Title
Review of China's Low-Carbon City Initiative and Developments in the Coal Industry

Author
Fridley, David

Publication Date
2013-03-31

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Review of China's Low-Carbon City Initiative and Developments in the Coal Industry

David Fridley, Nina Zheng Khanna and Lixuan Hong
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

September 2012

This work was supported through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

Review of China's low-carbon city initiative and developments in the coal industry

David Fridley, Nina Khanna and Lixuan Hong
China Energy Group
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory

Executive Summary

As China continues its double-digit economic growth, coal remains the principal fuel for the country's primary energy consumption and electricity generation. China's dependence on coal in coming years makes its carbon emission intensity reduction targets more difficult to achieve, particularly given rising electricity demand from a growing number of Chinese cities. This paradox has led the government to pursue cleaner and more efficient development of the coal industry on the supply side and "low carbon" development of cities on the demand side. To understand and assess how China may be able to meet its energy and carbon intensity reduction targets, this report looks at the recent development of low carbon cities as well as new developments and trends in the coal industry. Specifically, we review low-carbon city and related eco-city development in China before delving into a comparison of eight pilot low-carbon city plans to highlight their strengths and weaknesses in helping achieve national energy and carbon targets. We then provide insights into the future outlook for China's coal industry by evaluating new and emerging trends in coal production, consumption, transport, trade and economic performance.

China's low carbon development programs began in 2007 and have taken off in the last two years with the launch of several national programs. Across the National Development and Reform Commission's eight pilot low carbon cities, this study found large divergence amongst the low carbon plans in terms of targets, scope, content and implementation procedures due to lack of explicit definitions and guidelines. While all pilot cities have set carbon-related targets, the linkage between carbon and energy appears neglected as only two cities have set energy intensity targets while three cities have set non-fossil fuel penetration targets. Some cities such as Hangzhou, Xiamen and Baoding have adopted sector-specific 12th Five-Year Plans (FYP) in support of its low carbon city plans, but most cities lack the supporting regulations and policies needed to execute its low carbon development plans. This suggests that more guidance and direction from the central government, as well as greater understanding and capacity-building

at the local levels, are needed for low carbon development to effectively address China's energy and carbon emission reduction challenges. In addition, roadmaps of the low carbon city plans need to be formulated and sector-based targets should be decomposed from the overall targets to enable better implementation, performance evaluation and policy adjustment. At the same time, more market-based, rather than administrative, instruments need to be introduced alongside third-party surveillance and evaluation of low carbon city plan implementation.

Despite improved productivity in coal production, expanded scales of coal mines and enterprises, enhanced resource utilization and conservation and improved mining safety during the 11th FYP period, China's coal industry still faces concerns and challenges with resource sustainability, environmental degradation, low productivity and spatial mismatch between coal supply and demand. As a result, the 12th FYP for Development of the Coal Industry set for the first time a coal production cap of 3.9 billion metric tons (Bt) coal for 2015 along with other targets on industry consolidation, technology and safety improvements, regional production shifts and inter-provincial transport, comprehensive resource utilization and conservation and environmental protection.

On the production side, this study finds that the production of lower quality lignite coal has risen in recent years and production is increasingly concentrated in larger and centrally administered state-owned mines. The last twenty years have also demonstrated a continual geographic shift in coal production from eastern and middle China to western China, where the vast majority of coal resources are located. The transportation needs for moving all this coal is a challenge and transport bottlenecks, particularly in the railway system, will remain as recent capacity expansions have been insufficient at keeping pace with demand growth. Water transport has become the major mode of coal transport, with truck transport serving as supplemental mode for short-distance transfers. An emerging area in coal production is coal seam methane extraction and utilization, which has risen with increasingly ambitious targets over the last five years. While the 12th FYP and supporting policies present an optimistic future for the coal seam methane industry in China, challenges with limited technical knowledge and capacity, long-distance transmission and power grid connections remain.

In terms of coal consumption, this study finds that almost all of the recent rapid rise in coal demand can be attributed to China's rising power demand driven by urbanization and industrialization. China, in turn, faces an intensifying coal-power conflict due to uneven regulatory reform and different pricing structures (i.e., fixed electricity retail prices but rising coal prices). The Chinese government has attempted to address the coal-power conflict by proposing plans to develop coordinated coal-power bases but their potential impact remains to be seen. Coal demand in other sectors is likely to plateau soon as growth in iron and steel, cement and other heavy industry moderates and energy demand from the buildings sector are met with higher quality fuels such as electricity. Power sector decarbonization is therefore the key to reducing growth in China’s coal demand. Another potential source of demand is coal-based polygeneration, which is being aggressively pursued to promote comprehensive coal utilization to co-produce chemicals, liquid fuels and power. The overall coal demand outlook through 2020 ranges from a high of 4 Bt coal in the IEA outlook to 3.5 Bt coal in the LBNL model.

This study also found emerging trends in domestic and international coal trade flows with important implications for the coal industry’s outlook. In terms of international coal trade flows, China’s coal imports are increasingly concentrated within the Asia-Pacific region with suppliers in the region providing 88% of China’s imports. Coal imports from the world market have reduced costs compared to northern coal for (primarily southern) coastal importers and provide a swing source for coastal power producers facing fixed electricity prices and rising domestic coal costs. China’s growing dependence on Asian-Pacific coal suppliers, however, will be shaped by outlook for coal exports from the major suppliers of Indonesia and Australia on the supply side; and competing demand from Japan, Korea, and Taiwan on the demand side.

Looking forward, recent industry trends suggest that increasing coal production in coming years will be more challenging than in the past decade. These tell-tale technical, economic and physical trends include: a declining rate of mechanization growth, a declining rate of worker productivity growth, increased transportation costs and logistical problems, rising investment costs, rising production costs, and declining energy return on direct energy investment. These all point to greater difficulties and challenges in increasing China’s coal production over the next five to ten years when domestic coal demand is expected to continue rising.

Table of Contents

List of Tables

List of Figures

1. Introduction

In the past decade, China has continued to witness double-digit growth in gross domestic product (GDP), accompanied by accelerated industrial development and urbanization. This has led to an unparalleled demand for primary energy, resulting in a 250% growth in total primary energy consumption from 5,971 million metric tons (Mt) of coal equivalent (Mtce) in 2000 to 14,837 Mtce in 2010. At the same time, China's urbanization rate exceeded 50% for the first time in 2011 and new cities are springing up at unprecedented rates across the country alongside continued expansion of existing mega-cities. Coal, currently accounting for nearly 70% of China's total primary energy consumption and 80% of its electricity generation, will remain the cornerstone of China's energy supply even although ambitious exploration and development of alternative energy sources such as hydro, nuclear and wind has been pursued in recent years. China's dependence on coal in coming years makes its carbon emission intensity targets more difficult to achieve, leading the government to pursue a dual strategy of addressing energy and carbon from both the supply and demand side. On the supply-side, China recently released its 12th Five-Year Plan (FYP) for the coal industry outlining the next five years of development focused on improving consolidation and efficiency, reducing environmental and safety impacts and setting a coal production cap. On the demand-side, China started promoting the development of "low-carbon" cities as a strategy for addressing climate change, environmental quality and public health challenges with its rapid urban development.

