid rain problems were experienced across large regions of Southern China. Air pollution is also attributed to the higher incidences of lung diseases, cancer and respiratory system problems, poor visibility in some cities caused by smog and haze and many other environmental problems.

China has taken a number of measures to curb emissions of air pollutants from coal-fired power plants and the actions have been strengthened over the years. The 'Law on the Prevention and Control of Atmospheric Pollutants' was enacted in 1987 (revised in 1995 and 2000). The 'Environmental Protection Law' was issued in 1989 (amended in 2014). China's first emission standards 'Emission standards (trial) of three industrial wastes (GBJ 4-73)' was issued in 1973 in which emission limit values (ELV) were set (for each stack in relation to its height) for PM and SO_2 emissions from boilers and industrial processes. In 1991, China replaced GBJ 4-73 with 'Emission standard of air pollutants for coal-fired power plants (GB 13223 1991)', which was revised in 1996 and changed its name to 'Emission standard of air pollutants for thermal power plants (GB 13223-1996)'. The GB 13223-1996 set lower ELVs for SO_2 and PM, and for the first time set ELV for NOx. As illustrated in Figure 4, China's efforts to control air pollution are reflected in its increasingly tough emission standards which were amended in 2003 and again in 2011, and have now become one of most stringent emission standards in the world. The new standards are more stringent for plants in regions where the air pollution problems are most serious. Limiting values for mercury emissions from coal-fired power plants have also been added to the latest Emission Standard (GB 13223-2011).

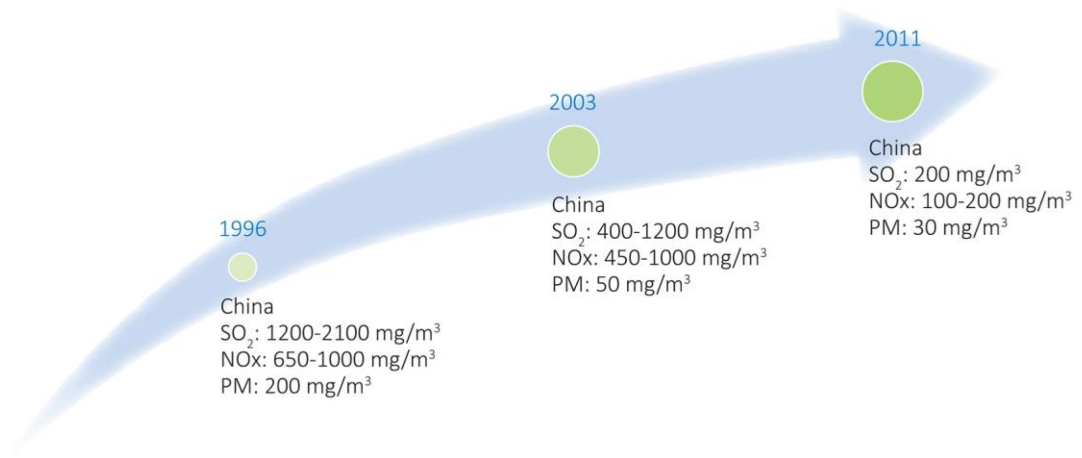

Figure 4 Changes in ELVs set in the emission standard GB 13223 over the years (modified from Hao, 2013)

In 1995, the amended 'Air Pollution Prevention Act' set up two acid rain and SO_2 pollution control zones for targeted actions for SO_2 emissions control. Specific targets and legal requirements were set in the 10th, 11th and 12th FYP for air pollution prevention and control. Most experts agree that the policy measures have paid off to a certain extent (*see* Figure 5). By the end of 2014, almost all coal-fired generating units had been equipped with flue gas desulphurisation (FGD) systems. PM collection devices had been upgraded to high-efficiency systems with an average efficiency of 99.75%. SCR (selective catalytic reduction of NOx) systems had been installed on 82.5% of coal power units. As a result, the SO_2 emissions reduced from the peak value of 13.5 Mt in 2006 to 6.2 Mt in 2014, a reduction of 54.1%. Total NOx emissions in 2014 were reduced by 38.2% compared to the peak value in 2011. Total PM emissions from thermal power plants were reduced from 4 Mt in 1980 to 0.98 Mt in 2014, a reduction of 75.4% although the thermal electric power generated in 2014 was sixteen times that of 1980. Furthermore, in 2013 the utilisation of coal ash and desulphurisation by-product gypsum reached 69% and 72%, respectively, water consumption and waste water discharge decreased from 3.9 and 1.31 kg/kWh in 2001 to 2 and 0.1 kg/kWh in 2013, respectively (Wang, 2015). Figure 5 shows total emissions of three major air pollutants from coal-fired power plants and their percentages in the national total emissions between 2000 and 2012. It can be seen from Figure 5 that the total emissions of SO_2 showed marked decreases since 2006 (which is attributed to the large-scale of deployment of FGD).

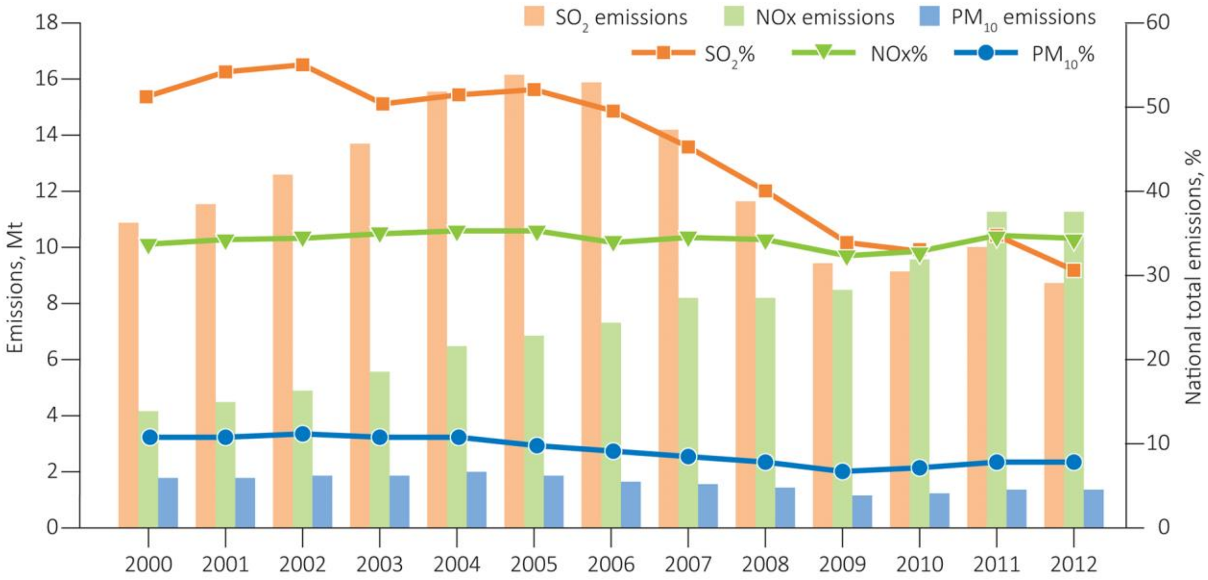

Figure 5 Changes in total emissions of air pollutants from coal-fired power plants between 2000 and 2012 (modified from Patel, 2014)

Despite the increasingly stringent emission standards, strong policies and legislation in place and significant reductions in emissions of air pollutants from coal-fired power plants that have been achieved so far, China is still having serious air pollution problems. In 2014, in the 161 cities where air quality was monitored, only 16 cities met China's new Ambient Air Quality Standards (AAQS GB 3095-2012). The percentage of cities that have annual average concentrations of SO_2, NO_2, PM_{10} and $PM_{2.5}$ meeting those set in the AAQS were 88.2%, 62.7%, 21.7% and 11.2%, respectively (Chen, 2015). Much of the problem is caused by coal use in non-power sectors such as coking, steel and cement production, coal to chemicals and industrial boilers for the production of process steam and heat that have poor energy and environmental performance. In recognition that China's economic growth model is unbalanced, uncoordinated and environmentally unsustainable, a growth model called 'new normal' has been articulated with increasing force and clarity at the highest levels of China's government recently. It focuses on achieving better quality growth that is more economically and environmentally sustainable. Over the past years, China's energy policies and development strategies have been increasingly focused on energy conservation, efficiency improvement, the use of renewable energy and reduced reliance on coal. Moreover, climate change has been ever more highlighted in China's energy and environmental policies. The following sections review the major development of China's policy and regulatory initiatives aimed at efficiency improvement and reductions of air pollutants and CO_2 emission from coal power generation, and the progress to date in achieving these goals. The key policy elements include 'Large substituting small' (LSS), 'Energy conservation and emissions reduction', and reducing carbon intensity. The former two measures, in effect, have been driving R&D (research and development) and the deployment of HELE technologies for power generation from coal in China.

3.2 Large substituting small

3.2.1 Closing small, inefficient units

The earlier reform and opening up of the power sector to various investors resulted in the construction of many small conventional thermal power plants during the 1980s and 1990s. Many of these power generating units are condensing steam turbine generators and are energy inefficient with few or no air pollutant emission control devices installed. These small units consume much more fuel and emit more CO_2 and other pollutants to generate the same amount of electricity than large, modern generating units. Table 2 compares the energy efficiencies of the different power generation technologies used in China in 2006. It can be seen from Table 2 that a 100 MWe class subcritical unit consumes about 30% more coal than a 600 MWe class SC unit, on a g/kWh basis.

Table 2 Energy efficiency of different power generation technologies in China in 2006 (Tian, 2008)

Technology	Size (MWe)	Coal consumption rate (g/kWh)	Net efficiency (%)
Ultra-supercritical	1000	285.6	43.03
	600	292.0	42.09
Supercritical	600	299.0	41.10
Subcritical	300	340.0	36.15
	100	410.0	29.98
	50	440.0	27.93
	25	500.0	24.58
	12	550.0	22.35
	6	>600	20.48
2006 average		367.0	33.49

In identifying small, conventional thermal power generating units as the most inefficient and polluting element in the power sector, China started to take steps to close small, inefficient generating units in the late 1990s. In 1995, the former State Planning Commission together with several other state ministries, jointly issued the 'Notice on strict control of small thermal power equipment manufacturing, construction' which banned the production and building of condensing turbine generators smaller than 3 MWe and restricted the construction of thermal power generating units smaller than 25 MWe. In 1999, the then State Economic and Trade Commission published 'On issuance of the notice on shutting down small thermal power units' (国经贸电力[1999]833 号) requiring condensing steam turbine generators with a capacity of 25 MWe or smaller to close by the end of 1999, conventional thermal power generators of 50 MWe or smaller using low or medium steam pressure to close by the end of 2000, and the conventional generators of 50 MWe or smaller using high steam pressure to close by 2003. However, from 2002, China started to experience an unexpected reoccurrence of severe power shortages due to a fast increase in energy demand driven by accelerated economic growth. In response, power generation capacity increased sharply in the following years (*see* Figure 6). Also, the systematic closure of small units that had been carried out for five years came to a halt. By the end of 2004, there were 3796 thermal power generating units of 6 to 50 MWe with a total capacity of 46.7 GWe, accounting for over 10% of China's total power generation capacity. In addition, there were a number of distributed power generators of 6 MWe or smaller with a total capacity of 15 GWe (China Huadian, nd).

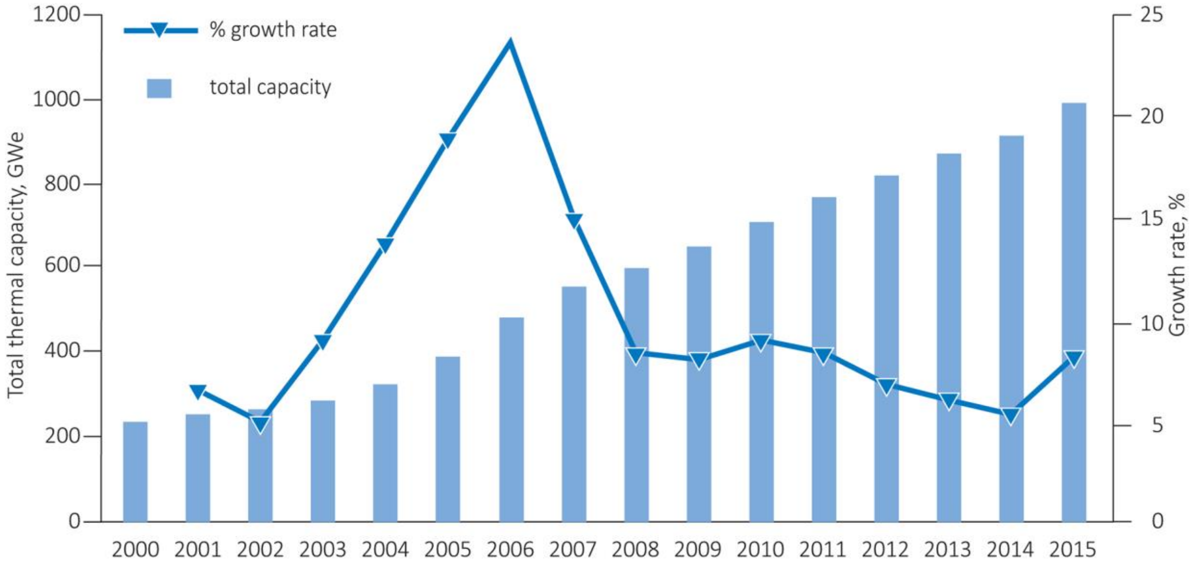

Figure 6 Total installed thermal power generating capacity and the thermal capacity growth rate in China between 2000 and 2015

3.2.2 Programme of large substituting small

In 2002, the State Council approved the '10th FYP (2001-2005) for acid rain and SO_2 pollution control within the two control zones' which set the targets to reduce total SO_2 emissions within the two zones by 2005. The main aims were: to promote the use of washed coals within the two control zones; to ban the production of high sulphur coal (S >3%); to close small thermal power generating units with capacity of ≤50 MW and to reduce the power supply coal consumption rate by 15–20 g/kWh; and to make compulsory the installation of desulphurisation and low NOx combustion systems on new coal-fired power plants as well as to existing plants around cities or those burning medium and high sulphur coal in order to comply with the emission standard. In 2006, China failed to meet the energy conservation and emission control targets set in the 10th FYP. The high fraction of small, inefficient and polluting units in the power generating fleet were largely blamed for China's failure to meet these targets and for the worsening acid rain and air pollution problems.

Recognising resources and the environment as major constraints to further development, China shifted its development pattern from being resource intensive to one with an emphasis on efficiency, resource conservation, and environmental sustainability. National targets to reduce energy intensity by 20% from 1.22 tonnes standard coal equivalent (SCE) per unit of GDP (2005 value) to around 0.98 t SEC/GDP, and to reduce the total emissions of major pollutants by 10% by 2010 were set in the Master Plan of 11th FYP (2006-2010). China also strengthened its actions to push forward the LSS Program. In 2004, the NDRC issued the 'Notice on requirements for coal-fired power plant project planning and construction' (发改能源[2004]864 号) which set technical standards for new coal-fired power plants:

- all new coal-fired power plants should, in principle, have unit generating capacities of 600 MWe or larger and power supply coal consumption rates of 286 g/kWh or lower;
- all new coal-fired power plants should have particulate removal and desulphurisation systems installed;
- in urban areas where there are potential markets for heat, combined heat and power (CHP) plants with unit capacity of 300 MW should be built whenever it is possible;
- for planned power plants where coal needs to be transported over long distance, supercritical (SC) or ultra-supercritical (USC) generation technology should, in principle, be employed.

It also set requirements for water and land conservation, and encouraged the use of gangue (a waste coal) as fuel for power generation.

The '11th FYP for Pollution Prevention and Control within Acid Rain and SO_2 Control Zones' (2006-2010) set national and regional targets for SO_2 emission reduction and aimed to close small thermal power generating units with a total capacity of 51.48 GWe by the end of 2010. It also contained a list of units to be closed which involved 679 plants with 2196 units. The '11th FYP for Energy Development' set the targets to achieve an energy conservation rate of 4.4%/y which was equivalent to reducing CO_2 emissions by 360Mt (carbon); to reduce the coal consumption rate of coal power generating units from 370 g/kWh in 2006 to 355 g/kWh by 2010; and to reduce in-plant energy consumption from 5.9% to 4.5% for the same period. It also set a priority to develop HELE technologies including 600 MWe or larger SC and USC generation technologies.

In January 2007, the State Council approved and issued 'Views on accelerating the shutting down of small thermal power units' (国发[2007]2 号) by NDRC and NEA, signalling the start of the LSS programme. 国发[2007]2 号 laid down requirements within the 11th FYP period of closing:

1) all conventional thermal generating units of 50 MWe or smaller;
2) all conventional thermal generating units of 100 MWe or smaller with 20 plus years of service;
3) all kinds of generating units of 200 MWe or smaller with designed service life shorter than their actual years in service;
4) generating units of all kinds with a power generation coal consumption rate 10% higher than 2005 local (provincial, county, city) average or 15% higher than 2005 national average;
5) generating units of all kinds not meeting environmental standards.

The Programme further established the 'Build after decommission' principle making a link between decommissioning inefficient small units and eligibility for a new power project as shown in Table 3.

Table 3 The principle of 'Large substituting small'

Unit capacity of new power project (MWe)	Required decommission (% new project capacity)
300	80
600	70
1000	60
200 (CHP)	50

The Programme also required parallel installation of FGD to all new coal power projects and accelerated retrofitting of desulphurisation units to all coal-fired generating units larger than 135 MWe that were not included in the LSS programme.

3.2.3 Implementation measures

The implementation of a programme as massive and sophisticated as this one needs to be well-designed, organised, coordinated and executed. China has taken a number of measures including economic incentives, command and control methods and support for R&D to ensure the effective implementation of the programme.

Organisational structure and accountability system

The programme implementation is led at the national level by NDRC and supported by other government agencies including NEA (the State Electricity Regulatory Commission until 2013), the State-owned Assets Supervision and Administration Commission of the State Council (SASAC), MEP, Ministry of Land and Resources, Ministry of Water Resources, Ministry of Finance, as well as major grids. Leading groups for implementation are set up at provincial and local levels, consisting of local development and reform commissions and other government agencies as well as local utility companies. The NDRC, acting on behalf of the central government, signed the binding memorandum of understanding with governors of provinces/municipalities and heads of major energy corporations to ensure the integrity and accountability of programme implementation. In turn, the provincial governors held chiefs of lower-level governments in their constituencies accountable. The national targets of energy conservation and emissions reduction were broken-down and then assigned to each city, county, and major local enterprise for compulsory implementation. At each level, the governments and companies are accountable to higher-level governments/companies if they fail to accomplish the task assigned. As for the LSS programme, provincial governments and major electricity companies were required to submit detailed implementation plans to NDRC before the end of March 2007. The plans included enforcing execution and addressing post-decommissioning issues such as re-employment and financial settlements (Tian, 2008). The local governments were also required to regularly report their implementation progress to NDRC. On the other hand, provincial governments and major power producers have the flexibility to take different approaches to reach their committed targets.