From the supply-side, China is focusing on the coal industry in particular as coal has been a double-edged sword, having contributed to national economic growth but also directly responsible for severe environmental degradation and public health issues. Coal is the top source of air pollution in China and its direct combustion without adequate control measures have resulted in significant emissions of particulates, SO_2 and NO_x. An estimated 350,000-400,000 people die prematurely from outdoor air pollution and an additional 300,000 die from indoor air pollution every year (World Bank, 2007). Translated into economic terms, coal contributes to China's total hidden costs of air and water environmental damage and adverse health effects, estimated to equal 7.1% of national GDP in 2007 (Mao et al. 2008). In recent years, concerns are also growing over the role of coal in exacerbating global climate change as coal burning is the largest contributor to China's carbon emissions, accounting for 83% of total energy-related CO_2 emissions in 2009 (Fridley et al. 2011). In 2007, China surpassed the U.S. as the largest energy-related CO_2 emitter and a recent report from the Joint Research Centre of the European Commission and the Netherlands Environment Assessment Agency predict that China's per capita emissions could overtake the U.S. as early as 2017. Besides growing international pressure to reduce coal consumption over climate change concerns, China is also facing domestic pressure to reduce fossil fuel consumption over energy security, climate change adaptation and local environmental pollution concerns.

China is attempting to balance the integral role of coal to China's energy supply and economic development with mitigation of its negative environmental and public health externalities through its 12th FYP for the industry. On one hand, this plan highlights that coal will remain a primary fuel source for China over the long-term with the government's continued efforts to improve coal production efficiency through industrial restructuring and technological improvements. On the other hand, it also reflects the government's emphasis of the need to improve safety and compliance with emission standards. The 12th FYP for the coal industry also includes for the first time a cap on total coal production by 2015 in support of the national plan to meet 2020 energy and carbon emission intensity reduction targets.

While the 12th FYP will undoubtedly provide an important policy framework for shaping the future development of China's coal industry, a deeper understanding of the coal industry and the related transport and power industries is needed to understand if and how the 12th FYP targets can be effectively met. For instance, reaching the coal production cap will be crucial to achieving China's other targets for total energy consumption, energy mix and carbon emission; but the feasibility of the 3.9 Bt coal production cap is uncertain. Experience in the 11th FYP have shown that efforts to reach the ambitious energy intensity reduction target set by the central government may be overshadowed by local governments' strong desire for higher economic growth. If China again achieves faster economic growth than planned over the next five years, then it will become very difficult to meet the coal supply and demand targets. Thus, a comprehensive review and evaluation of China's recent coal production and consumption trends and emerging issues with domestic and international coal trade flows are needed to accurately assess the outlook of coal to 2015 and beyond.

From the demand-side, China has zeroed in on shaping the development of existing and new cities that have a profound impact on global carbon emissions. As home to buildings and energy services, commerce, transport and infrastructure, cities and urban areas are estimated to consume 75% of the world's energy and produce up to 75% of its greenhouse gas emissions. China has been undergoing fast urbanization, with the annual rural to urban migration of approximately 13 million people and the number of cities soaring from 193 in 1978 to 657 in 2010. By the end of 2011, China's urbanization rate reached a record 51.3% and is expected to increase to 79% by 2050 according to both United Nations World Urbanization Prospects and Chinese forecasts (UN DESA 2012, Jiang 2011). With a per capita commercial energy consumption that is three times higher than that of rural areas, urban areas are thus the crux of carbon emissions reduction from an end-user perspective. Beginning in 2007, the idea of low-carbon cities emerged as a potential strategy for improving environmental and public health quality while reducing energy intensity in China's growing urban areas. Low-carbon cities emphasize addressing climate change by decoupling economic growth from fossil fuel and shifting towards consumption that is based on energy efficiency, renewable energy and green transportation. To promote the idea of low-carbon cities and to lead by example, the National Development and Reform Council launched a low-carbon demonstration program involving five low-carbon pilot provinces and eight pilot cities. Each city has subsequently developed its own low carbon city plan, but the idea of a "low-carbon city" remains ambiguous and undefined. An evaluation and assessment of the development of low carbon cities in China – and particularly the plans and actions of the eight pilot cities – are needed to understand the role that these cities could play in helping China control its future energy demand and carbon emissions.

This report approaches the outlook on China's low carbon development both from the perspective of demand with a focus on the development of low carbon cities and the perspective of supply with a focus on the coal industry. It begins with a review of low-carbon city and related eco-city development in China, then delves into a comparison of the eight specific pilot low-carbon city plans to highlight their strengths and weaknesses in helping China achieve its energy and carbon targets. The second section of the report provides an in-depth review of historical and new developments in China's coal production trends, including changes in mine ownership, size, geographic distribution of production and the emerging industry of coal-bed and coal-mine methane. The third section focuses on coal consumption, reviewing changes in coal consumption drivers, the intensifying coal-power conflict and emerging development of coal-based polygeneration. Next, the domestic and international flows of coal trade are evaluated to identify and assess evolving transport bottlenecks and international coal resource constraints. Lastly, the outlook on China's coal industry for 2015 and beyond is discussed taking into consideration coal supply and demand forecasts and emerging trends on the industry's economic performance.

2. Low carbon city review

2.1 Background

The Chinese government has started to emphasize greenhouse gas and particularly carbon emission mitigation as part of its national strategy for development in recent years. In 2007, China issued its National Climate Change Program; in 2008, a White Paper on China's actions and strategy on climate change was published; in 2009, the State Council announced a target of reducing the carbon intensity of its GDP by 40-45% by 2020 compared to the 2005 level. This emission mitigation target was incorporated into the national 12th FYP for the very first time.

As the center of population, industry, transport and infrastructure, cities have a profound impact on global carbon emissions. Cities and urban areas are estimated to consume 75% of the world's energy and produce up to 75% of its greenhouse gas emissions. China has been undergoing fast urbanization, with the annual migration of approximately 13 million people from rural areas to urban centers. The number of cities in China has also increased from 193 in 1978 to 657 in 2010. By the end of 2011, China's urbanization rate reached a record 51.3% and is expected to further rise to 79% by 2050. Because urban energy consumption per capita is estimated to be three times higher than that of rural areas (excluding non-commercial energy such as biomass), and indirect energy consumption through infrastructure and urban consumption of goods is even higher, the development of low-carbon cities is crucial to mitigating carbon emissions in China.