Policy measures

The rapid increase in energy demand driven by the country's economic growth resulted in a fast pace of capacity addition (two-digit annual increase rate between 2005 and 2011 as shown in Figure 6). The 'Notice on requirements for coal-fired power plant project planning and construction' (发改能源[2004]864号) set technical standards for new coal-fired power plants and a priority for large units with efficient and clean technologies (600 MW and 1000 MWe SC and USC units). As discussed in Section 3.2.2, the decommissioned capacity of inefficient small units was the key criteria of eligibility for a new power project to be included in the national power development plan, which was the basis for the government's approval of projects. For provinces and municipalities that substituted more decommissioned capacity and resettled employees of the decommissioned plants satisfactorily, their new power projects could be prioritised in the national power development plan. The government would increase capacity in the plan for each province and municipality according to its total decommissioned capacity. In the case of interprovincial projects, capacity addition would be retained by the province where the decommissioned units located, and the corresponding deduction in capacity would be made to the neighbouring province(s) where the corresponding new project was built. In addition, grid companies are banned from purchasing electricity generated by the small units that reached the scheduled decommissioning time.

Relatively new (<15 years in service) power generating units were encouraged to convert to biomass-fired power plants or CHP subject to the government's approval with close supervision by provincial authorities. Priority would be granted to large and medium CHP units in metropolitan areas, and CHP units with back-pressure steam turbines and biomass-fired plants in medium and small cities and towns. To prevent power companies from using CHP as an excuse to avoid shutting down small units, CHPs and units with high fuel consumption were subject to online monitoring and periodic verification by provincial governments. Those failing to meet regulations would be ordered to conduct efficiency retrofits within a designated period. Failure to meet the retrofitting deadline or failure to meet regulations after retrofitting would lead to enforced decommissioning. These measures were designed to prevent policy evasions, for example power generation projects of inefficient small units disguised as cogeneration or gangue and other waste fuel-based power plants. Power generation of CHP units was strictly subject to heat demand and was monitored closely. Excessive supply of power in heating seasons and power generation in non-heating seasons were treated as ordinary small units. Small units in public utility are also strictly forbidden to be transferred to captive power plants.

Supervisory teams were sent by the government to conduct on-the-spot verification and registration for each inefficient small unit decommissioned. A list of decommissioned units has been published online for public monitoring to ensure that these units are truly and permanently decommissioned (Tian, 2008; ChangCe Thinktank, 2009).

Economic instruments

In order to promote the decommissioning of small and inefficient power units, several measures have been taken to increase their operation costs. Many of the small units were invested in by local governments or local state-owned enterprises. They were important sources of local fiscal revenue and were job providers. These plants, especially the captive power plants of industrial enterprises, received local subsidies such as higher prices on their power sales and/or exemption of taxes and surcharges to which ordinary power plants were subjected. To remove this market distortion, the LSS programme has taken measures to level the playing field, including:

- capping the power prices of captive power plants at the regional average;
- forbidding local subsidies to purchase power generated from small units;
- removing regulated funds and surcharge exemption from captive power plants;
- banning the transfer of power plants from public utility to captive use;
- enhancing supervision of environmental standards, and
- enforcing pollution fines to increase the cost of violating environmental standards.

In August 2007, the State Council issued the ‘Energy Conservation Electricity Dispatch Scheduling Rule (trial)’ (国办发〔2007〕53 号) setting the following priority in electricity dispatch sequence:

- non-adjustable units of renewable energy, such as wind power, solar energy, ocean energy, hydro power;
- adjustable hydro, biomass, geothermal renewable energy units and waste incineration units that meet the environmental protection regulations;
- nuclear power units;
- coal-fired CHP units which generate electricity according to the heat requirements, units which utilise residual heat, steam, pressure, coal refuse, coal bed gas;
- natural gas, coal gasification units;
- other coal-fired units, including CHP without heat load;
- oil-fired units.

The priority in dispatch of electricity from the same type of thermal power units is to be decided firstly by the energy efficiency and then by the waste discharge amount of the units. The most energy efficient units with least waste discharge are prioritised.

In April 2007, NRDC issued the 'Notice on Reducing Tariff of Small Thermal Power Units to Promote Their Shut Down' (特急 发改价格〔2007〕703 号) requiring a reduced tariff for small thermal power units according to the following:

- for all small thermal power units described by 1) to 3) in 国发[2007]2 号 (*see* Section 3.2.2) that have a tariff higher than the local benchmark tariff for coal-fired generating units, depending on if they are equipped with an FGD system, the tariff should be reduced to the same level as the local benchmark tariff for coal-fired generating units with or without an FGD system, respectively, and shall not receive any subsidies after tariff reduction;
- for small thermal units that came into service after 2004 and have a tariff higher than the benchmark tariff, the tariff should be reduced to the benchmark level;
- for small thermal units commissioned before 2004 that have a tariff lower than the benchmark tariff, their tariff should remain at the same level; for small thermal units commissioned before 2004 that have a tariff higher than the benchmark tariff, their tariff should be reduced from 2007 in two years to the benchmark level if the current tariff is 0.05 ¥/kWh higher than the benchmark tariff, or in three years from 2007 if the current tariff is 0.05–0.10 ¥/kWh higher than the benchmark tariff;
- for CHP units, based on a reasonable share of electricity and heat costs, the heat price should be gradually increased while the tariffs reduced accordingly, in order to compensate for the heating costs.

To encourage and compensate for the early shut down of small units, owners of the decommissioned units would continue to be allocated quotas of scheduled generation hours, emissions, and water use for a certain period (typically 2 years with a 3-year maximum). They were allowed to trade these quotas with power producers of large units at a price not higher than that before the tariff reduction. For the quotas allocated to the already decommissioned small thermal units that had been sold to power producers of large units, the prices were exempt from tariff reduction. Therefore, the earlier the units are decommissioned, the longer they enjoy a large income from trading these quotas. The government also allows grids and efficient power producers to offer discounted prices on electricity sold to enterprises with captive power plants that are decommissioned. The grids and efficient power producers, in general, would like to offer price discounts from their increased revenue resulting from the decommissioning of captive power plants to encourage more decommissioning. Twenty decommissioned power producers in Henan Province traded 1.36 billion kWh of scheduled generation quota for ¥80 million in 2006. Twenty-three decommissioned power producers in the same province traded 1.42 billion kWh for ¥90 million in the first half of 2007 (Tian, 2008).

Measures have also been taken to safeguard against supply interruption and to address post-decommissioning issues such as treatment of the assets and debts of the decommissioned units and arrangements for the staff made redundant by the decommissioning but are not discussed here.

3.2.4 Continuing with the LSS programme

The programme's first year of implementation reflected different levels of progress, and revealed different abilities in various areas, companies, and ownerships to absorb the impacts of financial losses and employment. The five largest power producers in China (Datang, Huaneng, SPIC, Huadian and Guodian) demonstrated a better ability to balance the financial losses incurred from decommissioning and to re-employ the redundant workers. In 2007, these five companies decommissioned small units with a combined total capacity of 8.78 GWe, accounting for over 61% of China's total decommissioned capacity. The intensified competition for the market share as introduced by major sector reform since 2002 also provided strong incentives to these companies to expand their capacities of efficient plant. This could be done only by decommissioning more inefficient small units and at a faster pace than that designed in the programme. However, decommissioning proved to be a much tougher challenge for smaller and single business power producers. These companies usually have less financial resources to cross-subsidise the financial losses incurred and fewer in-house job opportunities for re-employment.

The first year of implementation also showed regional differences. Developed areas and areas with greater potential for further expansion of power capacity demonstrated a stronger ability to absorb the impact while poorer areas with weaker public finances and less dynamic local economies found that the implementation was harder to carry out. These challenges would be expected to become tougher in the following years after the comparatively easy jobs had been completed first. Also, slow progress was found in some areas as a result of a weak commitment and poor coordination of relevant local authorities and lax enforcement of implementation measures. These findings helped the government fine-tune implementation measures, which emphasised the worsening business environment of the inefficient small units. The government used taxes, surcharges, funds, subsidies, and transfers of payment to form an exit mechanism for inefficient small units, as well as detailed and concrete arrangements for the employees involved (Tian, 2008).

The LSS programme continued into the 12th FYP period (2011-2015). The '12th FYP for Energy Conservation and Emission Reduction' set the target to close 20 GWe of small thermal power units. The small units to be closed were identified in the 12th FYP as:

- conventional coal-fired generating units of ≤100 MWe;
- conventional thermal generating units of ≤50 MWe, and oil-fired boilers and units with a capacity of ≤50 MWe that are mainly used for power generation;
- coal-fired generating units of ≤200 MWe with designed service life shorter than their actual years in service.

The 'Action Plan on Upgrade and Reconstruction of Coal-Fired Power Plants for Energy Conservation and Emission Reduction (2014-2020)' of 2014 further required the accelerated closure of:

- conventional thermal generating units of ≤50 and ≤100 MWe (grid connected);

- coal-fired generating units of ≤200 MWe that reached their designed service life and were not to be converted to CHP and;
- units that failed to meet the new emission standards and were not to be upgraded. The total capacity to be closed by 2020 is set to be 10 GWe.

3.3 Energy conservation and emissions reduction

'Energy conservation and emissions reduction' has been one of the key elements in China's energy and environmental policies. Thus China has introduced a wide range of policy initiatives using various approaches such as the LSS programme, energy efficiency improvements and investment in renewables and clean technologies.

3.3.1 Efficiency improvement

One of the root causes of China's environmental problems is the country's heavy reliance over the last 30 years on coal. Not only has coal been extensively employed in the power sector but also it has traditionally been used in lower standard plants across industry. Realising that resources and the environment are the major constraints to its economic development, China began a step-by-step restructuring of its power and industrial sectors. The '10th FYP for Energy Development' set a target of achieving an overall energy efficiency of 36% by 2005, an increase by 4% points compared with that of 1997. The '10th FYP (2001-2005) for acid rain and SO_2 pollution control within the two control zones' set a target of reducing the coal consumption rate for power supply by 15–20 g/kWh by 2010. As described in Section 3.2.2 in 2004, China set technical standards for new coal-fired power plants to have a maximum coal consumption rate of 286 g/kWh. China further strengthened its efforts to improve energy efficiency across industry by laying down a national target for annual energy saving of 4.4% in the '11th FYP for energy development' (2006-2010).

In August 2012, the State Council approved the '12th FYP (2011-2015) for Energy Conservation and Emission Reduction' which set out the requirement to reduce the coal consumption rate of thermal power plants by 8%, from 333 gSEC/kWh in 2010 to 325 in 2015, and to reduce in-plant energy consumption by 0.13% points, from 6.33% in 2010 to 6.2% in 2015. It further required upgrading of heating boilers to improve efficiency and increased the share of CHP in areas where heating is centrally supplied. The '12th FYP for Energy Development' issued in January 2013 again requires that the coal consumption rate of thermal power plants be reduced by 0.6%/year to 323 gSEC/kWh and the overall energy efficiency to be increased to 38% by 2015. The binding targets set in the FYPs are shown in Table 4.

Table 4 Various targets set in the FYPs and Action Plans

11th FYP for Energy Development			
Energy intensity reduction	20%		
12th FYP for Energy Development			
Energy intensity reduction	16%		
Non-fossil fuel in energy mix	11.4%		
12th FYP for Energy Conservation and Emission Reduction			
	2010	**2015**	**Change %**
Power supply coal consumption rate, g/kWh	333	325	-2.4
In-plant power consumption rate, %	6.33	6.2	-0.13
Grid line loss rate, %	6.53	6.3	-0.23
Air pollutants emission reduction			
Industrial SO_2	2073	1866	-10
Industrial NOx	1637	1391	-15
Thermal power plants SO_2	956	800	-16
Thermal power plants NOx	1055	750	-29
Action Plan on Prevention and Control of Air Pollution			
Coal consumption cap	≤65% in primary energy mix by 2017		
Energy Development Strategy Action Plan (2014-2020)			
Primary energy consumption by 2020	coal	natural gas	non-fossil fuel
	≤62%	≥10%	15%
Coal consumption by 2020	Total coal consumption ~4.2 Bt, reduction by 100 Mt from 2012 level in Beijing, Tianjin City and Hebei Province, negative growth in Yangzi River and Pearl River Delta		
installed renewable and cleaner energy generation capacity by 2020, GWe	hydro: 350 wind: 200 solar: ~100 nuclear: 58 (with 30 GWe under construction)		

In 2014, the State Council General Office issued the 'Action Plan on Energy Development Strategy (2014-2020)' (国办发(2014)31号), requiring the implementation of coal power plant upgrading programmes and for existing power generating units of ≥600 MWe (except for air-cooling units) to reduce their coal consumption rate to 300 g/kWh within 5 years. In response, NRDC issued the 'Action Plan on Upgrade and Reconstruction of Coal-Fired Power Plants for Energy Conservation and Emission Reduction (2014-2020)' (发改能源[2014]2093号). It sets new technical standards for coal-fired power plants:

- all new coal-fired power plants nationwide should have an average power supply coal consumption rate lower than 300 g/kWh;

- by 2020, existing coal-fired power generating units, after upgrading, should have an average power supply coal consumption rate of ≤310 g/kWh. Among these the units with a capacity of ≥600 MWe should have an average power supply coal consumption rate of ≤300 g/kWh;
- new coal-fired power projects should, in principle, adopt ≥600 MWe USC generating units and 1000 MWe class units should have a designed power supply coal consumption rate of ≤282 and ≤299 g/kWh while the 600 MWe class units have a designed power supply coal consumption of ≤285 and ≤302 g/kWh for wet-cooling and air-cooling, respectively;
- new coal power projects of ≥300 MWe heating units or CFB (circulating fluidised bed) units burning low grade coal should, in principle, adopt SC steam conditions; for CFB generating units burning low grade coal, the 300 MWe class units should have a designed power supply coal consumption rate of ≤310 and 327 g/kWh while the 600 MWe class units should have a designed power supply coal consumption rate of ≤303 and 320 g/kWh for wet-cooling and air-cooling, respectively.

The Action Plan outlines measures for the comprehensive and systematic upgrade of the 300 and 600 MWe class subcritical and SC units in order for them to achieve the best energy efficiency achievable by the comparable power generation technology, and for the conversion of ≤200 MWe units to CHP. By 2020, existing utility units of ≥300 MWe and captive power generating units of ≥100 MWe located in Eastern China should, after upgrade, meet the ELVs set for gas-fired power plants (PM 5, SO_2 30 and NOx 50 mg/m^3, respectively).

The Action Plan also encourages the development of CHP plants to replace or eliminate the disbursed small coal-fired heating boilers and sets a target for the share of coal based CHP generation capacity in the total installed coal-fired power generation capacity to reach 28% by 2020. Where the fuel supply can be ensured, captive coal power plants located in key regions (Beijing, Tianjin City and Hebei Province, and Yangzi River and Pearl River Delta) should be converted to natural gas-firing by 2017.

However, on 15 December 2015, the MEP, NRDC and NEA jointly issued the 'Work Programme of Full Implementation of Upgrade and Reconstruction of Coal-Fired Power Plants for Ultra-low Emissions and Energy Conservation (环发[2015]164号)'. The Work Program rescheduled the Upgrading Programmes so that, provided the power supply is secured, the upgrading and reconstruction of coal-fired power plants in Eastern China that were planned to be completed in 2020 should now be completed by 2017. Also, all coal-fired utility units of ≥300 MWe and captive power generating units of ≥100 MWe (excluding W-flame down-fired and CFB boilers) should be upgraded or reconstructed to ultra-low emission units (emissions of PM SO_2 and NOx ≤10 mg/m^3, 35 mg/m^3, 50 mg/m^3, respectively). The upgrade or reconstruction of coal power generating units of ≥300 MWe (excluding W-flame down-fired and CFB boilers) located in Central China should aim for a completion date before 2018 and those in Western China should aim to be completed before 2020. The target for 2020 is 580 GWe of upgraded or reconstructed coal power plants. Coal power generating units which cannot be upgraded or reconstructed must be retrofitted with high efficiency SO_2, NOx and PM emission control systems and must meet environmental standards. The total capacity of retrofitted plants should be around 110 GWe. Power units of ≤300 MWe, in particular those power generating units operated for ≥20 year and CHP units operated for ≥25 years, which fail to meet the energy and environmental performance standards after upgrade should be shut down. The Work Programme sets a goal to shut down obsolete units with a total capacity of ≥20 GWe during the 13th FYP period (2016-2020). The Work Programme also outlines measures to provide financial support, electricity price subsidies and allocation of more utilisation hours (in general, 200 hours more) to generators with high efficiency and ultra-low emission power plants.

The NDRC, MEP and NEA will guide, coordinate and monitor the implementation of the Upgrading programme. Provincial and local governments as well as heads of major electricity companies are required to make detailed implementation plans. The NEA will send teams to work with local competent authorities and heads of power generators to ensure the implementation. After construction of a new power plant or upgrade of an existing plant is complete, the energy and environmental performance of the plant will be independently tested and assessed, and an evaluation report will be sent to the NEA and local government.

In May 2015, the NDRC issued the 'Action Plan for Clean and Efficient Utilisation of Coal (2015-2020)' (国能煤炭[2015]141号) which set the priority to develop and deploy high efficiency and ultra-low emission coal power generation technologies and to accelerate the upgrading and reconstruction of existing coal-fired power plants. It also sets a timetable to close down the obsolete, inefficient small coal-fired boilers, to upgrade existing coal-fired boilers and establishes a target for over 50% of boilers to be high efficiency models by 2020.

3.3.2 Emissions reduction

As discussed in Sections 2.1.3 and 3.1, China has steadily strengthened its policies on air pollution prevention and control over the past two decades in a variety of ways such as increasingly stringent emission standards, AAQS, TEC and FYPs. The 10th and 11th 'FYP for Acid Rain and SO_2 Pollution Control within the Two Control Zones' and the '12th FYP for Air Pollution Prevention and Control in the Key Regions' set national and regional targets for the reduction of major air pollutants emissions and outlined measures for emissions prevention and control. These measures include a ban on producing and burning high sulphur coal, encouraging the use of washed coal and enforced installation/retrofitting emission control systems. Despite all these actions, air pollution is a long-standing problem in China. Following major air pollution episodes in late 2012 and early 2013 that received widespread global media attention and caused a public outcry in China, the State Council issued 'Action Plan on Prevention and Control of Air Pollution (国发(2013)37号)' on 12 December 2013. This Action Plan contains a mixture of general aspirations, concrete measures and targets. Ten measures are outlined as follows:

1) enhance overall treatment and reduce discharges of multiple pollutants (including efforts to rectify small coal-fired boilers and accelerate construction of FGD, de-NOx and PM control projects in key sectors);

2) adjust and optimise industrial structure and promote economic transition;

3) speed up technological reform of enterprises and improve the capability of scientific innovation;

4) quicken the steps to adjust the energy structure and increase the supply of clean energy;

5) strengthen environmental thresholds, optimise industrial pattern and set strict limits to high energy consumption and high pollution projects in ecologically fragile or sensitive areas;

6) improve the role of market mechanisms and environmental economic policies;

7) improve the legal system and ensure strict supervision and management by law;

8) establish the regional coordination mechanism and integrated regional environmental management;

9) establish a monitoring, early warning and emergency response system to cope with heavy air pollution and;

10) clarify the responsibilities of all parties and encourage public participation to jointly improve air quality.