At the beginning of 2008, Shanghai and Baoding became the first cities to join a new World Wildlife Fund (WWF) initiative to explore low carbon development strategies for China's urban areas. The NDRC initiated a low carbon pilot province and city program in July of 2010, including five provinces and eight cities across the country. The eight low carbon pilot cities are located across the country and include: Tianjin, Baoding, Hangzhou, Chongqing, Nanchang, Guiyang, Xiamen and Shenzhen; the five low carbon pilot provinces are Yunnan, Guangdong, Hubei, Shaanxi, and Liaoning (Figure 1).

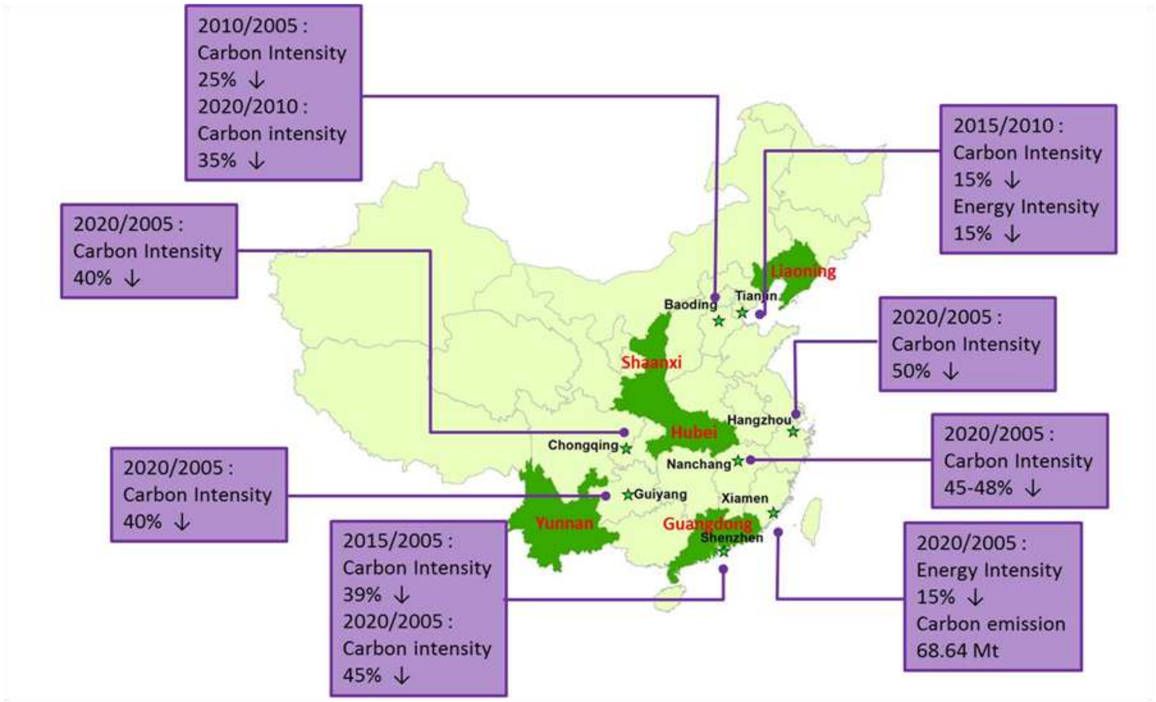


Figure 1. Map and Major Targets of NDRC's Eight Low Carbon Pilot Cities

As part of the pilot program, each pilot city was asked by NDRC to develop and propose a low carbon development plan, formulate supporting policies, develop low carbon industry, establish CO_2 emission statistics and management system and encourage low carbon lifestyles and consumption. Table 1 shows the action plans of the eight pilot low carbon cities. As seen from the table, these pilot cities are in different stages of developing and implementing their action plans. As a low carbon pilot city under both the WWF and NDRC programs, Baoding was the first to propose its low carbon action plan and program while Chongqing's low carbon action plan was just approved by NDRC in March of 2012.

Table 1. Summary of Low Carbon Plans for Eight Pilot Cities

City	Action Plan	Issue Time	Drafting Institution
Tianjin	Tianjin's climate change program	March, 2010	Tianjin Development and Reform Commission
Baoding	Baoding city people's government views on building low carbon city	December, 2008	Baoding Municipality Government
Hangzhou	Hangzhou city people's committee and government views on building low carbon city	December, 2009	Hangzhou Municipality Government
Chongqing	The action plan for Chongqing low carbon pilot city	March, 2012	Chongqing Development and Reform Commission
Nanchang	The action plan for Nanchang low carbon pilot city	November, 2011	Nanchang Municipality Government
Guiyang	Guiyang city low carbon development action plan framework (2010-2020)	July, 2010	Guiyang Municipality Government
Xiamen	The overall planning framework for low carbon city of Xiamen	January, 2010	Xiamen Construction & Administration Bureau
Shenzhen	Medium- and Long-term plan for Shenzhen low carbon development (2011-2020)	February, 2012	Shenzhen Development and Reform Commission

Table 2 lists some key socioeconomic parameters of the eight pilot low carbon cities in 2010. It illustrates the divergence of these cities in terms of urbanization, economic development and industrial structure. The urbanization rate of these eight cities[1] range from 38.9% in Baoding to 100% in Shenzhen, and the per capita GDP of Shenzhen is almost 5 times that of Baoding. Additionally, the size of each city's population varies vastly among the eight cities; the population of the provincial-level city Chongqing is approximately 8 times that of Xiamen. Agriculture contributes a mere 0.1% of Shenzhen's GDP compared to nearly one-third in Chongqing, where the service sector remains relatively undeveloped—28% of total GDP—compared to over half in Guiyang and Shenzhen. Industry (including construction) accounts for more than half of GDP in all cities but Hangzhou, Guiyang, and Shenzhen.

---

[1] Chinese cities are defined by administrative boundaries and contain at least 100,000 non-agricultural residents. City size classes, however, are defined by the non-agricultural inhabitants only.