In particular, the Action Plan sets a coal consumption cap of ≤65% of total annual energy consumption by 2017 and aims to reduce coal consumption, ban construction of captive coal-fired power plants and prohibit the approval new coal-fired power generation projects except for CHP projects in three key regions (Beijing-Tianjin-Hebei, Yangzi River Delta and Pearl River Delta). It also bans the construction of coal-fired boilers of ≤20 t/h (steam) in urban areas.

The 'Action Plan on Upgrade and Reconstruction of Coal-Fired Power Plants for Energy Conservation and Emission Reduction (发改能源(2014)2093 号)' issued a year later further requires that all new coal-fired power plants in Eastern China (Liaoning, Hebei, Shandong, Jiangsu, Zhejiang, Fujian, Guangdong and Hainan Province, and Beijing, Shanghai and Tianjin City) meet the ELVs set for gas-fired plants; all new coal-fired power plants in Central China (Heilongjiang, Jilin, Shanxi, Anhui, Hubei, Hunan, Henan and Jiangxi Province) should have air pollutant emission values that meet, or are close to, the ELVs for gas-fired plants.

To incentivise the deployment of HELE technologies, the NRDC, MEP and NEA jointly issued the 'Notice on Issues Related to Support Policy on the Implementation of Ultra-Low Emission Coal Power Plant Electricity Price (发改价格[2015]2835号)' in December 2015. Subsidised feed-in tariffs for electricity generated from ultra-low emission (emission values of PM SO_2 and NOx ≤10 mg/m^3, 35 mg/m^3, 50 mg/m^3, respectively) coal-fired power plants were introduced from 1 January 2016. For ultra-low emission coal power plants commissioned before 1 January 2016, the feed-in tariff is subsidised by 0.01 ¥/kWh, while for those commissioned after 1 January 2016, the tariff is subsidised by 0.005 ¥/kWh.

3.4 Energy and carbon intensity reduction

In parallel with efforts to improve energy efficiency, policy measures such as promoting the use of renewables and new sources of energy and a cap on coal consumption, are also in place to reduce the country's energy and carbon intensity.

3.4.1 Energy and carbon intensity reduction

Climate change is taken seriously at the policy level, especially now that China has become the world's largest carbon emitter. At the Copenhagen climate talks in 2009, China pledged to reduce the carbon intensity (CO_2 emission per unit of GDP) by 40–45% in 2020, relative to 2005 levels, and to have at least 15% of primary energy produced from non-fossil energy sources by 2020. In December 2011, the State Council issued the 'Work Program of Control of Greenhouse Gas Emissions during 12th FYP period (国发(2011)41 号)' which set a national target of reducing CO_2 intensity, by 2015, to 17% lower than that of 2010. In one of the most serious demonstrations of China's commitment to address climate change, China and the USA jointly agreed to separate unilateral actions to curb greenhouse gas (GHG) emissions on the side-lines of the November 2014 summit of the APEC forum. China planned to peak its GHG emissions by 2030 and to increase the share of non-fossil fuels in primary energy consumption to around 20% by 2030.

In the past, China's energy policies emphasised energy saving and were focussed mainly on improving energy efficiency across industries and other sectors. The '10th FYP for Energy Development' aimed to reduce the nation's high energy consumption per unit GDP ratio by 15-17% (equivalent to a saving of 30-34 Mt SEC or a carbon emission reduction of approximately 150 Mt) during the 10th FYP period. The '11th FYP for Energy Development' laid down national targets of annual energy saving of 4.4% and reducing energy intensity from 1.22 tSCE/GDP in 2005 to 0.98 tSCE/GDP (2005 value) in 2010, which would result in a decrease in CO_2 emissions by 360 Mt (as carbon). The '12th FYP for Energy Conservation and Emission Reduction' set a new target of energy saving from 1.034 tSEC/GDP in 2010 to 0.896 tSEC/GDP (2005 value), a decrease of 16% (equivalent to a saving of 670 Mt SEC during 12th FYP period). The Action Plan on Prevention and Control of Air Pollution further set a cap on coal consumption in the primary energy mix to 65% by 2017. The targets for energy intensity reduction over the years are listed in Table 4. Measures have also been taken to curtail the scope and role of heavy industry via a similar administrative approach to that taken for the power sector. They too aim to forcibly close small and dirty plants and mandate industrial consolidation to create super-producers with scale and improved efficiency.

The economic reform plan unveiled at the Chinese Communist Party's Third Plenum in November 2013 incorporated a clear emphasis on sustainable development and better management of resource consumption. China's top leadership has embraced a strategy to diversify away from coal, improve industrial energy efficiency, and invest billions in clean energy and pollution mitigation. In November 2014, the State Council issued the 'Energy Development Strategy Action Plan (2014-2020)', which, some believe, sets the tone for the 13th FYP for energy development strategy. The Action Plan aims to reduce China's energy and carbon intensity through a set of measures and mandatory targets, promoting more efficient, self-sufficient, and innovative energy production and consumption. The main targets include a cap on annual primary energy consumption of 4.8 billion tonnes (Bt) SCE until 2020, and a maximum annual coal consumption of 4.2 Bt. The main reduction of coal consumption is to be achieved in regions of Beijing-Tianjin-Hebei, the Yangtze River Delta and the Pearl River Delta. The share of non-fossil fuels in the total primary energy mix is to rise from 9.8% in 2013 to 15% by 2020. The share of natural gas is to rise above 10%, while that of coal will be reduced to below 62%. In addition, installed nuclear power capacity is to reach 58 GWe by 2020, with an additional 30 GWe expected to be under construction in 2020. Installed capacity of hydro-, wind and solar power in 2020 is expected to reach 350, 200 and 100 GWe, respectively (*see* Table 4). Measures to reduce coal use include reducing coal-intensive activities (such as closing steel and cement factories), increasing efficiency, promoting fuel switching and investing in renewable and cleaner energy sources. Also, China is transitioning away from energy-intensive industry and exports toward a service-based economy and high-value-added exports. China's economy is currently undergoing a major structural transformation towards a new development model focused on achieving better quality growth that is more economically and environmentally sustainable emphasising reductions in air pollution and other forms of local environmental damage, as well as in GHG emissions.

3.4.2 Renewables and cleaner energy sources

During the 11th and 12th FYP periods, China published a wide range of polices to promote the deployment of renewables (hydro, biomass, wind and solar) and cleaner energy sources such as gas (including coal bed methane and shale gas) and nuclear. Targets have been set in the FYPs and Energy Development Strategy Action Plan (2014-2020) to increase the ratio of natural gas, wind, solar, hydro and nuclear power in the energy mix (*see* Table 4). Renewables are a significant part of China's initiative to reduce coal demand. However, hydropower opportunities are now limited and therefore solar and wind are the primary near-term sources of power generation and coal substitution that the government can boost. China has become one of the fastest growing wind and solar power markets in the world and a world leader in the development of non-fossil energy. The targets of a total installed capacity of 21 GWe for solar and 100 for wind power by 2015 set in the 12th FYP were already exceeded by the end of 2014 with around 24 and 115 GWe solar and wind installed, respectively.

An important policy change has been the central government's embrace of distributed power generation, which allows for an increasing use of rooftop solar installations and the growth of solar power in rural areas, where connecting to main power grids is difficult. In addition, China intends to create more utility-scale solar power, particularly in far-flung regions such as Xinjiang, that will eventually be connected by ultra-high voltage transmission lines to send power to dense population areas. The 'Energy Development Strategy Action Plan (2014-2020)' also sets a priority to develop nine large, modern wind power bases mainly in northern China, as well as to develop distributed wind power generators in southern and central China and off-shore wind power.

3.5 Technology proliferation support

In addition to the policy initiatives and actions discussed above, China has invested increasingly in clean-technology sectors, most notably clean coal technology (CCT). China has taken great steps to incentivise the development of CCT. The national goals, strategic objectives and priority areas of technology development are set in the FYPs. For instance, the 1000 MWe and 600 MWe USC, 250–400 MWe class integrated gasification combined cycle (IGCC), and 600 MWe class circulating fluidised bed (CFB) reactor were priorities for technological development, domestic manufacturing and deployment in the 11th FYP. In December 2011 the NEA issued 'The National Energy Science and Technology Development 12th FYP', which set the goals and targets for development of:

- advanced-USC power generation technology with steam conditions of >700°C/30 MPa and energy efficiency of up to 50% (2011-2017/18);
- 1000 MWe class USC electricity generation and double reheat technology with domestic intellectual property rights (2011-2017);
- CCS technologies, and reduction in energy consumption and capital costs of CCS (2011-2020);
- large-scale (400–500 MWe) IGCC processes including complete technologies for polygeneration systems, integrated designs and equipment manufacturing (2013-2017);
- high efficiency, high-temperature particulate removal and desulphurisation systems, pre-combustion CO_2 capture technologies and IGCC polygeneration process optimisation (2013-2017);
- building an IGCC demonstration plant (2014-2018);
- advanced-USC technologies (such as double reheat, optimised integrated design, and design with minimised high-temperature pipe) demonstration plants (2015-2018);
- HELE technologies and building a water conservation, HELE demonstration power plant (2011-2015).

In March 2012, the Ministry of Science and Technology (MOST) published the 'Special 12th FYP for Science and Technology Development for Clean Coal Technology' emphasising the goals and strategic objectives of R&D of the key technologies outlined in the 'The National Energy Science and Technology Development 12th FYP'. Furthermore, it set R&D priorities in:

- advanced-USC technologies with a unit capacity of 600 MWe and aims to build an Advanced-USC demonstration power plant during 13th FYP period;
- 600 MWe class CFB USC boiler with techno-economic performance comparable to those of pulverised coal-fired boiler of similar size, and 50–300 MW class energy efficient, ultra-low emission CFB boiler technology;

- towards zero emission IGCC process;
- 1200 MWe class USC (>600°C) power generation technology and equipment and demonstration plant;
- advanced technologies for control of air pollutant emissions from coal combustion.

The MOST is responsible for supporting the R&D of key technologies relating to CCT. Projects sponsored by MOST's State Centre for Evaluating Science and Technology (S&T) Projects include the 'Special Grand National S&T Project', '973 Plan', '863 Plan' and the 'National S&T Supporting Program' (http://www.most.gov.cn/). There are also many competitive research projects funded by different government bodies and utility companies. As a result of huge investment and intensive R&D activities, HELE technologies are being introduced into China's coal-fired power plants in a short period along with the development of technological capability and domestic manufacturing capacity. Today, the most efficient and lowest emission clean-coal plants in the world are not found in Europe or the USA but are instead found in China.

3.6 Accomplishments

Faced with a number of serious energy challenges such as energy supply security and environmental cost, China has launched several important policy initiatives that involve quite different sets of strategies to achieve their ultimate goals. These initiatives include efforts to reform the state-owned enterprises and the pricing systems for energy products, the radical reduction of air pollution, and the continued reduction of energy intensity and carbon emissions. They have had a major effect on the energy mix, particularly in the power generation sector, and yielded some impressive results.

3.6.1 LSS programme

China's effort to close small, inefficient and polluting power generating units dates back to the late 1990s. Targets were set and lists of the small units to be closed by 2004 were published. However, China experienced an unexpected power supply shortage from 2002 due to the much faster growth rate of energy demand driven by accelerated economic development since 2000. Consequently, the planned closure of the small units stopped and instead, more small power generating units were installed. The total coal-fired power capacity with unit size smaller than 100 MW increased from 69.1 GWe in 2000 to 108.1 GWe in 2005 and 140.1 GWe in 2010. It should be noted that although some of the new small thermal power units added to help release local electricity shortage used technology not necessarily different from the decommissioned ones, many were for the cogeneration of heat and power with much higher thermal efficiencies, or for the utilisation of non-coal fuels such as waste heat, biomass, and municipal solid waste (China Huadian, nd; Xu and others, 2013). When the power shortage eased in 2006, China consolidated its actions to close small inefficient power plants and introduced the LSS Programme. By the end of 2010, China had closed small power plants with a total capacity of 16.9 GWe. The share of generating units of ≥300 MWe in the coal-fired power generation capacity increased from 38.9% in 2000 to 45.5% in 2005 and to 67.1% in 2010. Table 5 compares China's thermal power generation mix at the end of 2006 with 2012. During the 11th FYP period, China further shut down small units with a total capacity of 76.83 GWe, exceeding the target of 50 GWe set. This was equivalent to 19% of the total thermal power capacity at the end of 2005. The available data showed that the 14.4 GWe small coal-fired units that retired in 2007 had an average age of 27 years and an average efficiency of 483 g/kWh in terms of coal consumption for power supply. The LSS Programme continued into the 12th FYP period. It is estimated that China decommissioned small thermal generating units with a total capacity of around 95 GWe between 2005 and 2014. The planned total capacity of small units to be closed in 2015 is 4.23 GWe and China aims to close over 20 GWe of inefficient thermal power units by 2020 (CEC and others, 2011; CEC, 2015a; Xu and others, 2013; Wang, 2015; Ma, 2015).

Table 5 China's thermal power generation mix in 2006 and 2012

As the end of 2006[a] (Tian, 2008)		
Unit size (MWe)	**Installed capacity (GWe)**	**% of total thermal capacity**
1000 class	Not available	Not available
600 class	125.79	26.0
300 class	82.25	17.0
100-300 class	130.63	27.0
100	113.99	23.6
50	91.30	18.9
25	51.60	10.7
6	21.30	6.4
As the end of 2012[b] (Burnard and others, 2014; NBSC, 2015a)		
Unit ≥1000 MWe	58	7.1
600 MWe ≤ unit <1000 MWe	247	30.1
300 MWe ≤ unit <600 MWe	239	29.2
200 MWe ≤ unit <300 MWe	42	5.1
100 MWe ≤ unit <200 MWe	30	3.7
60 MWe ≤ unit <100 MWe	6	0.7

[a]: thermal generation capacity; [b]: coal-fired generation capacity.

By the end of 2014, China has installed 100 USC power generating units of ≥1000 MWe (63 at the end of 2013). The share of units ≥300 MWe in the installed thermal power capacity rose to 77.7% and the share of units ≥600 MWe reached 41.5%. In addition, a large number of small and inefficient coal-fired heating boilers have been replaced by CHP generation units. The share of CHP units in the thermal power generation capacity increased from 13.3% in 2000 to 28.9% in 2013 (Wang, 2015; Ma, 2015). Figure 7 shows the changes in China's coal power generation structure between 1995 and 2014.

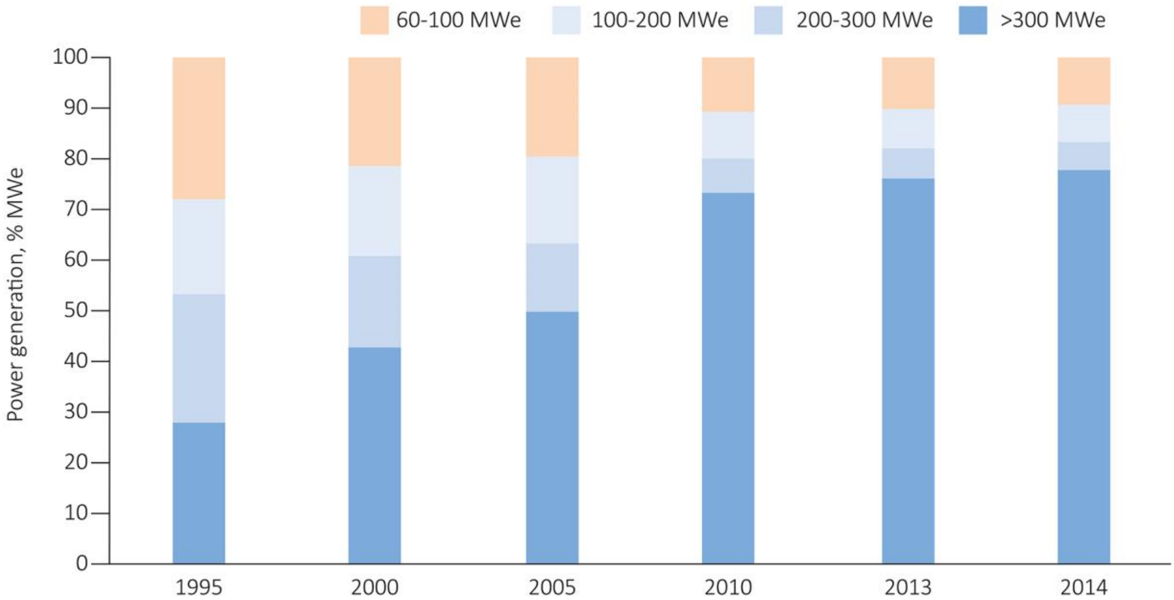

Figure 7 Changes in China's coal power generation structure (CEC, 2015a)

3.6.2 Energy conservation and emissions reduction

Owing to the LSS Programme and effective promotion of technological optimisation and upgrading of coal-fired power plants, China's coal-based power generation structure has improved over the years as illustrated in Figure 7, and the energy efficiency of coal power generation has improved year after year. Figure 8 shows the average national coal consumption rate for power supply between 2003 and 2015. It shows that the target of reducing the average power supply coal consumption rate to below 323 g/kWh by 2015 set in the 12th FYP was achieved in 2013. The national average coal consumption rate in 2015 was 315 g/kWh, which exceeded the target by a big margin and represents a 55 g/kWh reduction from 2005 level (CEC, 2016a). The average net energy efficiency of China's thermal power plants increased from 26.1% in 1978 to 36.9% in 2010 and to 38.6% in 2014. The efficiency figure of 38.6% represents the average efficiency of coal-fired plants in 2014 since about 90% of the country's thermal power plants are coal-fired (Wang, 2015).