Table 2. 2010 Socioeconomic Indicators of Low Carbon Pilot Cities

City	Population	Per Capita GDP (RMB)	Primary Sector Share of GDP	Secondary Sector Share of GDP	Tertiary Sector Share of GDP	Urbanization
Tianjin	12,938,224	72,994	2%	53%	45%	79.6%
Baoding	11,194,379	18,462	15%	52%	33%	38.9%
Hangzhou	8,700,400	68,398	4%	48%	49%	73.3%
Chongqing	28,846,170	27,596	32%	69%	28%	53.0%
Nanchang	5,042,565	47,174	6%	56%	38%	65.7%
Guiyang	4,324,561	25,941	5%	41%	54%	70.2%
Xiamen	3,531,347	71,808	1%	51%	48%	52.7%
Shenzhen	10,357,938	95,000	0.1%	48%	52%	100%

2.2 Parallel Programs

In addition to the low carbon pilot program launched by the NDRC, parallel programs have also been appearing at both central and local government levels in recent years. By February 2011, 230 of 287 prefecture-and-above level cities have proposed plans to establish an “eco-city”, while 133 of these cities have gone a step further by setting targets to construct a “low-carbon city” (China Society for Urban Studies 2010). In addition, China currently has 11 major indicator systems for low-carbon and eco-city development. He (2012a) compared the major concepts of eco-city, low carbon city and low carbon eco-city, which can be summarized as follows:

- Eco-city: enhances well-being of citizens and society through integrated urban planning and management that harness benefits of ecological systems and protects and nurtures assets for future generations
- Low carbon city: emphasizes addressing climate change challenges that cities may confront, decouples economic growth from fossil fuel use by shifting towards consumption based on renewable energy, energy efficiency and green transportation
- Low carbon eco-city: combines two concepts by featuring energy-saving and environmentally friendly city symbolizing low energy consumption, low pollution and low carbon emissions

These parallel programs are summarized below (He 2012a):

2.2.1 Eco-city program in Ministry of Environment Protection (MEP)

To promote the scientific development of a “resources saving and environmental friendly society”, the Ministry of Environmental Protection (MEP) initiated in 2003 a program to establish eco-counties, eco-cities and eco-regions within China. MEP issued “National Ecological County, Ecological City Establishment Assessment (trial)” on December 13, 2003. The program requirements were revised by the MEP in 2005. Under the revised plan, basic requirements must be met for cities to be considered an eco-city, including (MEP 2007):

1. Establish an "eco-city construction plan" to be considered, promulgated and implemented by the Municipal People's Congress.
2. Establish independent environmental agencies
3. Achieve higher levels of energy savings beyond government-assigned targets
4. Achieve eco-environmental quality evaluation index that is among the best in the province.
5. 80% of counties (including county-level cities) must reach the national ecological construction targets to be named National Environmental Protection Model City.

By July of 2011, 38 cities have been named “Ecological City (County)” under MEP’s guideline and assessment, including cities in Jiangsu (Zhangjiagang, Changshu, Kunshan, Jiangyin, Taicang, Yixing, Wuxi Binhai, Xishan District, Huishan District, Wujiang, Wuzhou Wuzhong District, Gaochun, Nanjing Jiangning District, Jintan, Changzhou Wujin District, Hai’an), Shanghai (Minhang District), Zhejiang (Anjie, Yiwu, Lin’an, Tonglu, Pan’an, Kaihua), Beijing (Miyun, Yanqing), Shandong (Rongcheng), Guangdong (Shenzhen Yantian District, Zhongshan, Shenzhen Futian District, Nanshan District), Sichuan (Shuangliu, Chengdu Wenjiang District), Anhui (Huoshan), Shaanxi (Xi’an Saba Ecodistrict), Liaoning (Shenyang Dongling District, Shenbei New District), and Tianjin (Xiqing District)[2].

2.2.2 Eco-garden city program in Ministry of House and Urban and Rural Development (MOHURD)

MOHURD initiated the National Garden City program as early as 1992, and by the end of 2010, MOHURD had released 13 groups of National Garden Cities with a total of 184 cities under this program[3]. In June 2004, MOHURD decided to initiate the establishment of Eco-garden City based on the program on National Garden City. Qingdao, Yangzhou, Nanjing, Hangzhou, Weihai, Suzhou, Shaoxing, Guilin, Changshu, Kunshan, Jincheng, and Zhangjiagang were listed as among the first group of demonstration cities.

The general requirements of qualifying as an Eco-Garden City are as follows:

1. Develop complete urban ecological development strategy, measures and action plans
2. Establish a complete urban green space system
3. Emphasize both cultural landscape and the natural landscape

---

[2] MEP, National Eco-City (District, County) Name List: http://sts.mep.gov.cn/stsfcj/mdl/201107/t20110722_215314.htm (Released on July 22, 2011, accessed on Sep 18, 2011)

[3] A full list of the cities granted “National Garden City” can be found at: http://zh.wikipedia.org/wiki/%E5%9B%BD%E5%AE%B6%E5%9B%AD%E6%9E%97%E5%9F%8E%E5%B8%82

4. Improve city infrastructure
5. Provide good urban living environment
6. Active participation by the community and the general public in the public interest policies and measures related to the formulation and implementation of the Eco-Garden City
7. Exemplary implementation of the national and local urban planning, ecological and environmental protection laws and regulations.

Those cities already awarded "National Garden City" can apply to be nominated as an Eco-garden City. Going further than the requirements of a Garden City, an Eco-garden City places more emphasis on the assessment of urban environmental quality. Compared to the "Garden City" evaluation standards, "Eco-garden City" assessment includes additional indices such as measurement of ecological protection, ecological construction and restoration standards, comprehensive species index, index of native plants, the proportion of urban heat island effect, urban ecological environment, and public satisfaction evaluation.

MOHURD also created a basic indicator system for assessment, which includes 19 main indicators classified into three categories: urban ecological environment indicators, urban living environment indicators and urban infrastructure indicators.

Table 3. City Participation in Eco- and Low-Carbon City Programs by Province

Provinces	MEP Eco-city	MOHURD Eco-garden city	NDRC Low-carbon city demonstration
Anhui	Huoshan		
Beijing	Miyun, Yanqing		
Chongqing			Chongqing
Fujian			Xiamen
Guangdong	Shenzhen Yantian District, Zhongshan, Shenzhen Futian District, Nanshan District		
Guangxi		Guilin	
Guizhou			Guiyang
Heibei			Baoding
Jiangsu	Zhangjiagang, Changshu, Kunshan, Jiangyin, Taicang, Yixing, Wuxi Binhai, Xishan District, Huishan District, Wujiang, Wuzhou Wuzhong District, Gaochun, Nanjing Jiangning District, Jintan, Changzhou Wujin District, Hai'an	Yangzhou, Nanjing, Suzhou, Zhangjiagang, Kunshan, Changshu	
Jiangxi			Nanchang
Liaoning	Shenyang Dongling District, Shenbei New District		

Shaanxi	Xi’an Saba Ecodistrict		
Shandong	Rongcheng	Qingdao, Weihai	Shenzhen
Shanghai	Minhang District		
Shanxi		Jincheng	
Sichuan	Shuangliu, Chengdu Wenjiang District		
Tianjin	Xiqing District		Tianjin
Zhejiang	Anjie, Yiwu, Lin’an, Tonglu, Pan’an, Kaihua	Hangzhou, Shaoxing	Hangzhou
Cities cross programs	Zhangjiagang, Nanjing, Kunshan are in both MEP and MOHURD programs; Hangzhou in both MOHURD and NDRC programs.		