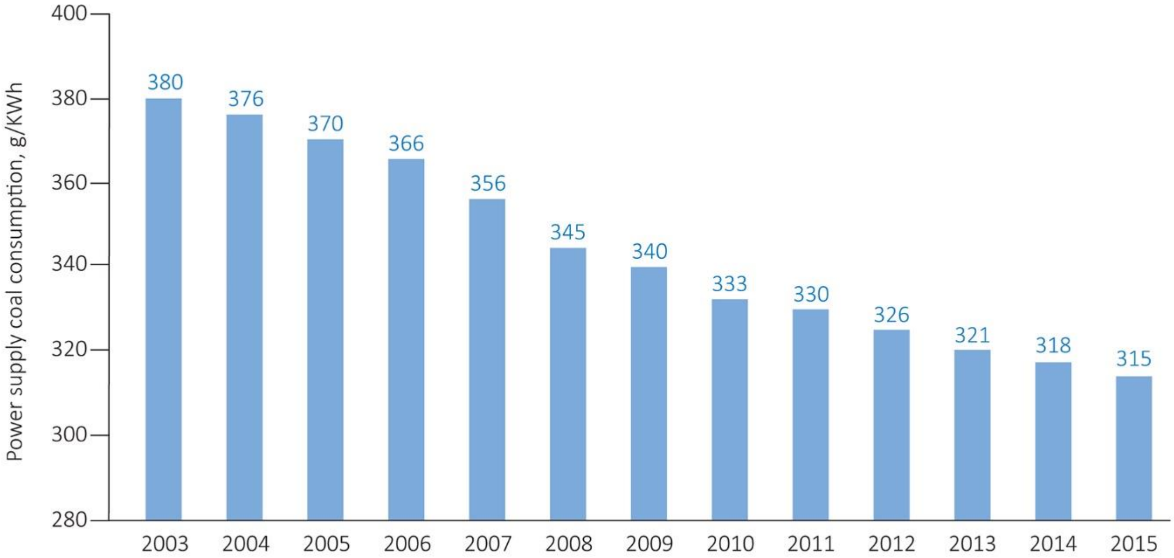

Figure 8 National average power supply coal consumption rates (Data source: http://www.cec.org.cn/guihuayutongji/)

As discussed in Section 3.1, the emissions of air pollutants from coal-fired power plants have reduced significantly in recent years owing to the large scale deployment of FGD, de-NOx and high-efficiency particulate removal technologies. Despite the energy penalty of FGD systems, China still managed to reduce in-plant electricity consumption as a percentage of total generation from 7.3% in 2000 to 6.3% in 2010 and 5.8% in 2014 (http://www.cec.org.cn/guihuayutongji/). On the other hand, according to a recent preliminary statistical analysis of CEC (2015a), the total emissions of PM, SO_2 and NOx from thermal power plants in 2014 were 0.98, 6.2 and 6.2 Mt, respectively. These represent a decrease of 31.0%, 20.5% and 25.7% from the 2013 emission level for PM, SO_2 and NOx, respectively. The total amount of PM, SO_2 and NOx emitted from thermal power plants in 2014 was halved compared to that of 2006.

3.6.3 Reduction in energy and carbon intensity

Reducing the energy intensity of growth has been a major priority of China since at least the 11th FYP. Energy intensity targets are set for national, provincial, and local governments in China, and are rigorously monitored and supervised. These and other initiatives in various sectors have contributed to a steady decline in the energy intensity of China's economy over the last decade, following a spike in the early 2000s. Figure 9 shows the reduction in energy intensity in China between 2006 and 2014 and Figure 10 shows the accumulative reduction of China's energy and carbon intensity during the 12th FYP period.

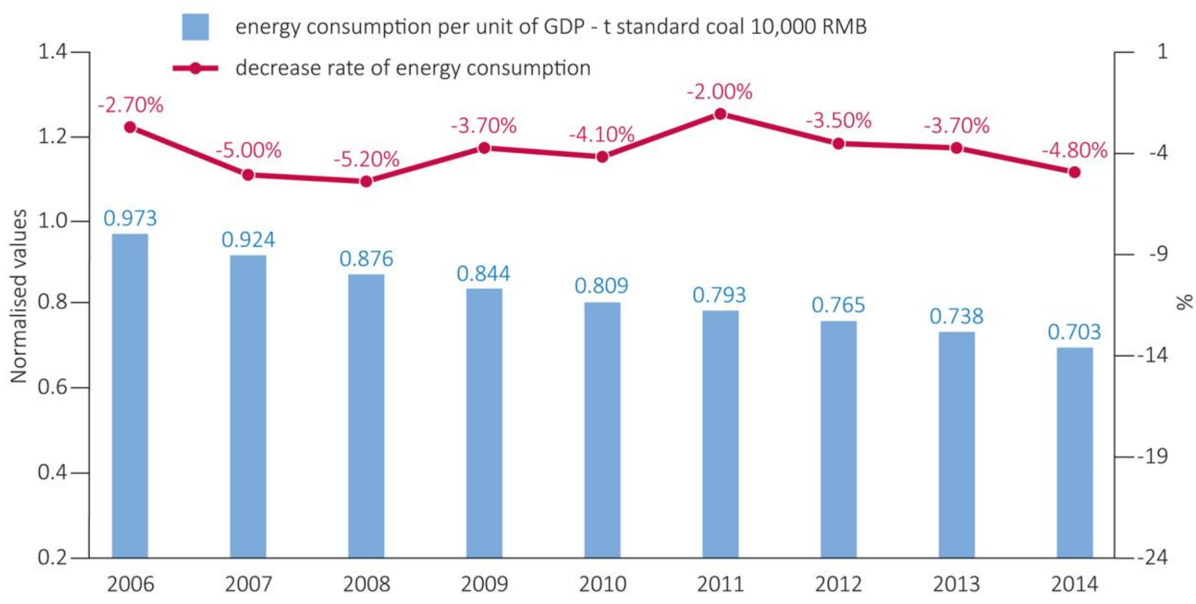

Figure 9 Reduction in energy intensity in China between 2006 and 2014 (Li and Sun, 2015)

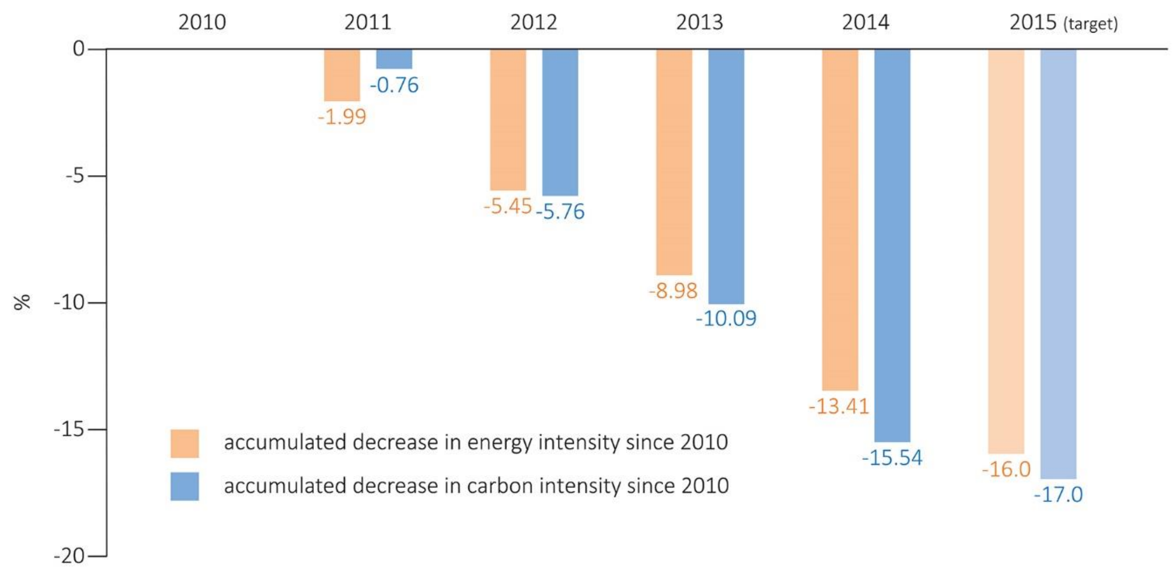

Figure 10 Accumulated reduction in energy and carbon intensity in China between 2010 and 2015 (Song and others, 2015)

For many years, around 80% of electricity generated in China was from coal combustion. Over the last decade, there has been a substantial increase in the generation capacity of renewable power. The share of coal power in China's total installed power generation capacity has fallen in past years. The share of electricity generated from coal has also decreased in the last few years, see Figure 11. In the meantime, the share of electricity from cleaner energy sources including hydropower, wind, solar and natural gas has increased steadily.. Figure 12 shows the increases in the share of power from cleaner energy source in the total power consumption during 2011 and 2015.

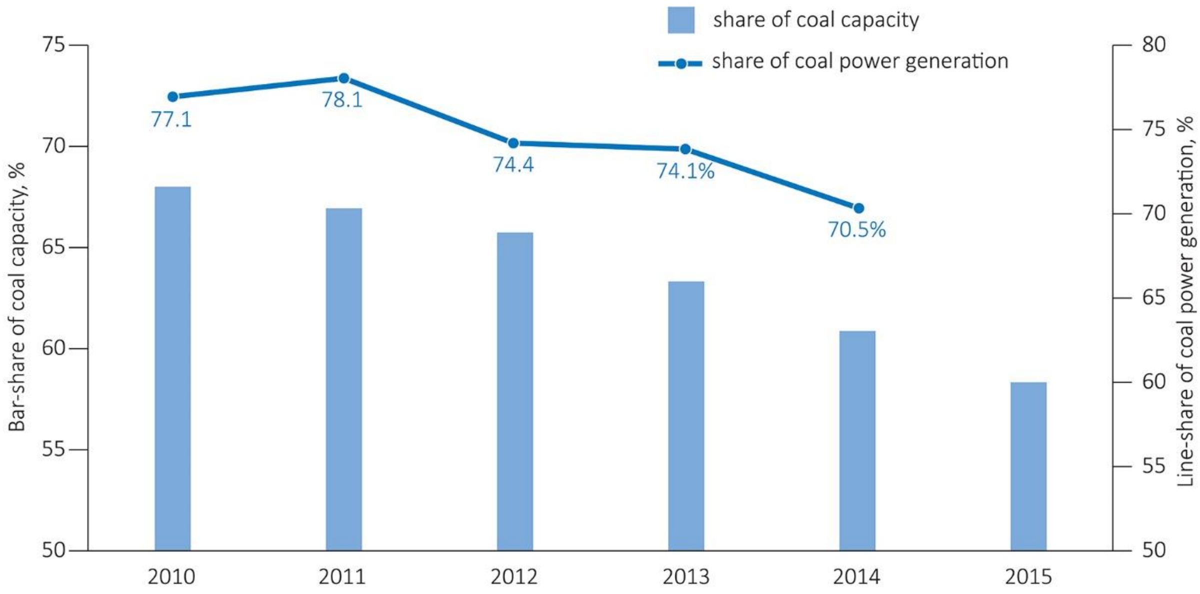

Figure 11 Changes in the share of coal power between 2010 and 2014/15 (Data source: CEC www.cec.org.cn/guihuayutongji/tongjxinxi/niandushuju/)

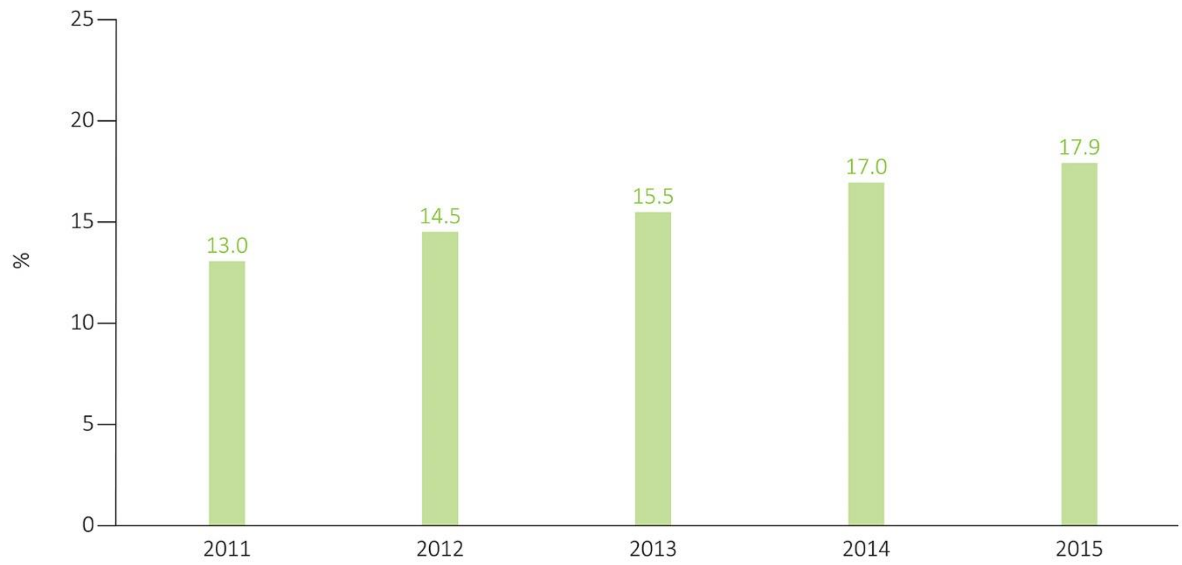

Figure 12 Shares of power from cleaner energy sources in the total energy consumed in China between 2011 and 2015 (NBSC, 2016)

With continued optimisation of coal power generation structure, the deployment of HELE technologies for power generation and improved management as well as development of renewable power, the carbon intensity of power generation has decreased over the years. According to CEC (2015a), a total of approximately 6 Bt of carbon emissions were saved between 2006 and 2014 (based on 2005 value) through measures such as the development of renewable energy, improvement of coal power plant efficiency and reducing transmission loss (*see* Figure 13). In 2014, the CO_2 emission for a unit of electricity generated was 19% less than that of 2005 (CEC, 2015a).

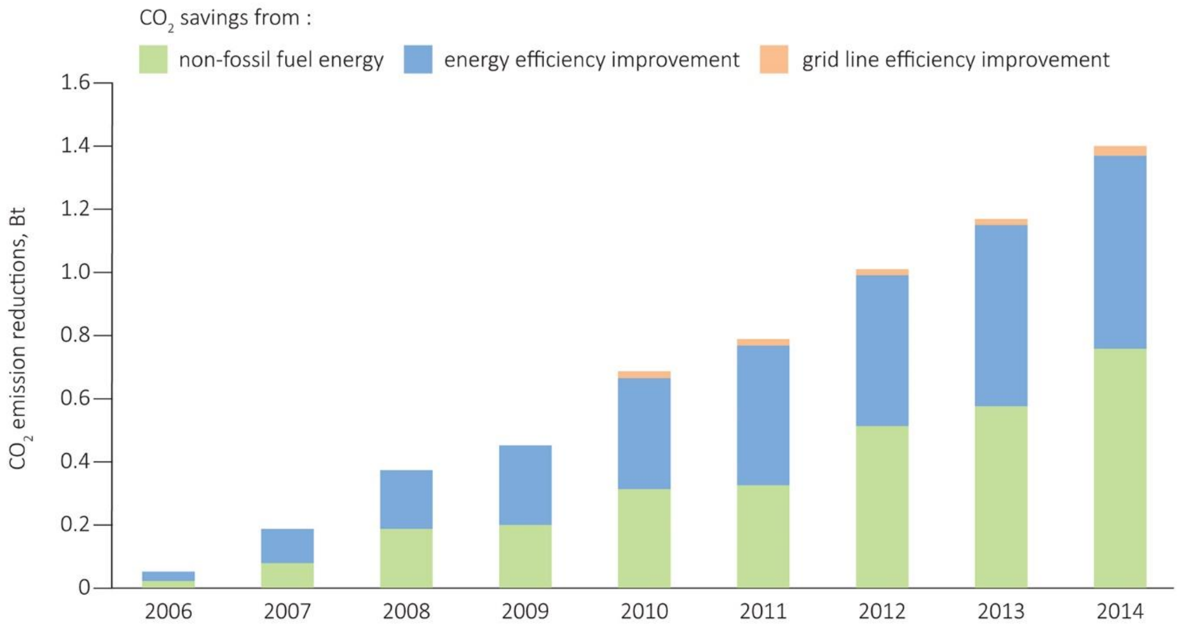

Figure 13 Accumulated reduction in CO_2 emissions from power plants between 2006 and 2014 (CEC, 2015a)

3.6.4 Renewable energy

China has the world's largest hydropower capacity, which accounts for approximately 30% of the global total. By the end of 2015, the total installed hydropower capacity was 319.4 GWe, accounting for 21.2% of the country's total installed capacity (CEC 2016a). Since the enactment of the Renewable Energy Law in 2005, China has provided strong incentives to develop renewable energy and China's investment in wind and solar power over the past decade has been impressive. China has developed the world's largest production capacity for wind and solar energy equipment and now has the most wind and solar power installed in the world. Wind power has grown rapidly in recent years and is now the third largest generating source in China, after coal and hydropower. Figure 14 shows the growth of wind power capacity between 2004 and the first half of 2015. During the 12th FYP period, the average annual growth rate of China's wind power capacity and wind power generation was both 29% (SGCC, 2015). By the end of 2015, China had a total installed wind power capacity (grid connected) of 129 GWe, accounting for 8.6% of China's total power generation capacity (www.gov.cn/xinwen/2016-02/04/content_5039051.htm).

The 12th FYP set a target to have a total installed solar power capacity of 21 GW by 2015. This target was exceeded in 2014 with a total installed grid-connected capacity of 26.52 GW (NBSC, 2015b). The average annual growth rate of solar power capacity and solar power generation during the 12th FYP period was 170% and 219%, respectively (SGCC, 2015). According to the NEA's data, at the end of 2015, China's total installed PV (photovoltaic) solar power capacity reached around 43 GW (including both grid-connected and distributed solar power), surpassing Germany as the world number one (CCC Info-Net, 2016). Now, China is the world leader in the development of renewable energy.

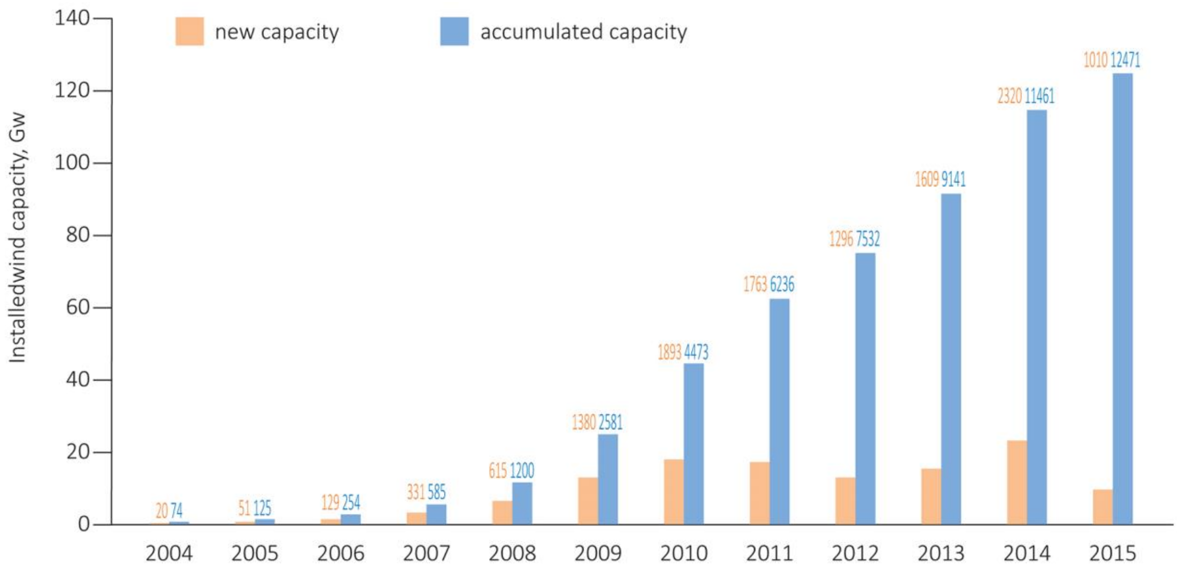

Figure 14 Growth in China's total installed wind power capacity (CREIA, 2015)

Overall, by the end of 2015, the share of generation capacity of non-fossil fuel in the total installed generation capacity reached 35% (CEC, 2016a).

4 Chinese HELE technologies

As discussed in the previous chapter, China has made it a national priority to improve the energy efficiency and reduce emissions of its coal-fired power plants. Increasingly stringent energy and environmental performance standards have been implemented for both new and existing power plants. Technology innovation will be decisive in determining whether the goals are achieved. Innovation has become a growing priority for China and the 12th FYP set a target for R&D spending to rise to 2.2% of GDP by 2015. Technology innovation, particularly CCTs (*see* Section 3.5) are central to China's plans for energy development. Over the past two decades, China has adapted and improved on technologies developed overseas and achieved cost reductions through process innovation, incremental manufacturing and deployment at scale. In the meantime, China has developed its own technologies and optimised engineering designs that are applicable to various parts of the power generation process. China is beginning to play more of a leading role in developing and deploying HELE technologies, drawing on its growing base of skills and R&D capabilities. The HELE technologies employed in China's coal-fired power plants, either new or upgraded existing plants, and the improvement in energy efficiency and emissions reduction achieved are reviewed through case studies in the following sections.

4.1 Upgrading existing plants

4.1.1 Waigaoqiao No. 3 power plant

With the progress of the LSS programme, a number of new SC and USC units with capacities ranging from 600-1000 MWe have been built in China over the past decade. One of China's first such projects was the Shanghai Waigaoqiao No. 3 power plant which has two coal-fired 1000 MWe USC units and started commercial operation in 2008. The steam turbines, turbine-generators and boilers were supplied by Shanghai Electric Corporation under license from Alstom (boilers) and Siemens (turbines). Siemens also directly supplied additional components for the steam turbines and generators. Both units are equipped with FGD and SCR (selective catalytic reduction) for NOx emissions control. When it first came online, it operated at a net efficiency of 42.73%, making it one of the most efficient coal-fired power plants in the world at the time (Overton, 2015). The main operating parameters of Waigaoqiao No. 3 are shown in Table 6.

Table 6 The main operating parameters of Waigaoqiao No. 3 (Feng, 2015)

Rated output	1000 MW
Maximum output	1059.97 MW
Design heat rate	7320 kJ/kWh
Main steam pressure	25.86 MPa
Main steam temperature	600°C
Reheat steam temperature	600°C

Throughout the project, emphasis was placed on optimisation and technological innovation as related to design, equipment selection, construction, commissioning, start-up and operation. Since the units began commercial operation, the pace of technological innovation has continued. The company has implemented many innovative projects and developed a series of technologies for energy saving and emissions reduction. Some of the key technological innovations deployed in Waigaoqiao No. 3 are discussed below.

Flue gas heat recovery

Flue gas temperatures are normally ≤130°C, so the energy available for recovery is limited. Compounding this is the issue of erosion of the heat exchanger surface caused by SO_2, SO_3 and NH_4HSO_4 (after installation of the SCR system), which results in reduced heat recovery from the flue gas. In addition, fly ash can adhere to the surface of the exchanger. The combination of the alkaline ash and the sulphuric acid dew can form a concrete-like substance that is difficult to remove and hinders operation of the heat exchanger. At Waigaoqiao No. 3, this problem is addressed through the development of a new type of finned heat exchanger that is installed in the low ash zone of the FGD between the booster fan and the FGD tower. It reduces abrasion and the risk of ash accumulation and blockage. In addition to waste heat in the flue gas, heat generated by the induced fan and the booster fan is also recovered with this arrangement. This heat is transferred to the condensate, so steam extraction can be reduced. The reduced energy extraction from the turbine offsets the power consumption of the FGD system.

The FGD flue gas heat recovery systems for the two units became operational in 2009. To date, they have performed well with minimal erosion detected. The performance test revealed that the unit efficiency was improved by 0.4% points, and the water consumption of the FGD was reduced by 45 t/h (Feng, 2015; Overton, 2015).

Improving the air preheater seal

Air leakage can lead to increased power consumption by all fans due to the increased air and gas flow. In addition, leakage can reduce the heat exchanger efficiency and thus decrease boiler efficiency as well.

Similar to most large modern boilers, the Waigaoqiao No. 3 power plant uses rotating air preheaters with designed air leakage of <5%. Although such air preheaters have many advantages, a nonlinear 'mushroom' deformation of the rotor can occur during operation. The clearances between the rotating and stationary parts are not easily controlled, leading to an increase in air leakage. After the first year of operation, the actual air leakage at Waigaoqiao No. 3 was less than 6%.

To reduce air leakage, a contacting, flexible and wear controlled sealing device has been developed. The flexibility of this new seal compensates for the deformation of the rotor and the non-linear variation of clearance between the rotating and stationary parts of the air preheater leading to a significant reduction in air leakage. Reduced air leakage has meant that auxiliary power consumption (including FGD and SCR) was reduced to below 3.5% and the unit efficiency increased by 0.29% points as a result (Feng, 2015).

Flexible Heat Regenerative Technologies

Flexible regenerative technologies expand the regeneration medium from classical feedwater to water, air and coal. An additional adjustable high-pressure steam extraction point was added to maintain the final feedwater temperature, and minimise the temperature drop during low-load operation. In addition, the temperature drop of the flue gas downstream of the boiler economiser at low-load conditions can be reduced so that the SCR need not be shut down at low loads. Also, the fast response of the extraction steam pressure by the control valve means that the unit frequency response is faster. At the same time, the SCR catalyst can operate under optimised conditions by adjusting the boiler heating surface, achieving high efficiency during the unit whole load range.

The air regeneration system matches extracted steam to the air preheaters to heat the air entering the boiler. The higher air and feedwater temperatures at the waterwall inlet during low load operation improve combustion stability and efficiency as well as water dynamics. The coal powder regeneration system dries and heats the coal powder at the outlet of the mills, improving combustion stability and efficiency, especially when high-moisture coal is used. These technologies not only benefit the boiler's combustion and operation but also improve unit efficiency by recovering heat from extraction and reducing heat loss in the condensers. Applying flexible regenerative technologies at 75% of load can improve unit efficiency by 0.2% points (Overton, 2015).

Boiler feedwater pump turbine

A 100% turbine-driven feedwater pump was adopted at Waigaoqiao No. 3 power plant (the first in China), eliminating the motor-driven pump. This boiler feedwater pump turbine, with its own condenser, is able to start up independently using steam from a neighbouring boiler. The boiler feedwater pump can operate at a wide range of speeds and saves a substantial amount of energy during start-up. It also simplifies the system control strategy, eliminates the risk of minimum flow valve leakage and improves equipment safety. Compared with competing options, this specific boiler feedwater pump increases the unit efficiency by 0.117% points (Feng, 2015).

Improved boiler start-up

This technology primarily uses steam in place of oil to heat up the boiler. The feedwater of the start-up unit can be heated by steam from elsewhere in the power plant. The boiler can then be warmed by the heated feedwater and the evaporated steam from the separator. When boiler fans start, the cold air is heated by the hot economiser; then the hot air heats the cold air from the flue gas side in the air preheater, establishing a 'hot furnace and hot air' condition before ignition. This approach speeds up start-up, reduces auxiliary load and fuel consumption and, thus, emissions. Waigaoqiao No. 3's start-up time is ≤2 hours (including cold start-up), oil consumption is ≤15 tonnes, power consumption is ≤80000 kWh, and coal consumption is ≤200 tonnes (including the steam used for heating) (Overton, 2015).

The new start-up method minimises catalyst sintering, poisoning, carbon and ash deposit, and formation of hydrates on the surface of the SCR catalyst, leading to a substantial extension of SCR catalyst lifetime (Feng, nd).

Optimising turbine operation and steam parameters

Siemens' SC and USC turbines operate on sliding pressure mode. An overload valve is introduced to the turbines at Waigaoqiao No. 3 for grid frequency regulation and overload control. Changes in load are met by opening the overload valve or closing the main steam control valves. Turbine efficiency reduces as the overload valve opens. In cases where the overload valve is frequently opened and closed or is maintained slightly open, erosion and leakage are likely to occur. To avoid this, the design parameters and the control mode were optimised by first, setting the opening point of the overload valve to the rated load point which corresponds to the maximum cooling water temperature. Thus, frequent opening of the overload valve can be avoided as the load demand will always be equal to or lower than the rated output. Secondly, on the turbine load control mode, the turbine load is adjusted indirectly by controlling the amount of extraction steam (rather than directly adjusting the condensate flow). In this way, the main control valves are fully open while the overload valve is always closed eliminating the throttling loss across the valves. Through this approach, transient turbine output can be obtained and the load requirements set by demand will be satisfied by adjusting the boiler combustion system.

This approach speeds up the response to load change and increases the range of load change. The Waigaoqiao No. 3's load change rate for frequency control is now ≥15 MWe/min. It is claimed that the unit operational efficiency has been improved by 0.22% points as a result although these benefits cannot be detected during performance tests (Feng, 2015).

Prevention of solid particle erosion (SPE)

Oxidation of steam-side components and the subsequent production of oxide particles have been a serious problem for SC and USC units worldwide for decades. Steam-side oxidation of boiler tubes reduces heat transfer rate, and as tube-wall temperature rises, the oxidation becomes more serious. In some cases, the oxides may peel off and block the tubes resulting in overheating and boiler tube explosion. Solid particles formed also erode the turbine blades causing serious turbine damage and thus decreasing the efficiency. The particles can also erode the sealing surface of the bypass valve plug during start-up, causing leakage and allowing steam to bypass the turbine, further decreasing efficiency. Some Chinese plants have experienced efficiency losses of 8% or more in their first few years of operation as a result. Figure 15 shows the damage caused by steam-side oxidation to the equipment of power plants.

After years of research, a comprehensive approach to prevent SPE has been developed and implemented at Waigaoqiao No. 3. The measures include:

- blowing out the oxides from the boiler tubes as soon as possible to avoid them entering into the turbine;

- deploying a large-capacity bypass system designed to bypass the turbine during unit start-up and also implementing a high-momentum flushing procedure to send oxides directly to the condenser during start-up;
- using a new configuration design and control strategy to avoid eroding the bypass valve plugs;
- using steam to heat the feedwater that is used to heat the boiler during start-up and also during low-load operation.

Figure 15 Oxide deposits on boiler tubes (left), solid particle erosion on turbine blades (centre) and bypass valve plug (right) (Feng, 2015)

Inspections after 30 months of operation with these strategies in place showed virtually no oxidation of boiler tubes and no erosion of the turbine blades as shown in Figure 16. Notably, a performance test indicated that the turbine efficiency had not deteriorated since the initial power plant start-up (Feng, 2015).

Figure 16 Pipe from the second reheater tube left) first blading of an IP turbine (right) after 30 months of operation (Feng, 2015)

Any modifications associated with these projects have been implemented during planned annual maintenance. Through such modifications, the efficiency and the overall performance of the units have been significantly improved. The net plant efficiency increased from 42.73% in 2008 to 43.53% in 2009, 43.97% in 2010 with an average capacity factor of 74–75%. In 2011, the average net efficiency further improved to 44.5% (including FGD and SCR) (*see* Figure 17). This means the unit net efficiency including FGD and SCR has reached above 46.5% at rated conditions (that is at full load). The contribution of each of the technologies to the plant efficiency improvements are shown in Figure 18. Compared to other advanced coal power plants of similar size in China with an average net efficiency of 41.2%, Waigaoqiao No. 3 uses 230,000 tonnes less standard coal and emits 480,000 fewer tonnes of CO_2 annually. Emissions of SO_2

(60 mg/m³), NOx (≤30 mg/m³) and PM (11 mg/m³) are comparable or even lower than the emissions of gas turbine plants (Feng, nd; Overton, 2015).

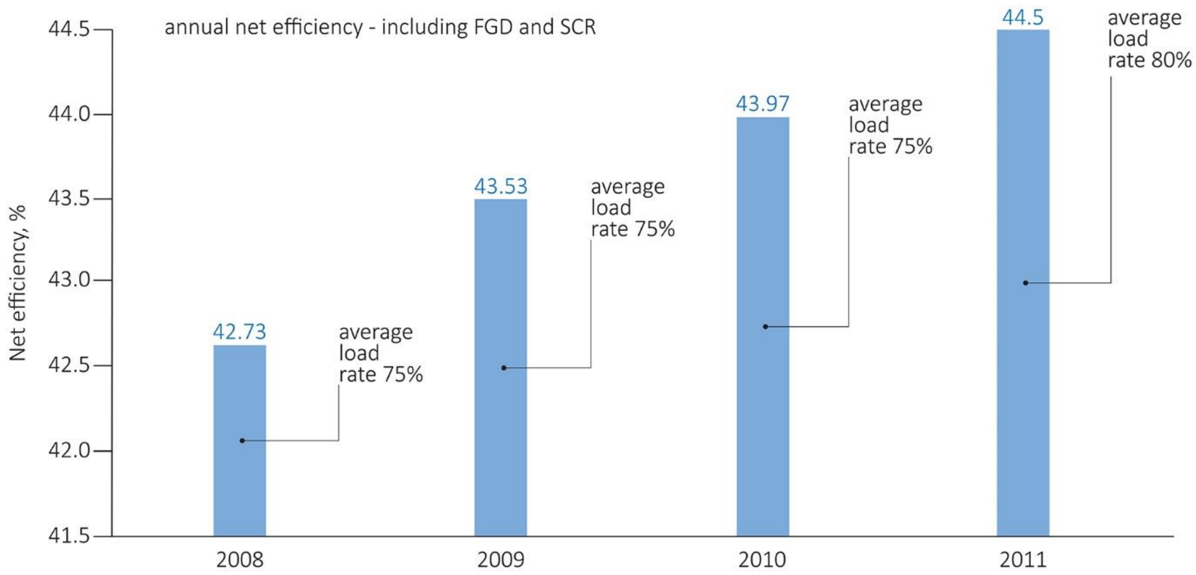

Figure 17 Energy efficiency improvments at Waigaoqiao No. 3 (Feng, nd)

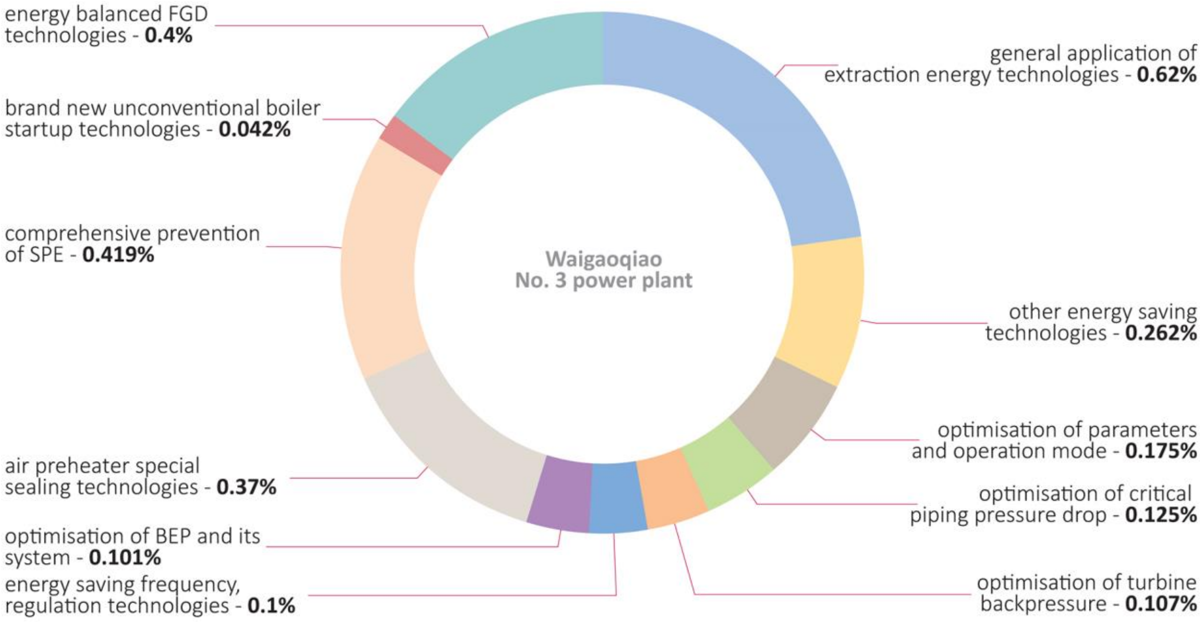

Figure 18 Energy efficiency gains through various technological innovations at Waigaoqiao No. 3 (Feng, nd)

4.1.2 Guohua Sanhe power plant

Owned and operated by Shenhua Guohua Power Company, the Guohua Sanhe power plant has 2 x 350 and 2 x 300 MWe coal-fired subcritical power generating units that were commissioned in 2000 and 2007, respectively. The plant is in Sanhe city, Hebei province which is within the key control region and must comply with the emission values of PM ≤5 mg/m³, SO_2 ≤35 mg/m³and NOx ≤50 mg/m³. Sanhe unit No. 1 was the first existing coal-fired power unit in China to be upgraded to an ultra-low emission unit and became operational on 23 July 2014. The technologies applied at Sanhe No. 1 include combined low-NOx burners and SCR, high-efficiency ESP (electrostatic precipitator equipped with low-temperature economiser and upgraded with high-frequency power and four conventional electrodes), limestone-gypsum wet FGD, wet ESP and a natural draft cooling tower. For PM emissions control, the dust resistivity is reduced by reducing the flue gas temperature from 150°C to 105°C so the PM concentration in the flue gas can be controlled at ≤20 mg/m^3 with a high-efficiency dry ESP. The waste heat of the flue gas is recovered by heating the condensate, resulting in a decrease in coal consumption rate by 1.5 g/kWh. The PM concentration is further reduced by a wet FGD system. The flue gas leaving the FGD passes through a wet ESP to ensure the PM concentration in the flue gas is ≤5 mg/m^3. The flue gas is discharged through the cooling tower and two units share one cooling tower, eliminating the stack.