Note: The Eco-garden cities (12 cities) were selected from the National Garden City (184 cities) by MOHURD. All statistics updated by July 2011.

Sources: MEP, MOHURD and NDRC government official document and notice.

2.2.3 Eco- and Low carbon cities in Local Governments

With the policy push by NDRC on low carbon development, many other cities have proposed establishing targets to become low carbon cities, and include among others, Zhuhai, Jilin, Ganzhou, Wuxi, Wanshou, Changping, Chang-Zhu-Tan (Table 4). By conducting city-wide low carbon planning and setting up city-level energy and emission targets, these cities aim to receive the central government’s policy, project and program support. Those efforts have strengthened the movement to develop low carbon cities in China (The Climate Group 2010). However, the implementation details of these plans and targets are still not well addressed.

Table 4. Cities with Low Carbon Development Targets

City	Low carbon city strategy and target
Chang-Zhu-Tan	Changsha-Zhuzhou-Xiangtan approved as pilot Resources Saving and Environment Friendly comprehensive reform area. December 4, 2007.
Chengdu	*“Action plan on constructing low carbon city in Chengdu (2010)”* 2020 Targets: CO_2 intensity reduction by 35% compared to 2010; CO_2 per capita of less than 5.5 ton; Clean energy as 25% of industrial value.
Jilin	“*Low Carbon Development Roadmap for Jilin City (2010)*” Emissions for city to peak in around 2020 and decline to 60% of business-as-usual scenario by 2030. Compared to the business-as-usual scenario, primary energy demand to fall to 28.18 Mtce and 33.51 Mtce in 2020 and 2030, respectively.
Wuxi	“*Wuxi low-carbon city development strategic planning (2010)*” 2020: carbon intensity reduction by 45% compared to 2010

2.2.4 International program

Many organizations and research institutions have partnered with government and other stakeholder to start exploring the planning and best practices of low carbon cities in China (The Climate Group 2010). In the fall of 2007, the Rockefeller Brothers Fund began supporting a study to develop a low-carbon economy roadmap for Guangdong province and Hong Kong. In 2008, WWF launched its pilot project on "low carbon city development program" and selected Baoding and Shanghai as the first two pilot cities in recognition for their leadership. In October 2008, UNDP, the Government of Norway and the EU jointly launched a project to support Chinese provincial climate change programs and projects. By end of 2010, more than 30 provinces, autonomous regions and municipalities in China have started to prepare for provincial level climate change plans with cities identified as key parts of the program.

The UK Strategic Programme Fund (SPF) has also supported Jilin City, Nanchang, Chongqing and Guangdong province in its low carbon city development research and planning. Supported by the Energy Foundation's China Sustainable Energy Program, Tsinghua University and research institutions in Suzhou and Shandong have conducted preliminary studies of low-carbon strategy for Suzhou. In June 2010, the Switzerland-China Low Carbon Cities Project was launched, and Yinchuan, Beijing Dongcheng District, Dezhou, and Meishan were selected as pilot cities, with emphasis on city management, low carbon economy, transportation and green buildings.

2.3 Overview of NDRC Low Carbon City Plans

According to NDRC's requirements, low carbon plans should include clear targets as well as key achievements and specific measures for CO_2 emissions, industrial structure adjustment, energy structure optimization, energy efficiency improvement, and the increase of carbon sinks. However, NDRC has neither provided a definition for the low carbon city nor recommended specific guidance and methods on how to compile a low carbon city plan. In order to highlight key elements behind low carbon planning, we compared and assessed the low carbon city plans of the eight pilot cities in terms of their targets, scope, planning procedure and measures. The comparison and assessment is based on an in-depth review of low carbon strategies in these eight municipalities.

2.3.1 Target

Besides an overall carbon target shown in Figure 1, the low carbon city plans also include a series of sub-sectoral targets for industrial, building and transportation sectors as well as ecological and other targets. Table 5 categorizes and summarizes the detailed low carbon targets proposed in the low carbon city plans of the eight pilot cities. Several differences among municipal low carbon plans can be identified from the perspective of target setting and allocation:

- The city needs to decide whether to adopt a relative or absolute carbon target. Following the country’s commitment to a carbon intensity reduction target for 2020, all pilot cities except Xiamen have set a carbon intensity reduction target. Baoding and Chongqing have both carbon intensity and emission targets. Xiamen has gone a step further than other cities by not only setting an overall municipal carbon emission target, but also specific emission targets for industrial, building and transport sectors.
- Most pilot cities have set only a final target for 2020, but Shenzhen has proposed both an intermediate target for 2015 and a final target for 2020. Setting an intermediate target helps link the low carbon plan with city’s 12th Five Year Plan and enables intermediate policy evaluation and adjustment.
- Because linkages between carbon intensity and energy intensity targets in the low carbon plan have not been made clear by the NDRC, only a few pilot cities have set energy-related targets. For example, Tianjin and Xiamen have adopted energy intensity targets, while Chongqing, Nanchang and Shenzhen aim to improve their share of non-fossil fuels in the future. In Shenzhen’s plan, for instance, the share of natural gas, solar PV, biomass and wind energy will be at least 50% and 60% of the total primary energy consumption in Shenzhen in 2015 and 2020, respectively.