For SO_2 emissions control, the FGD flue gas by-pass was removed to ensure 100% flue gas desulphurisation. The gas-gas heat exchanger (GGH) was also removed, eliminating the negative effects of possible gas leakage of the GGH on the desulphurisation rate. Meanwhile, energy consumption of the FGD system was reduced significantly. The design of the absorption tower has been optimised. A spray layer has been added to the bottom of the tower and a high-efficiency demister has been installed. The spray nozzles were replaced. For NOx emissions control, the low-NOx burners have been modified and air distribution optimised to enable the low-NOx burners to operate more flexibly and more reliably across the load range. The staging air ratios are also optimised so that NOx formation during coal combustion is ≤160–170 mg/m^3 at full load and ≤200 mg/m^3 across the whole load range. The SCR system has a NOx reduction efficiency of 80–85% and therefore stack NOx emissions can be limited to ≤40 mg/m^3. During the 168-hours test run, the emissions of PM, SO_2 and NOx from unit No. 1 were measured as 5.0 mg/m^3, 9.0 mg/m^3 and 35.0 mg/m^3, respectively, lower than a gas-fired power plant (Hebei Economic Daily, 2015).

The upgrade of the other three units at Sanhe power plant was completed by November 2015. Each unit took a different technical route to provide multiple technology references. Emissions of unit No. 2 during test operation in November 2014 were 3 mg/m^3, 10 mg/m^3 and 25 mg/m^3 for PM, SO_2 and NOx, respectively, lower than those of unit No. 1. In October 2015, Sanhe No. 4 set a new emission record for coal-fired power plants with emission values of 0.23 mg/m^3, 5.9 mg/m^3 and 20 mg/m^3 for PM, SO_2 and NOx, respectively (Shi, 2015). The boiler efficiency of unit No.4 increased from 93.91% to 94.78% and in-plant energy consumption decreased from 5.78% to 5.48%. Coal consumption for power supply was reduced by 24.47 g/kWh to 304.08 g/kWh (Shenhua Guohua Power Company, 2015).

After the plant upgrade, the coal consumption rate of the plant for power supply has decreased by 11.3 g/kWh, equivalent to an annual saving of 67,700 tonnes standard coal. The annual water saving is 600,000 tonnes. The cost of electricity is increased by approximately 0.01 Chinese Yuan. The emissions of PM, SO_2 and NOx have been reduced by 85.3%, 60.5% and 88.9%, respectively (Shi, 2015; Hebei Economic Daily, 2015).

Shenhua Guohua Power Company now plans to convert the Sanhe unit No. 1 and No. 2 to combined heat and power generation in 2016. The company has four coal-fired power plants in the Beijing-Tianjin-Hebei region. The upgrades of all four plants have been completed in the first half of 2016 and all the company's existing coal power units will achieve ultra-low emissions by the end of 2017 (Dong, 2015; Xu, 2015; Yu,2016).

4.2 New plants

4.2.1 Anqing Power Plant Phase II project

Shenhua Shenwan Energy Company's Anqing Power Plant Phase II is an expansion project of 2 x 1000 MWe that were commissioned in May and June 2015, respectively. The scope of the construction of the Anqing Phase II project includes two identical USC coal-fired power units, with limestone-gypsum wet FGD and SCR facilities. High steam parameters as well as a number of innovative technologies and designs are adopted at the plant to maximise net plant efficiency and minimise emissions.

High steam parameters

The main operating parameters of the Anqing II units are shown in Table 7. The two units operate at a main steam pressure of 28 MPa, and main and reheat steam temperature of 600 and 620°C, respectively. These parameters are higher than those used in Waogaoqiao No. 3, and in fact, they are the highest used in China on a plant of this size. Compared with a 1000 MWe unit using a steam cycle of 25 MPa/600°C/600°C, coal consumption of Anqing II units for power generation can be reduced by 1.94 g/kWh (Liu, 2015a).

Table 7 The main operating parameters of Anqing II (Liu, 2015a)

Rated output	1112 MW
Maximum output	1222 MW
Superheated steam flow	2910.12 t/h
Main steam pressure	28 MPa
Main steam temperature	600°C
Reheat steam temperature	620°C

Lower steam turbine backpressure

Reducing the backpressure on the steam turbines can increase the power plant efficiency. For every 1 kPa reduction in the turbine backpressure, heat consumption is reduced by 30 kJ/kWh resulting in a saving of about 0.75 g/kWh of standard coal. At Anqing II, the turbines operate at a backpressure of 4.89 kPa. In comparison to a standard unit with a backpressure of 5.1 kPa, the heat consumption of Anqing II units is reduced by 6.3 kJ/kWh and the standard coal consumption for power generation is reduced by about 0.21 g/kWh.

Nine steam extraction stages

Nine-stage regenerative steam extraction (extracting steam from nine different locations in the turbine to optimise boiler feedwater heating) is adopted at Anqing II. As compared to the typical eight-stage regenerative extraction, the heat consumption is decreased by 10 kJ/kWh and standard coal consumption for power generation is reduced by 0.34 g/kWh.

Flue gas waste heat recovery

Another approach adopted at Anqing II to improve plant efficiency is maximising the recovery of the waste heat in the flue gas and using it to preheat the boiler feedwater. Operating at the designed full load, the flue gas heat exchanger recovers 44,000 kW of heat, which reduced heat consumption by 45 kJ/kWh, and reduced the plant's standard coal consumption by 1.65 g/kWh.

Improved cooling tower design

It is the first time a high-yield water cooling tower design has been used at a 1000-MW unit in China (*see* Figure 19). Compared to a conventional cooling tower, the circulating pump lift is reduced by 10-11.5 metres and noise decreased by 8–10 dB. With this design, about 3790 kW/h of parasitic energy is saved, leading to a decrease in the in-plant power consumption by 0.38%, and the standard coal consumption for power generation by about 1 g/kWh (Liu, 2015a).

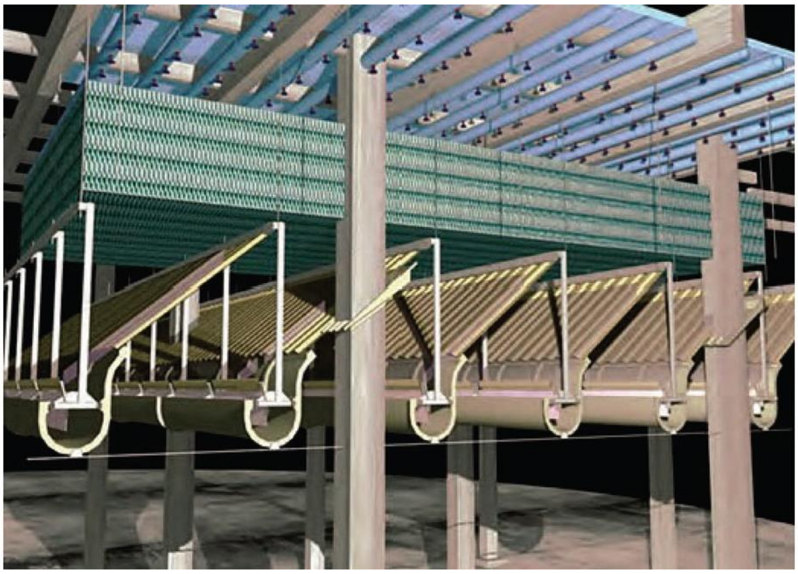

Figure 19 Internal structure of the high-yield wet cooling tower (Liu, 2015a)

Ultra-low emissions technologies

Advanced flue gas treatment technologies are deployed in Anqing II in order to achieve ultra-low emissions. The low-temperature economiser and high-frequency ESP with three chambers and five electric fields form the first stage of particulate emissions control. The PM removal efficiency of the ESP is around 99.86–99.9%. The PM concentration in the flue gas exiting the ESP is approximately 25 mg/m^3. The second PM removal stage is the high-efficiency spin exchange coupling (SPC) FGD system developed by Guodian Qingxin Company that simultaneously removes PM and sulphur (*see* Figure 20). Around 60% of the remaining PM is removed in the SPC FGD system. The final stage of PM removal is the rotary tube bundle PM demister, which has a PM removal efficiency of >70% so PM emissions of ≤3 mg/m^3 can be achieved. Compared to other PM emission control options, the capital and operating costs for the advanced tube bundle PM removal technology are lower, it has a smaller footprint and it can be used in new construction and retrofit projects.

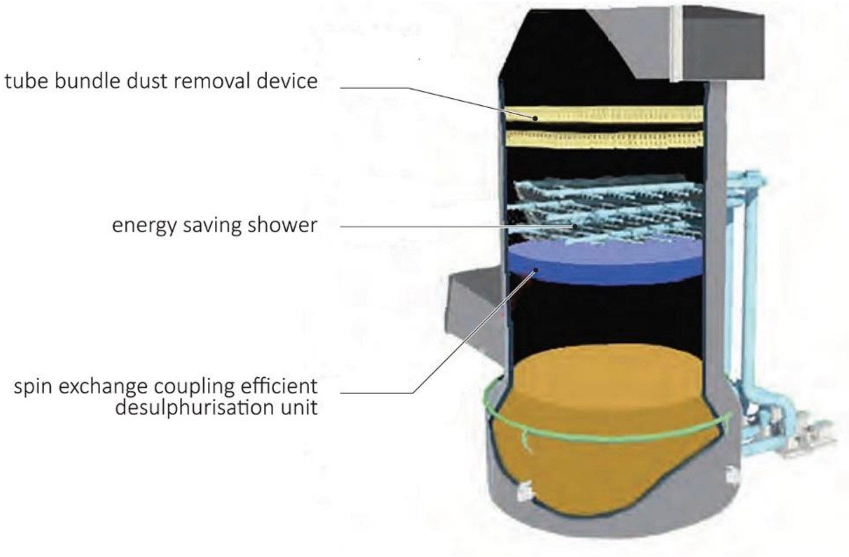

Figure 20 The FGD system based on spin exchange coupling and energy-saving spray (Liu, 2015a)

In the SPC FGD system, a device named a 'turbulator' is added in between the flue gas entrance and the first level of the FGD tower. The turbulator transforms the incoming gas flow from laminar to turbulent flow. Consequently, the liquid-gas contact area is increased and the gas-liquid mass transfer rate improved, which enhances desulphurisation and PM removal efficiencies. This system has an SO_2 removal efficiency of 97.8-99.7% and also consumes less power than other FGD systems and has low water consumption. Figure 21 shows the spin exchange coupling (SPC) unit. During the 168-hour unit test run, the FGD efficiency reached 99.7%.

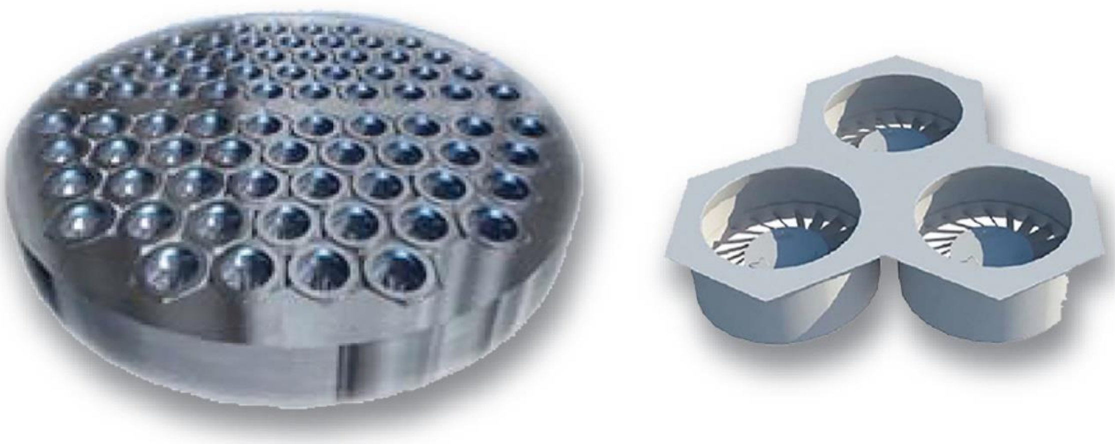

Figure 21 The SPC desulphurisation and de-dust unit (Guodian Qingxin, 2014)

For NOx emissions control, a low-NOx combustion system and SCR using urea as a reducing agent results in a denitrification efficiency of ≥95% (Liu, 2015a; Guodian Qingxin, 2014). The emissions of Anqing II units are 3 mg/m^3, 5 mg/m^3 and 20 mg/m^3 for PM, SO_2 and NOx, respectively (www.news.xinhuanet.com/energy/2015-11/18/c 1117185110.htm). In addition to low emissions, 100% of the fly and bottom ash, and desulphurisation by-products are utilised and there is no wastewater discharge.

The Anqing II unit 3 has a power supply coal consumption rate of 272.5 g/kWh and in-plant energy consumption of 4.01%; unit 4 consumes 273.9 g/kWh with an in-plant energy consumption of 4.06%. Based on the figures published by the company it was estimated that the net plant efficiency would be higher than 45% (Baruya, 2016). Compared with China's average plants of a similar size, the coal consumption of the Anqing II units is 15.15 g/kWh lower, saving 166,650 t/y standard coal which is equivalent to about 416,700 tCO_2/y saving. This represents a 5% decrease in CO_2 emissions compared to the average 1000-MWe plant in China, or a nearly 15% decrease in CO_2 emissions compared to the national average of coal-fired power plants.

With effective control of construction costs such as optimising purchasing, and lowering the procurement cost, the best possible price performance ratio was obtained. For the FGD absorber alone, the cost was reduced by 12 million Chinese yuan (US$1.9 million) compared to the original project budget. The project investment of ¥6.096 billion (US$950 million) was ¥547 million (US$85.7 million) lower than the approved project budget of ¥6.643 billion (US$1.04 billion), and the construction costs were reduced by 8.2%. The unit investment of 3048 ¥/kW (477.5 US$/kW) was 152 ¥/kW (23.8 US$/kW) lower than the budgeted amount, which meant that the total project investment of Anqing II project was less than that for comparable units in China (Liu, 2015a).

4.2.2 Guodian Taizhou Phase II Project

Guodian Taizhou Phase II Project is a USC, double reheat demonstration plant consisting of 2 x 1000 MWe coal-fired power generating units. The Taizhou II unit 3 and unit 4 are domestically designed, manufactured and built, and the world's first 1000 MWe class USC double reheat power generating units. The boilers, turbines and generators were supplied by Shanghai Electric. The steam cycle of Taizhou II adopts main steam pressure and temperature of 31 MPa and 600°C, and first and second steam reheat temperatures of 610°C. Tower boilers with tangential firing and dry bottom are employed at Taizhou II. Due to the introduction of double reheat, the heat absorption ratio of superheated steam and reheat steam changed to 72/28 compared to 82/18 for a USC, single reheat boiler, and hence the heating surface areas of superheater and reheaters need to be adjusted. Also, the required high-temperature heating surface area is increased significantly. Therefore, the heating surface inside the boiler needed to be redesigned to meet the superheat, first and second reheat requirements. At Taizhou II, a partition wall is inserted into the topside of the boiler for temperature control. The heating surface arrangement is shown in Figure 22 (Jiang, 2015).

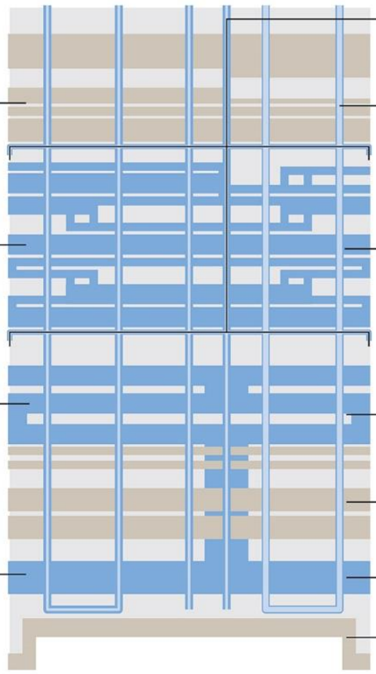

Figure 22 The heating surface design of Taizhou II USC, double reheat boilers (Jiang, 2015)

The turbine design adopts a tandem-compound, single shaft with five-cylinder and four-exhaust configuration. It is made up of a single-flow very high pressure (VHP) turbine, a double-flow high pressure (HP) turbine, a double-flow extra-large intermediate pressure (IP) turbine, and two double-flow low pressure (LP) turbines with 1146 millimetres last row blades. Extra-large IP modules are required due to the increased volume of steam flow with the superheated steam at 35 MPa. The shaft spans 36.7 metres. There are ten stages of steam extraction for regenerative feedwater heating. The turbine uses 9–12% chromium martensitic steels, such as CB2 for cast components and FB2 for forged components (rotor, valve and module casings). Start-up methods have been devised for ultra-high, high and medium pressure starts (Yang and others, 2014).

The Taizhou II unit 3 and unit 4 started commercial operation in September 2015 and January 2016, respectively. Unit 3 has reached a plant efficiency of 47.82%, the highest in China and in the world. The emissions of PM, SO_2 and NOx are 2.3 mg/m^3, 15 mg/m^3 and 31 mg/m^3, respectively. Its coal consumption for power supply is 256.8 g/kWh, 6 g/kWh lower than the previous world's best value. CO_2 emissions of Taizhou II units are 5% lower compared to those of conventional 1000 MWe class USC coal power generating units. The total investment of Taizhou II is 8.61 billion Chinese yuan. Compared with USC, single reheat 1000 MWe coal power units, the capital costs are increased by ¥0.5 billion due to the employment of double reheat technologies. However, the coal consumption rate of 256.8 is about 14 g/kWh lower than an average USC single reheat 1000 MWe unit. The two units at Taizhou II can save a total of 151,800 t/y standard coal. With today's coal price, the payback time is 6.25 years (http://www.sasac.gov.cn/n86114/n326638/c2180433/content.html; China Guodian, 2015).

4.3 Comments

China has recently commissioned several USC, double reheat coal-fired power plants and there are several more under construction or being planned. Besides Shanghai Turbine Work and Shanghai Boiler (owned by Shanghai Electric), several other Chinese companies now possess USC, double reheat technologies. For example, the boilers and turbines of Huaneng Anyuan power plant's 2 x 660 MWe USC, double reheat units are supplied by Harbin Boiler Company and Dongfang Turbine Company, respectively. The two units of Huaneng Anyuan plant in Anyuan, Jiangxi Province started commercial operation in June and August 2015, and they are the first USC, double reheat coal power generating units in operation in China. The plant has main steam pressure and temperature of 32.45 MPa and 605°C, and first and second reheat temperatures of 623°C. Different technological approaches are used to employ double reheat at Huaneng Anyuan. Detailed descriptions of the reheat technologies developed by various Chinese companies can be found in a recent report by Nicol (2015) for the IEA Clean Coal Centre. The two units are now operating smoothly with an energy efficiency of 44.37%. The in-plant energy consumption is 3.93%, lower than the national average. Advanced emissions control systems are installed at Huaneng Anyuan and the emissions of SO_2, NOx and PM are 15.1, 35.7 and 3.1 mg/m^3, respectively. Currently, there are around eight hundred 600 MW class coal-fired generating units in China. If all these units adopt double reheat technology, then 58 Mt/y of standard coal can be saved resulting in an annual reduction in CO_2 emissions of over 100 Mt (China Huaneng, 2015).