Table 5. Comparison of Overall and Sectoral Targets in Pilot Low-Carbon Cities

Target	Tianjin	Baoding	Hangzhou	Chongqing	Nanchang	Guiyang	Xiamen	Shenzhen
Overall targets								
Carbon intensity	×	×	×	×	×	×		×
Carbon emissions		×		×			×	
Energy intensity	×						×	
Non-fossil fuel share				×	×			×
Energy saving				×				
Industrial targets								
Industry emissions							×	
High-tech industry value added share		×	×	×	×			
Service sector value added share			×		×			
Cultural and creative industry value added share			×					
Low carbon industry value added share				×				×
Building targets								
Building emissions							×	
Green buildings share								×
Transport targets								
Transport emissions							×	

Public transport share			×					×
Bus ownership rate			×					
Electric bus share			×					
Metro length			×					
Bicycle lane length								×
The number of new energy cars					×			×
The number of free bicycles			×					
Ecological targets								
Forest coverage rate	×		×	×	×			
Wetland coverage rate	×							
Number of natural reserves	×			×				
Water saving	×			×				
Pollution control	×							
Per capita public green area			×					
Other targets								
R & D investment in low carbon technologies								×
Information dissemination				×				×

The sectoral targets vary significantly among the eight pilot cities. Even though the sectoral targets do not necessarily represent the comprehensive efforts required in each sector, they can nevertheless reflect each municipality's sectoral focus to some degree. In the industrial sector, Baoding, Hangzhou, Chongqing and Nanchang emphasize developing high-tech industry and increasing its value-added share in future; while Chongqing and Shenzhen have set clear targets for low carbon industry development, focusing on the manufacturing of wind, solar photovoltaic and electric and alternative fuel vehicles. In the building sector, Shenzhen is the most ambitious municipality in terms of green buildings, targeting a 40% and 80% share of green buildings by 2015 and 2020, respectively. In the transport sector, Hangzhou and Shenzhen have both been very active in promoting public transport and high efficiency and alternative fuel vehicles by creating a set of transport indicators. For instance, the share of public transport in Hangzhou and Shenzhen are expected to reach 50% and 65%, respectively, by 2020. In the ecological area, Tianjin has devised a comprehensive indicator system to increase its carbon sink. Moreover, Shenzhen has proposed other innovative and relevant targets such as the share of R&D investment in low carbon technologies and public awareness in its low carbon plan.

In general, existing low carbon targets in the low carbon plans of these pilot cities are inadequate and fragmented. No single pilot city has formed a comprehensive indicator system, in part because an explicit definition of low carbon city has not been developed. Besides, the interlinked relationship between carbon mitigation and energy conservation needs to be better highlighted in government policy documents.

2.3.2 Scope

The specific content of municipal low carbon plans and strategies can be summarized and categorized into a total of 76 focus areas within 10 different sectors. The 10 categories include education, dissemination and cooperation, citizen lifestyle, industrial structure adjustment, industrial energy efficiency, clean energy supply, transport, building, circular economy, urban ecology and spatial development and planning. The distribution of the focus areas among the 10 sectors is illustrated in Figure 2.

The greatest diversity in focus areas exists within the sector of “clean energy supply”, which includes focus areas related to clean energy technologies. A relatively large variety of focus areas can also be found in the transport, building and industrial structure adjustment sectors. A similarly broad focus seems to apply to urban ecology. Altogether, the measures and initiatives within these five sectors account for 54 out of the 76 different measures.

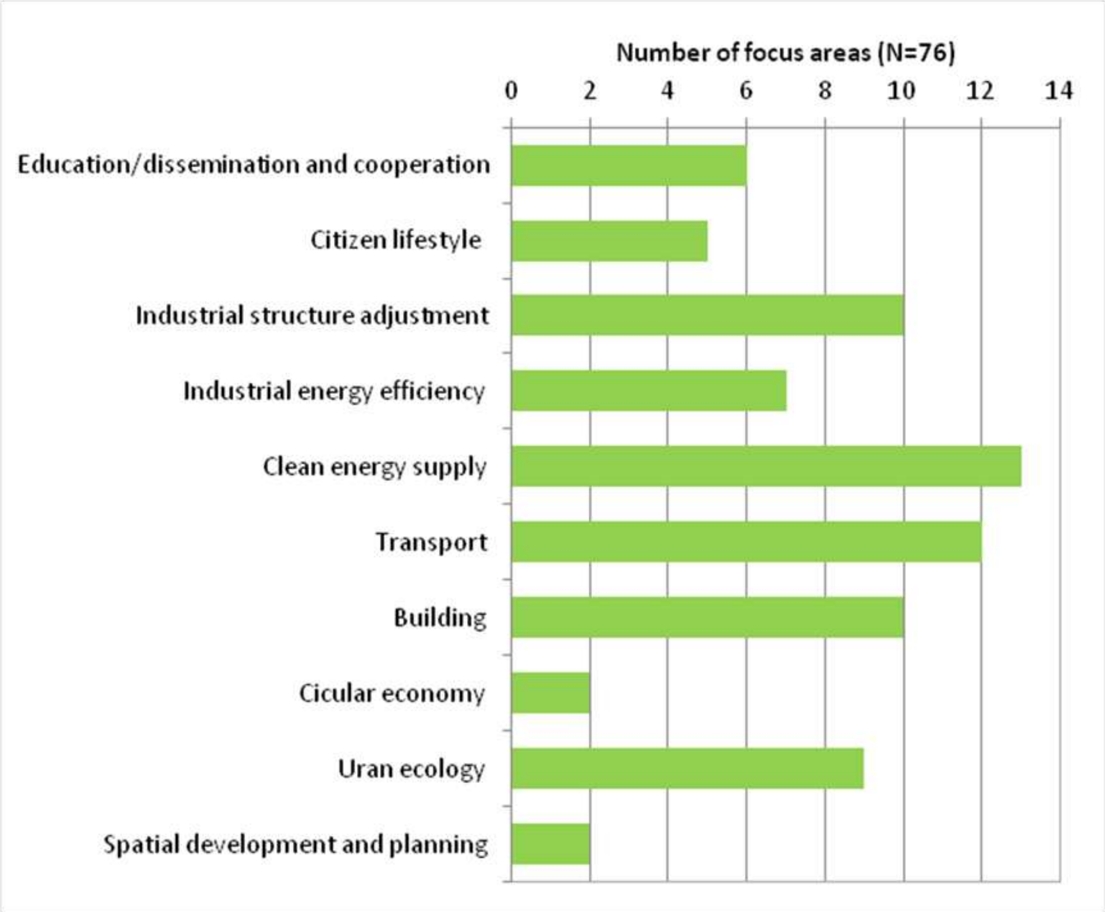


Figure 2. Comparison of Measures in Municipal Low Carbon Strategies

A detailed overview of the focus areas and their distribution can be found in Figure 3. Identifying the most frequently cited measures and strategies in low carbon plans helps shed light on how different local governments perceive and define low carbon development in the absence of national guidance. In terms of industrial structure adjustment, 7 out of 8 municipalities included the development of high-tech and low carbon industries in their plans. Other interests lay in developing modern service and cultural and creative industry sectors. Regarding the clean energy supply sector, biogas and solar PV are the two most popular technological options recognized in low carbon city plans, followed by biomass, geothermal and waste incineration power plants. In addition, there is also increasing awareness and emphasis on utilizing industrial solid waste and preserving forestry carbon sinks. Surprisingly, despite the central government's ardent energy efficiency efforts over the last five year, energy efficiency improvement measures including industrial energy efficiency, fuel economy standards, building labels and building energy conservation standards have received only modest coverage in low carbon city plans, but this may reflect the city's relative inability to affect these programs that are driven by central government policy. The awareness for solid waste and waste water treatment and recycling is also low, and there is a lack of diversified measures for developing a circular economy.

Overall, the scope of existing measures and strategies for low carbon city development is very broad. Most measures and strategies are also still at the infancy stage and lack explicit targets and specific program and implementation mechanisms. Therefore, the effects of these measures and strategies in promoting low carbon city development might be limited and insufficient over the short-term. This suggests that detailed plans focused on renewable energy and energy efficiency and conservation are needed to evaluate and prioritize a multitude of technologies and measures based on their respective contributions to the overall carbon target. Xiamen has exemplified this approach by supplementing its low carbon development plan with separate plans for renewable energy, building energy conservation, underground space development and utilization, urban ecology, green transport as well as low carbon campus.

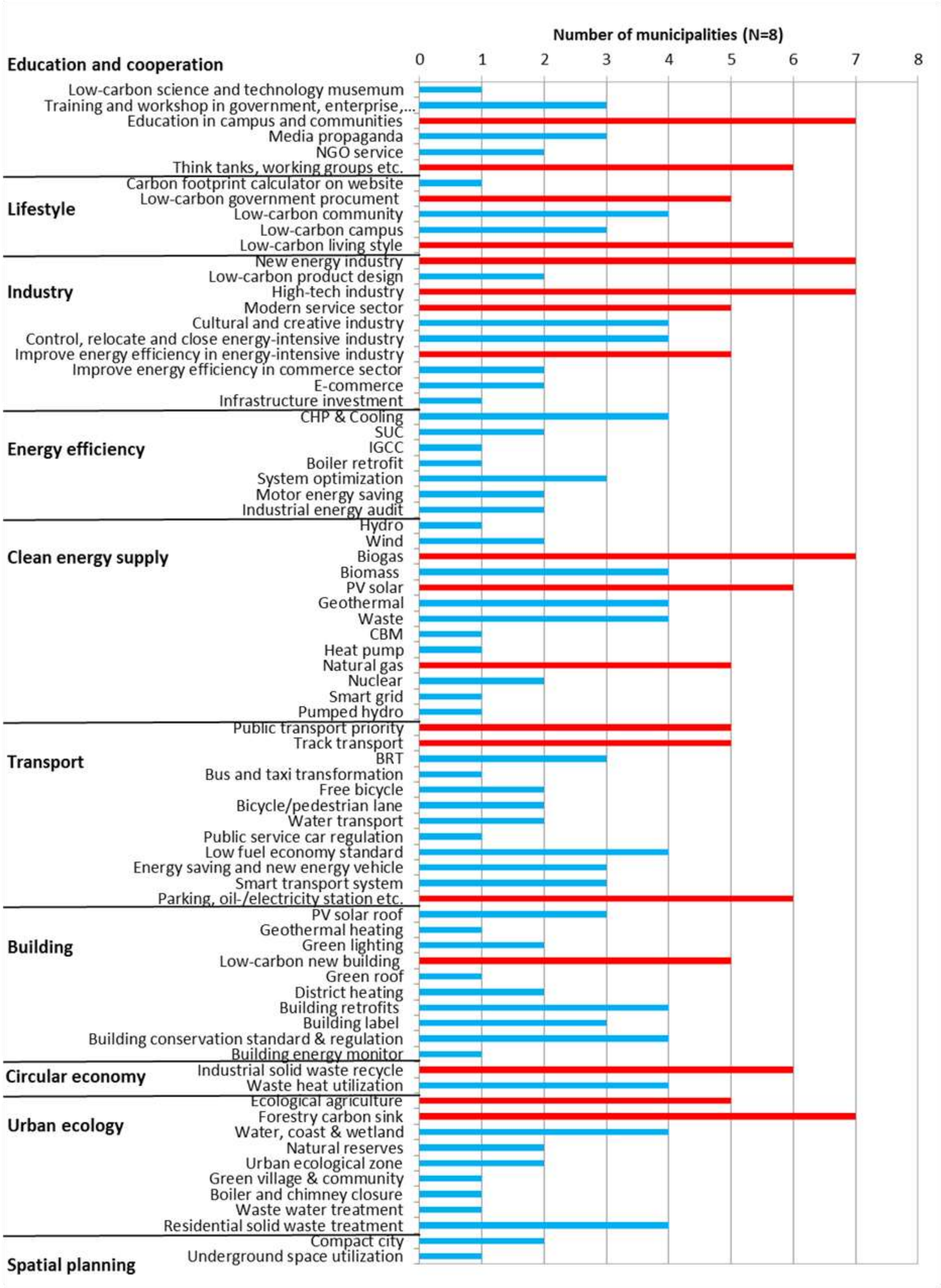


Figure 3. Comparison of Focus Areas Identified in Low Carbon Plans

2.3.3 Case Study: Hangzhou’s Planning and Implementation Procedure

While all eight pilot cities have adopted low carbon city development plans, very few have provided details on the process through which the plan was developed and the framework and processes for implementing the measures and targets in the plan. One exception is the city of Hangzhou, which was one of the earliest cities to propose a low carbon city plan to the NDRC and has already formed a comprehensive top-down framework for low carbon planning and implementation. Hangzhou also provides a good case study of how local government support and actions have supported and promoted the city’s low carbon plan. Information dissemination in Hangzhou is better compared to other pilot cities, since a multitude of relevant plans have already been made public.

Figure 4 shows Hangzhou’s model for low carbon development planning and implementation. It is mainly based on the decision-making process of the Hangzhou municipality government in response to the NDRC’s low carbon pilot city program. However, the model can also represent some common characteristics of other pilot cities.