China has also made significant advances in developing CFB and IGCC technologies. In 2013, China commissioned the 600 MWe SC CFB Baima demonstration power plant. The Baima CFB unit is the largest, and one of the few SC CFB generating units in the world. The steam parameters adopted by the Baima CFB unit are 25.4 MPa/571°C/569°C. Tests carried out in May 2014 demonstrated that the boiler performance continued to meet or excelled the design criteria after one year of commercial operation. In particular, emissions of SO_2, NOx and PM (192, 112 and 9 mg/m^3, respectively) are much lower than designed values and exceed expectations for burning low quality coal (Yue and others, 2015).

Also in 2013, China's first IGCC power plant, the 250 MWe Huaneng Tianjin IGCC demonstration plant started operation. The gasifier is a dry-feed, oxygen-blown, pressurised two-stage reactor with a capacity of 2000 t/d. In 2013, the first year of operation, the IGCC plant operated a cumulative 1400 hours and achieved 24-days continuous operation. A total of 220 GWh power was produced in the first year. In 2014, after some system modifications and optimisation, the reliability and availability of the IGCC plant improved significantly. By 10 September 2014, the IGCC plant had operated for a total of 3200 hours and the longest continuous operation reached 45 days, producing 700 GWh electricity. Different types of coal were tested at Huaneng Tianjin IGCC plant. The coal consumption for power supply was 385 g/kWh and in-plant power consumption was lower than 23% of the total power generated. Emissions of SO_2, NOx and PM were 0.9, 50 and 0.6 mg/m^3, respectively (China Huaneng, 2012; Chen, 2014; CEC, 2014). China is now at the forefront of developing and deploying HELE technologies for power generation from coal.

5 CO_2 emissions from coal power generation

5.1 Outlook

5.1.1 Coal consumption peak

China's economy is currently undergoing a major structural transformation towards a new development model called 'new normal' that embodies a focus on structural changes that can achieve lower but still strong economic growth (with an annual growth rate of around 6–7%) and a better quality in terms of its social distribution and impact on the environment. The new model places a strong emphasis on:

- shifting the balance of growth away from heavy-industrial investment and toward domestic consumption, particularly of services and innovation, as a means of raising productivity and climbing up the global value chain;
- reducing inequality, especially urban–rural and regional inequalities; and
- environmental sustainability, emphasising reductions in air pollution and other forms of local environmental damage, as well as GHG emissions.

This transition that is already happening (*see* Figure 23) will, to some extent, happen naturally and will be encouraged by policy-makers. In the Government Work Report made at the 12th National People's Congress held in March 2016, Premier Li Keqiang announced government targets of annual GDP growth rate of >6.5%, and a reduction of energy and carbon intensity by 15% and 18%, respectively, during the 13th FYP period (http://lianghui.people.com.cn/2016npc/n1/2016/0305/c402194-28174181.html). Also, China has experienced an economic downturn (*see* Figure 24) with strong declines in energy intensive industries in recent years. China's new economic growth strategy and slower growth rate will have a significant impact on its energy demand and consumption, and will ultimately reshape China's energy mix and its use of coal.

On the other hand, China's is committed to reducing CO_2 emissions and curbing air pollution. China's plans for structural reform of the energy supply system, to improve energy efficiency, develop renewable and cleaner energy, deploy HELE technologies, reduce coal use and build electricity super-grids are strong. The scale and pace involved means that China is, or will be, a world leader in some of these areas.

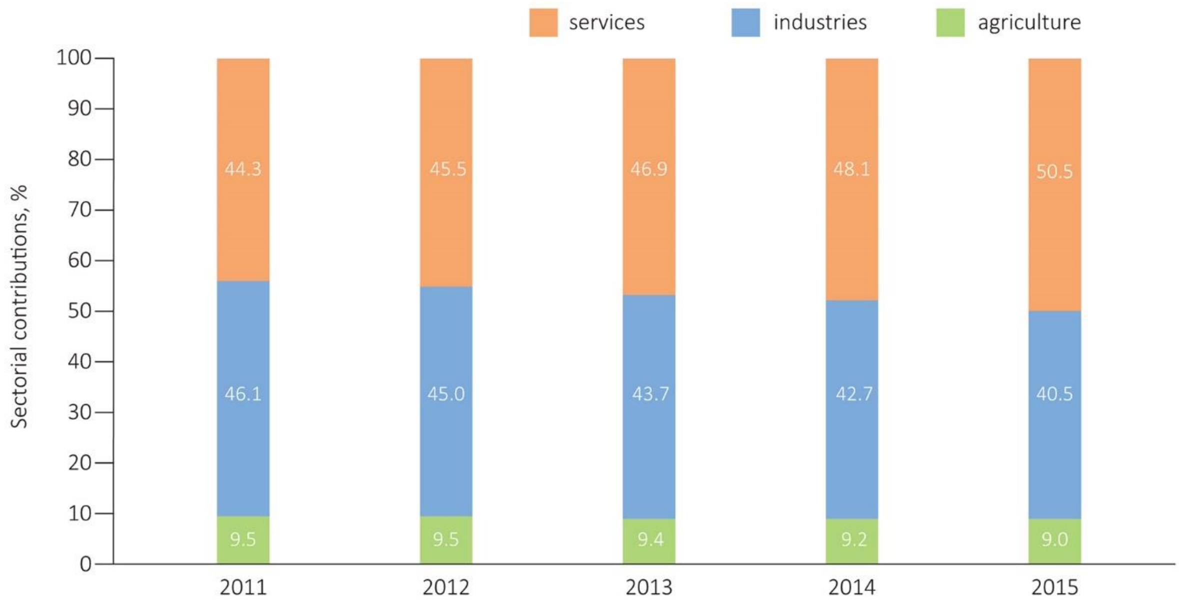

Figure 23 Changes in sectoral contributions to GDP between 2011 and 2015 (NBSC, 2016)

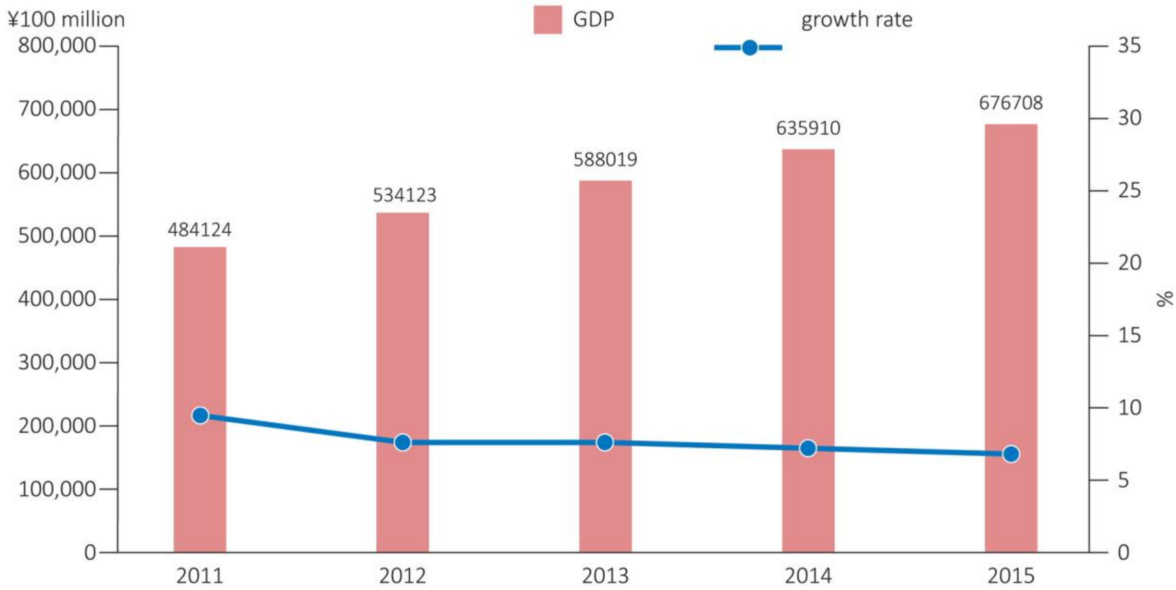

Figure 24 China's GDP and its growth rate between 2011 and 2015 (NBSC, 2016)

The question of when China's coal consumption/demand will peak is of great importance, both to China and globally, and hence it attracts worldwide attention. However, analysing this question is complex, and expert predictions differ widely. How, and to what extent, China will be able to reshape its use of coal has been the subject of great debate. Several studies conducted by different Chinese and international institutions show that China's coal demand will peak in the near future, but these studies diverge significantly in their assessments of when and at what level. To date, recent predictions of China's coal consumption peak between 2015 and 2030 and at a broad range of 3.9–4.8 Bt (Green and Stern, 2014; 2016).

Coal's role in China's overall energy mix has reduced progressively since 2011. Although China's coal use reached 4.24 Bt in 2013, the country's growth rate for coal consumption decreased to its lowest level since 2000. As a result of this decline, and coupled with other policy measures to promote greater reliance on alternative energy sources such as renewable energy, China succeeded in decreasing the ratio of coal in primary energy consumption from 70.2% in 2011 to 64% in 2015. According to the preliminary statistics (NBSC, 2015b; 2016), China's coal consumption in 2014 fell from the previous year by 123 Mt (-2.9%), the first time since 2000, and it continued to fall in 2015 by 3.7% (*see* Figure 25). The data cited in Figure 25 take into account the upward revisions in the summer of 2015 (shown in purple) to China's historical coal consumption made by NBSC following the once-in-five-year economic census, which took place in 2013 (http://www.stats.gov.cn/tjsj/ndsj/2015/indexch.htm). The census put China's coal data on a surer footing but it also caused some confusion about China's actual coal consumption. According to the adjusted figures, China's coal consumption in Standard Coal Equivalent (SCE) terms increased by less than 0.06% in 2014 (http://data.stats.gov.cn/easyquery.htm?cn=C01). The estimates by the US Energy Information Administration (EIA, 2015) indicated that China's coal consumption fell by 2% in 2014 when measured in terms of physical tonnage whilst there was essentially no growth in energy-content-based coal consumption.

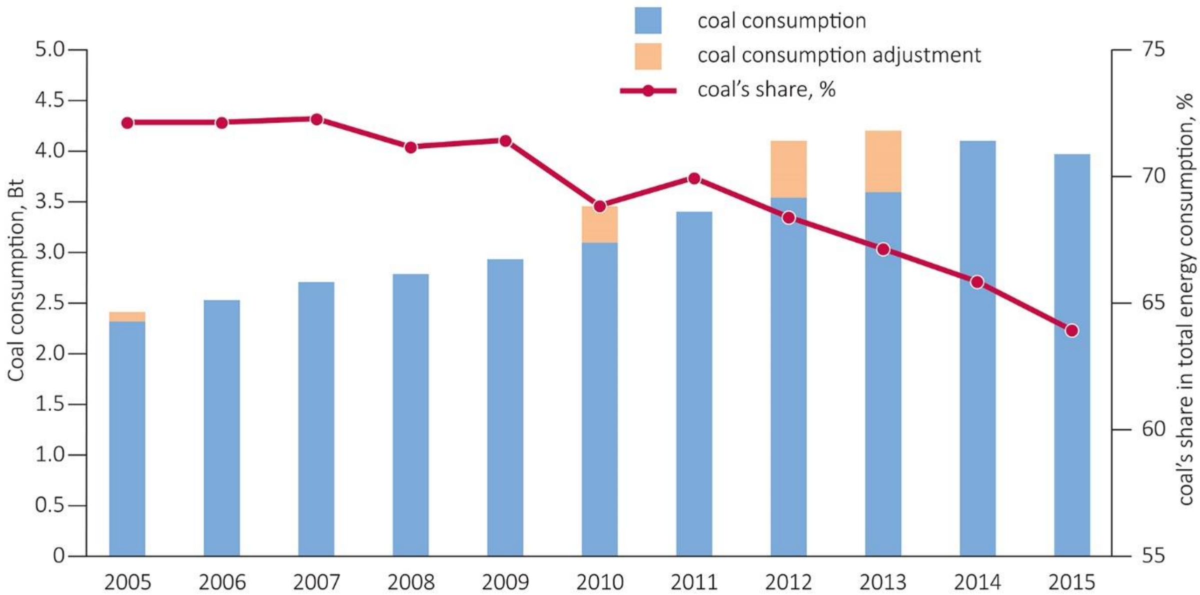

Figure 25 Consumption of coal and its share in total energy consumption (data source: NBSC)

After compound annual growth in coal consumption of >8% between 2001 and 2013, this turnaround is remarkable. The rapid change is also reflected in coal production and import data which fell in 2014 by 2.5% and 10.9%, respectively. Coal's decline continued in 2015 with annual coal production and consumption decreasing by 3.3% and 3.7%, respectively (NBSC, 2015b; 2016).

It should be noted that in spite of the recent revisions to China's historic coal data up to the end of 2013, it is generally believed that the 2014 and 2015 data are likely to be relatively accurate owing to changes in calculation methods made following China's once-in-five-year economic census in 2013. Also, the data are consistent with wider market trends, most relevantly in thermal power generation (where data are more reliable due to metering) and in heavy industry sectors such as steel and cement (Green and Stern, 2016). Therefore, the 2014 and 2015 coal data represent the general picture over this period: falling coal consumption.

Three major drivers can be attributed to the slowdown and decrease in coal use:

- economic transition;
- efficiency improvement and;
- development of renewable energy.

As discussed earlier, China is now entering the early phase of the 'new normal'. Partly as a result of this economic transition, GDP growth in China fell from an annual average of 10.5% over the period 2000-2010 to <8% over 2012-2014, and it fell further to 6.9% in 2015 (*see* Figure 24). China's slowing growth rate is linked to the changing structure of its economy, which is moving away from energy-intensive industries. Of particular importance in this structural change is the decreasing share of industry in GDP (*see* Figure 23). Notably, the steel and cement industries, which are especially high energy users, have begun to decline. In 2014, these industries grew much slower than in the period 2000-2013, at a rate of 1.2% for crude steel and 2.3% for cement. In 2015, the production of crude steel and cement fell from 2014 by 2.2% and 5.3%, respectively (NBSC, 2015b; 2016). Projections of energy-intensive industries reliant on coal, like steel and cement, have recently been revised downward and, in some cases, to a decline.

As a consequence of this transition and economic slowdown, there has been excess production capacity in sectors such as coal, steel and cement industries. New policies, for instance the 'Views on Resolving Overcapacity and Achieving Development of Coal Industry' (国发[2016]7号) and 'Views on Resolving Overcapacity and Achieving Development of Iron and Steel Industry' (国发[2016]6号) (issued in February 2016) have been formulated to strictly control any addition of new facilities and to accelerate the closure of inefficient, polluting production facilities. National targets are set to:

- shut coal mines with a total annual production capacity of ~500 Mt within 3–5 years starting from 2016, and restructure and upgrade coal production facilities with a total capacity of ~500 Mt;
- close inefficient, dirty crude steel-making plants with a total capacity of 100–150 Mt during the 2016-2020 period.

Similar actions are also being taken in other energy-intensive industries such as cement making. Combined with slower economic growth, this will lead to slower or even negative growth in coal demand and production. In April 2016, the NEA published the 'Guidance on 2016 Energy Development' (国能规划[2016]89 号) (http://zfxxgk.nea.gov.cn/auto82/201604/t20160401_2219.htm) (referred to as the

Guidance in the following). The Guidance caps 2016 coal production to ~3.65 Bt and sets a target to reduce the share of coal in the energy mix to below 63%.

These structural changes are occurring on top of ongoing energy conservation initiatives within industry, energy and other sectors. They have resulted in significant reductions in the energy intensity of China's economy over recent years (*see* Figure 10). China's actions to deploy more modern technologies and set higher standards for newly constructed plants have led to advances in the more efficient use of coal. At the same time growth of energy and power demand has been slowing. It is expected that the weak growth in demand for power will continue in the next few years owing to the reasons discussed above.

China has set targets to increase the share of non-fossil fuels in the country's energy mix to 15% by 2020 and to 20% by 2030, driven not only by energy security and climate concerns but also by efforts to reduce local pollution. Moreover, renewable energy capacity expansions are guided by technology-specific targets such as 200 GWe of wind power and 100 GWe of solar power by 2020. These targets are likely to be revised upwards in the 13th FYP as costs have plummeted and the industries have grown (Green and Stern, 2016). Indeed, this is evident from the Guidance that sets the targets to increase the share of non-fossil fuel energy to 13%, and the share of natural gas to 6.3% of total energy consumption in 2016. Solar and wind power capacity have expanded at astonishing rates in China in recent years as described in Section 3.6.4. In 2015, the share of non-fossil fuel energy in China's energy mix reached over 12%, exceeding the target of 11.4% set in the 12th FYP. Increases in the share of non-fossil fuel energy in China's energy mix and China's total non-fossil energy consumption during 1990 and 2014 are shown in Figure 26. The strong expansion of non-fossil energy supplies appears certain to continue into the 13th FYP period. China also set an ambitious target of 58 GWe of nuclear power generation capacity by 2020. The installed nuclear capacity increased by 36.1% from the previous year in 2014 and increased by 29.9% in 2015 with a total installed capacity of 26.08 GWe. The new hydro, nuclear, wind and solar power are significantly curtailing demand for coal power generation. China is also expanding its supplies of gas, along with domestic gas production and import capacity, as a key part of its plans to diversify the energy mix and reduce air pollution. Gas consumption grew at a compound rate of 14% per year from 2010 to 2014 (NBSC, 2015a). China has targeted an expansion of gas in primary energy consumption to ≥10% by 2020 (*see* Table 4).

To ensure achievement of the targeted non-fossil fuels share in the energy mix, the NDRC issued 'Measures for Protective Full Purchase of Renewable Power' (发改能源[2016]625 号) in March 2016. It outlines measures for grid companies to prioritise the purchase of all renewable power produced according to an annual power generation plan at a benchmark tariff determined by the state. Renewable power generated outside the annual power generation plan has dispatch priority.

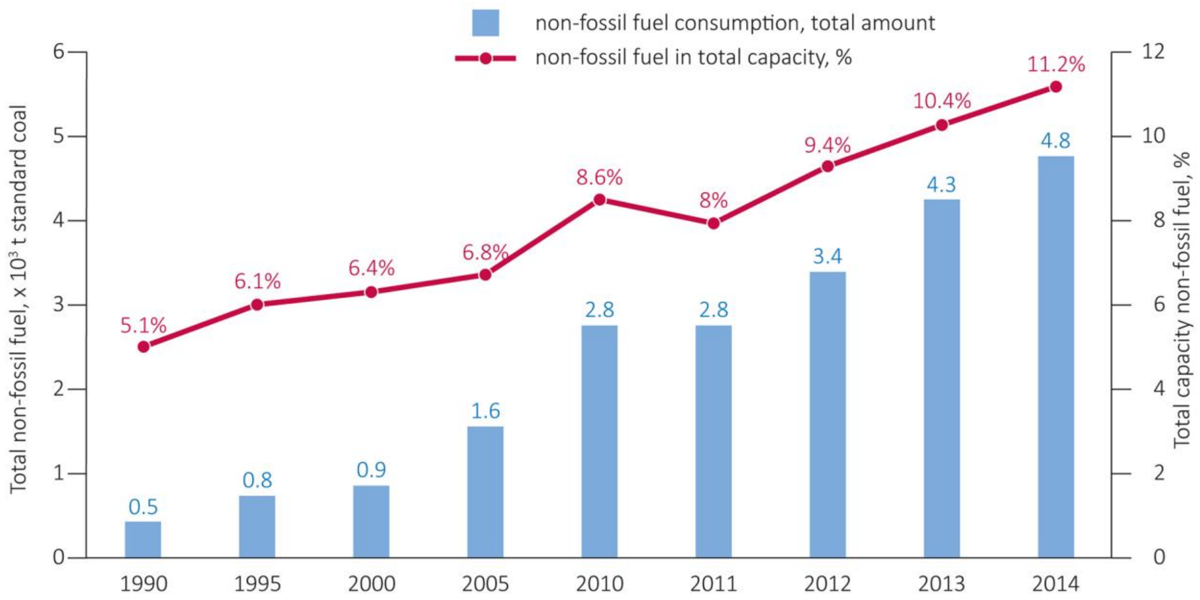

Figure 26 Share of non-fossil fuel in energy mix and non-fossil fuel consumption in China (Li and Sun, 2015)

The trend of moving away from energy-intensive industries, a slowing economic growth rate and strong declines in energy intensity suggests a medium-term future characterised by only modest growth in primary energy consumption. In the context of significantly slower growth in energy consumption, the combined effects of all of the measures above discussed have been the turnaround in China's coal consumption observed recently. The recent decreases in coal consumption prompted some experts to suggest that China's coal consumption peaked in 2013 (IEA, 2015c; Qi, 2016; Asuka, 2015). This opinion was shared with some caution by Mr Zhixuan Wang, the Vice President of China Electricity Council who argued that coal consumption would not peak in just one year. Rather, it might level off in several years with some fluctuation (www.eecg.net/dianlixingye/dianlixinwen/201601/163361.html). However, other scholars think that China's economy will rebound, driving the growth of coal demand and therefore coal consumption will peak some years later (Wu, 2016). Nonetheless, most researchers now agree that the slowdown in China's coal use is very likely to persist. Coal demand, if it grows at all, is likely to grow much more slowly than under the old economic model and is likely to peak at some point in the decade before 2025 or even before 2020 although exactly when and at what level remain a subject of debate.

5.1.2 CO_2 emissions from coal-fired power plants

Surpassing the USA in 2013, China now has the largest installed power generation capacity of 1508.28 GWe (an increase of 10.5% from 2014) in the world. Of this, 58.15% is coal-fired totalling 877.1 GWe, a decrease by 2.52% points compared to 2014 (CEC, 2016a). Owing to the rapid expansion of non-fossil fuel power, the share of power generated from coal has been decreasing in the past few years (*see* Figure 11). This trend is almost certainly to continue, particularly given the trajectory of government policies. Also, due to the economic transition and slower economic growth, there has been a sharp decrease in growth of power demand recently, most notably in 2015. Table 8 shows the growth rate of electricity generation between 2005 and 2015. It can be seen from Table 8 that there have been dramatic decreases in the growth rate of power generation in the past two years. It is projected that, during the 13th FYP period (2016-2020), power demand will grow but the growth rate will be slower. However, there is still a relatively big room for power generation growth and the total electricity consumption in 2020 is estimated to be around 8000 TWh (Terawatt hours) compared to the 2015 figure of about 5600 TWh (CEC, 2016b). One of the main drivers of China's future growth in electricity demand will be the mandated use of electric vehicles.

Table 8 Growth rate of electricity generation between 2006 and 2015 (Data sources: CEC and NBSC)

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Growth rate, %	14.1	14.5	5.7	6.7	14.8	11.9	5.4	7.7	4.3	0.3

As a consequence of much slower power demand growth and continued expansion of generation capacity of coal and other energy sources, China has turned from having a power supply shortage to a surplus. With the priority given to renewable energy, power generated from coal has been decreasing in the past two years. Although China's total power generation increased from the previous year by 4.0% in 2014, power from thermal plants fell by 0.3%, and coal use for power generation was reduced by 3.59% in 2014. In 2015, thermal power generation fell even further by 2.7% (NBSC, 2015b; 2016). Statistics from CEC (2016c) showed that in the first two months of 2016, total power consumption increased by 2% but there was a 0.5% points reduction in the growth rate compared to the same period of 2015. Thermal power generation continued to fall while power from non-fossil fuels increased. The thermal power generation was 4.3% lower and the reduction rate increased by 3.5% points from the same period in the previous year. At the same time, new coal-fired power plants continue to be built. In 2015, the addition of coal power generation capacity was 51.86 GWe, the highest since 2009. In addition, thermal power plants with a total capacity of 190 GWe are under construction, thermal power projects with a total capacity of around 200 GWe have been approved to be built and many more thermal power projects are proposed (Zhao and Cheng, 2016). Correspondingly, China now has a large system margin or potential overcapacity of coal power supply. As a result, the average hours of utilisation of coal power plants has decreased. In 2015, the utilisation of thermal power plants was 4239 hours, the lowest since 1969 (CEC, 2016a,c). Due to the large number of power plants that are under construction, it was estimated that the new capacity addition in 2016 would be around 100 GWe. Consequently, the utilisation hours of coal power plants in 2016 could be further reduced to less than 4000 hours (Zhang, 2016). The changes in power generated from coal and utilisation hours of thermal power plants since 2009 are shown in Table 9.

Table 9 Changes in coal power generation and utilisation hours of thermal power plants between 2009 and 2015

Year	2009	2010	2011	2012	2013	2014	2015
Generation, TWh	2866.5	3260.8	3696.1	3710.4	3977.6	3944.9	n/a
Growth, %		13.8	13.3	0.4	7.2	-0.8	-2.7
Utilisation hours	4865	5031	5305	4982	5021	4739	4329
Change, h		166	274	-323	39	-282	-410

On 21 April 2016, NDRC and NEA jointly published three policy documents that laid out measures to continue the LSS programme and shut down inefficient coal power generating units, to promote the orderly development of coal power generation, and to establish a coal power plant construction risk early warning system. The construction of new coal-fired power plants in areas with surplus power are strictly banned, the construction of some approved plants in 13 provinces are postponed until at least 2018, and the commissioning dates of some of the coal power units that are under construction are rescheduled (http://paper.people.com.cn/zgnyb/html/2016-04/25/content_1674368.htm). Liu (2015b), the Chairman of the State Grid Corporation forecast that China's coal power capacity would reach its peak value in 2020 at 1200 GWe. From 2020, China's power demand growth could be met mainly by renewable and cleaner energy sources, while power from coal would be gradually reduced and coal power plants would be shut down according to plan. Today, 47.7% of China's coal power capacity is comprised of subcritical units ≤300 MWe (Mao, 2016). The large supply margin of coal power gives China a good opportunity to close more of its less efficient, older and smaller (≤300 MWe) subcritical coal power units. China is currently in the process of developing its 13th FYP and it is unclear now what targets it will set for energy development and emissions control for the next five years to 2020. The 'Work Program of Full Implementation of Upgrade and Reconstruction of Coal-Fired Power Plants for Ultra-low Emissions and Energy Conservation (环发[2015]164 号)' sets a goal to shut down obsolete units with a total capacity of ≥20 GWe during the 13th FYP period (2016-2020). China can now afford to be more aggressive in closing its inefficient, subcritical coal units of ≤300 MWe, which will raise the average energy efficiency and reduce coal consumption for coal-fired power generation.

The NEA has recently clarified the four goals of 2016 energy development as structural optimisation, total consumption control, strengthening energy supply security and efficiency improvement. It set a coal consumption cap of around 3.96 Bt and a target to increase the power generation capacity of non-fossil fuel power to 35.7% of the total installed capacity by end of 2016 (www.ccchina.gov.cn/2016 年能源发展明确四大目标). Currently, around a quarter of electricity is generated from non-fossil fuel sources in China and this certainly will increase in the future. Due to the intermittent nature of wind and solar power, coal-fired power units will need to be used to balance the grid. There have been calls in China for the government to bring thermal power plants to play this modulation role (Zhao, 2016; Zhao and Cheng, 2016). For economic reasons, it is logical that large, more efficient SC/USC coal units operate as base-load power generation while smaller, less efficient subcritical units serve as peak-load or back-up capacities and to stabilise the grid. Also, smaller, subcritical units are better suited for this modulation role than SC/USC units. If China adopts this approach, then the utilisation hours of less efficient subcritical coal units will be lower than those of efficient SC/USC coal units, resulting in reduced coal consumption and hence lower CO_2 emissions for power generation.

As discussed in Chapter 3, China has developed a set of policies that have made major contributions to the efficiency improvement and emission reductions of its coal power generation fleet. As a result, the average net power plant efficiency rose from 36.9% in 2010 to 38.3% 2013 (38.6% in 2014), which was estimated to be equivalent to a reduction of 54.6 Mt of coal consumption and a lowering of CO_2 emissions by 99.7 Mt in 2013 (Andrews-Speed and others, 2014). Large gains in the efficiency of China's coal-fired power generation fleet have been achieved already through the LSS programme, performance/efficiency standards and other policy measures, meaning the rate of efficiency improvement may slow in future. However, there remains considerable potential for further efficiency improvement. The 'Action Plan on Upgrade and Reconstruction of Coal-Fired Power Plants for Energy Conservation and Emission Reduction (2014-2020)' increased the efficiency standards that existing and new coal plants must meet by 2020. China has a substantial fleet of modern SC and USC generating plants. Yet even these facilities are being called upon to make improvements. Many have upgraded their emission controls and made changes to improve energy efficiency. The continued shutting down of old and less efficient power units and progress of the Upgrade Programme mean that the net efficiency of China's coal power fleet will continue to improve leading to decreased coal consumption per unit of electricity generated.

Thus, it is expected that the transformation of China's energy sector will continue and indeed strengthen while the share of coal power generation falls. Despite the slower growth rate, power production and consumption are likely to increase in the near and medium term. However, driven by policies and targets to reduce coal consumption and expand non-coal energy sources, coal-fired power generation appears most likely to decline or level off. This, combined with continued improvements in power plant efficiency, means that it is quite possible that coal use in power generation will continue to fall. While there are many variables at play, the decline in coal used for power generation observed since 2014 may be an indication that CO_2 emissions from coal power reached a maximum in 2013. If CO_2 emissions from coal power generation do grow above the 2013 level, that growth trajectory is likely to be relatively flat before they start to fall.

5.2 CO_2 savings through HELE upgrade of coal-fired power plants

While the average efficiency in China was 38.6% in 2014, today's state-of-the-art coal power plants can achieve an efficiency of over 47%. Replacing or retrofitting a low-efficiency subcritical plant with a USC plant could reduce carbon emissions per unit of electricity generated by about 20% or more. Over the operational lifetime of a coal-fired unit, each percentage point increase in efficiency could result in CO_2 savings in the order of millions of tonnes. Typically, over 25 years, a 1% point increase on a 300 MWe unit operating at 37% efficiency could result in CO_2 saving in the region of 1 Mt. Therefore, the potential reductions in CO_2 emissions through upgrading the existing coal-fired power plants are extensive.

Barnes (2014) recently examined for the IEA Clean Coal Centre the prospect for the role of HELE coal power generation technologies in CO_2 abatement in China. He quantitatively analysed the potential impact of HELE upgrades on CO_2 emissions by comparing the base case performance of China's coal power fleet without HELE upgrades, other than additional capacity to meet increased demand, with scenarios where older plant is retired and replaced with HELE coal power plants on the basis of a 50-year and 25-year plant life. Under an assumption of continued annual growth of coal power generation, his results showed that by using state-of-the-art USC plant for new and replacement capacity, and through the retirement of old, less efficient units, CO_2 emissions were projected to rise less steeply than the increase in demand for coal-sourced electricity, reaching 6136 Mt in 2040. If China continues its policy of adopting the best technology and retiring older units on a roughly 25-year timescale, a largely advanced-USC (AUSC) based coal power fleet would see projected CO_2 emissions start to fall from year 2035 to 5153 Mt in 2040 (a 16% reduction over the base case scenario), despite a continuing upward trend in demand. If the most effective CO_2 abatement pathway is followed (25-year plant retirement, AUSC upgrades after 2025, CCS installation) emissions could fall to 750 Mt in 2040. Obviously, significant CO_2 savings can be achieved through actively pursuing HELE upgrades although China is already leading the way in the use of advanced steam cycles.

In short, in light of China's economic and policy trends affecting the structure of the economy and the coal consumption, the peak in China's CO_2 emissions is likely to occur before 2025 or even before 2020. The CO_2 emissions from coal-fired power generation might have reached a maximum level in 2013 and are likely to plateau or fall slightly over the next few years although some fluctuations are expected.

6 Concluding remarks

Over the last three decades or more, China has undertaken major structural reforms that have laid the foundation for subsequent long periods of strong economic growth. While this growth has lifted hundreds of millions out of poverty and made China the world's second largest economy, it has also heightened problems such as social inequality, intensified pollution and greenhouse gas (GHG) emissions. In the face of these and other challenges and opportunities, China aspires to shift its economy away from the energy-intensive, heavy industries to a more sustainable, efficient, innovative and socially equitable path for its future growth and development. Currently, China is making great efforts to promote green, low-carbon, climate resilient and sustainable development through accelerating institutional innovation and enhancing policies and actions.

As China is the world's leading CO_2 emitter, it plays a critical role in global efforts to curb greenhouse gas emissions and keep the global temperature increase below 2°C. Over the years China has introduced laws, standards, regulations, FYPs, action plans, and other policies at national and regional levels that are directly related to even broader policy measures for energy development, energy conservation, emissions control, and technology promotion among others. To date, China has already made considerable progress through the implementation of ambitious programmes aimed at improving energy efficiency of power generation as well as across a number of industrial sectors and a rapid scale up of renewable energy. China has steadily strengthened its formal policies relating to energy conservation and emissions reduction in a variety of ways. Overall, China has adopted many broad ranging new policies and taken concrete unilateral actions regarding energy efficiency improvement, emissions reduction, and low carbon energy development at a scale rarely seen in the rest of the world. What China has accomplished in these areas is very impressive. The energy intensity of China's economic growth has decreased steadily over the last decade from 0.973 t SEC/GDP in 2006 to 0.703 t SEC/GDP in 2014. The strategy to improve the performance of China's coal-fired power plants has been particularly effective. Substantial improvements in the efficiency of China's coal power generation fleet have been made through the LSS programme, performance/efficiency standards and other policy measures that effectively promote technological optimisation and upgrading of coal-fired power plants. The national average coal consumption rate for power supply has been reduced by a massive 55 g/kWh in ten years from 370 in 2005 to 315 g/kWh in 2015. The average power plant efficiency rose from 36.9% in 2010 to 38.6% in 2014, resulting in a significant reduction in coal consumption, CO_2 and other pollutant emissions. Despite the significant increase in net efficiencies of China's coal-fired power plant fleet, there is still considerable room for further efficiency improvements.

China's investment in renewable energy has been particularly strong. The wind and solar power capacity have been expanding at a staggering pace and China now has the world's largest wind and solar power capacity. China also has the world's largest hydropower capacity.

China has provided strong financing and policy support for the R&D of HELE technologies. China now possesses a range of HELE technologies that are being introduced into China's coal-fired power plants.

Currently, China is upgrading its existing coal-fired power plants to achieve ultra-low emissions and to improve efficiencies. Today, China has the world's most efficient and lowest emission clean-coal plants which have pollutant emission levels lower than a gas-fired power plant. China has broken several records for net plant efficiencies and air pollutants emission values of coal-fired power plant. The most advanced Chinese coal-fired power plants have achieved a net plant efficiency of >48.7% and emission levels as low as <1, ≤5 and ≤20 mg/m^3 for PM, SO_2 and NOx, respectively. In many ways, China is leading the world not only in developing alternative energy but in developing cleaner versions of existing technologies as well.

China has been ramping up its climate action commitments over time, with limits on coal use, rapid expansion of non-fossil energy, energy efficiency targets and measures and steps to rebalance its economy away from emissions-intensive industries which have major implications for energy demand and coal consumption. It was estimated that through measures such as the development of renewable energy, improvement of coal power plant efficiency and reducing transmission loss, a total of approximately 6 Bt of carbon emissions were saved between 2006 and 2014 (based on 2005 value). In 2014, the CO_2 emission for a unit of electricity generated was 19% less than that of 2005. Although China is already leading the way in the use of advanced steam cycles, there is still room for substantial CO_2 savings through actively pursuing HELE upgrades. If China continues its policy of adopting the best technology and retiring older units on a roughly 20-year timescale, further significant reduction of CO_2 emissions from coal power generation could be achieved in future.

As China is entering a new phase of economic development, and also due to the economic downturn, China has seen energy and power demand growth slowed, and coal consumption and power generation from coal decrease in the past two years. These trends appear to be continuing in 2016, indicating that CO_2 emissions in China will peak earlier than 2030, and are more likely to peak sometime within the next decade before 2025 or even before 2020. CO_2 emissions from coal power generation may have reached a maximum in 2013, whether temporarily or permanently, and are likely to plateau or fall slightly over the next few years although some fluctuations are expected.

Even as coal loses some of its prominence in China, it will remain an important cornerstone of China's economy. Therefore, China's energy development choices and strategies in the 13th FYP period will have impacts on global energy and environmental outlooks. The actions China takes in the next decade will be critical for the future of China and the world. The decisions China makes in the next year or so, as it develops its 13th FYP, will have a significant influence on the actions it takes in the next decade. It is certain that China will continue its efforts to improve energy efficiency across energy and other industrial sectors, diversify its energy mix and reduce reliance on coal, and reduce the energy/carbon intensity of its economy.

At present, China's actions and achievements are overlooked in many places. China's contributions are credible given its records in achieving ambitious goals on emissions reductions, efficiency improvements, limiting coal consumption, and developing and deploying low-carbon technologies. China's strategy for, and actions on, improving energy efficiency and reducing emissions can set an example for all countries. China could also play a critical role in global supply chains for HELE and low-carbon technologies as China is a world leader in developing and deploying low-carbon energy and clean coal technologies. China's experiences show what can be achieved with political will, commitment, appropriate strategies and policies, backed up by action.

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