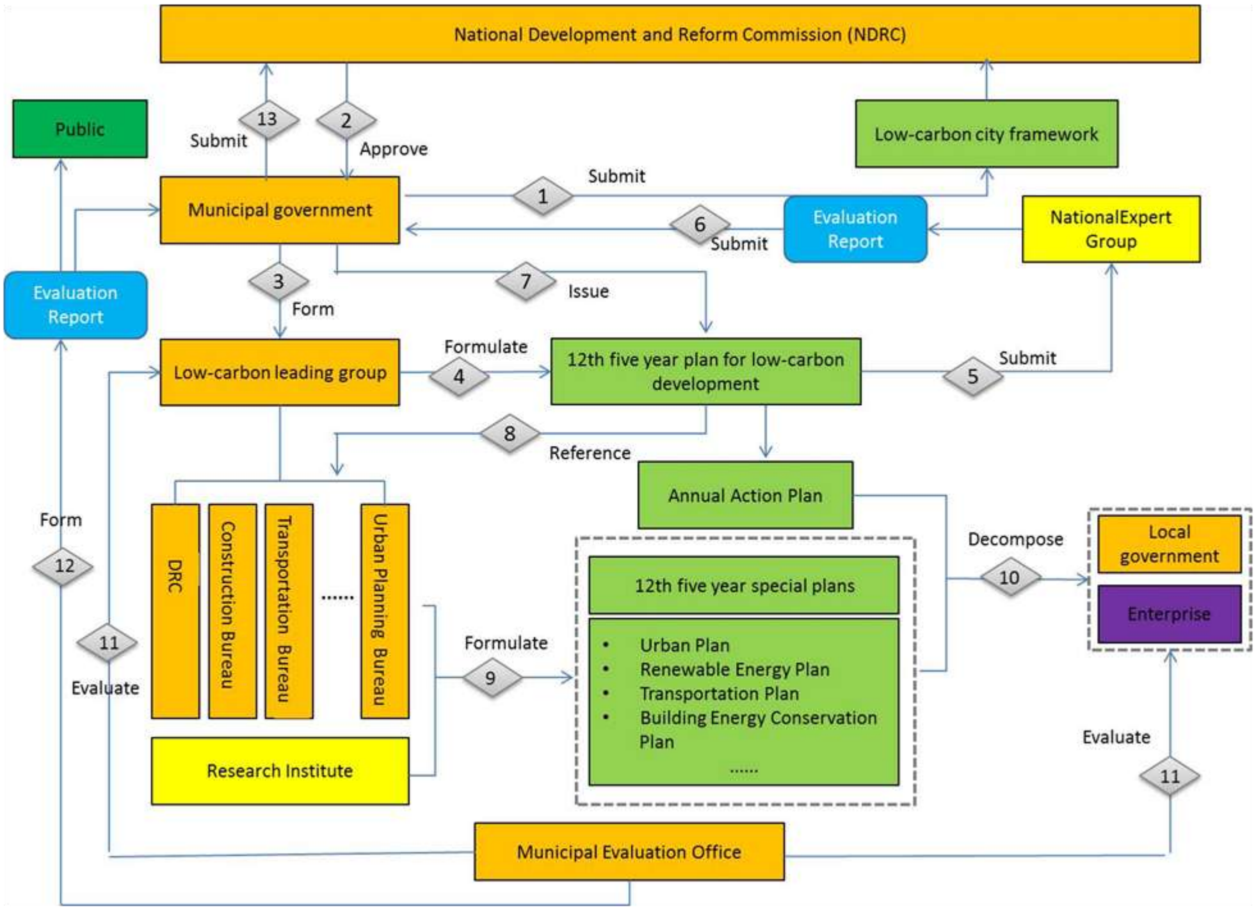


Figure 4. Hangzhou's Model for Low Carbon Planning and Implementation

The low carbon planning process begins first with the municipality government expressing its interest in building a low carbon city to NDRC. NDRC then issued the Notice on Low-carbon Pilot Provinces and Cities on July 19, 2010 and requested each pilot province/city to submit a low carbon plan. Typically, a low carbon advisory group consisting of the mayor and leaders of other relevant departments is established and placed in charge of planning and implementing the low carbon city program. After discussions and negotiations with different stakeholders, a more detailed low carbon plan is compiled and submitted to NDRC for further evaluation. Once the NDRC has approved the city's low carbon plan, the municipal government then issues the low carbon plan to each bureau as guidance for formulating their respective 12th FYP special plans and releases the plan to the public as well. The low carbon advisory group is also responsible for decomposing the overall target and measures of the low carbon plan to the annual action plan. Together with the sectoral 12th FYP special plans, annual targets will then be allocated to lower levels of governments (district, country and local governments) and enterprises. In addition, the municipal evaluation office will evaluate the performance of each level of government and enterprises and submit a report to the municipal government. The evaluation report summary is published online and open to the public for review and oversight. Table 6 shows the timeline of the low carbon city plan in Hangzhou.

Table 6. Regulatory Timeline of Hangzhou's Low Carbon City Plan

Institution	Plan/Action	Date of Issue
State Council	GHG emission control targets set for 2020	November 25, 2009
Hangzhou Municipal Committee	Hangzhou municipal committee and government's views on building low-carbon city is issued	December 29, 2009
Hangzhou Municipal Committee	Advisory group for low-carbon city development	May 25, 2010
National Development and Reform Committee	Notice on Low-carbon Pilot Provinces and Cities	July 19, 2010
Hangzhou Development and Reform Committee **Zhejiang Development and Planning Institute** **Expert Group Review**	Hangzhou's 12th Five year Plan for Low-carbon City Development	July 31, 2010
Leading group for low-carbon city development	Hangzhou's Action plan for Low-carbon City Development in 2011 1) Implement 12th FYP for low-carbon city development 2) Implement 12th FYP for building energy conservation 3) Formulate support regulations for building energy conservation management 4) Implement the 12th FYP for transportation 5) Decompose the municipal emission target to districts, counties and key enterprises 6) Establish the performance evaluation mechanisms 7) Establish emissions data statistic and management system 8) Establish the indicator system for low-carbon city 9) Carbon label pilot project	March, 2011
Hangzhou Development and Reform Committee **Hangzhou Municipal Transportation Bureau**	12th FYP for Transportation	August 28, 2011

Hangzhou Municipal Construction Committee **Hangzhou Urban Planning Bureau**		
Hangzhou Municipal Construction Committee	12th FYP for Building Energy Conservation	November 25, 2011
Hangzhou Municipal Government	Notice on Hangzhou's 12th FYP for Low-carbon City Development	December 14, 2011
Office of Hangzhou Performance Measurement Commission	Annually monitor and evaluate low-carbon plan implementation in related bureaus	Reported online monthly; annual report on the performance evaluation of bureaus. Raw data available when needed.

Hangzhou illustrates a transparent example of a comprehensive planning process that is not representative of other pilot cities. This stems from Hangzhou's strong motivation for further developing its strong tourism and cultural industries and boosting its reputation as one of the most livable cities in China. With the exception of Hangzhou and Xiamen, other pilot cities have not considered adopting sector-specific 12th FYP special plans to complement their low carbon city plans. Furthermore, most of the pilot cities have not gone as far as to decompose the overall targets into specific annual targets and projects for local governments and enterprises. Some pilot cities such as Nanchang and Baoding have set specific programs but not annual targets, which are important in improving the efficiency of project implementation as well as performance evaluation. Third, even though most pilot cities pledged to strengthen oversight and supervision of their low carbon city plan implementation, few have actually appointed a specific institution to take on this responsibility.

2.3.4 Case Study: Baoding's Industrial Park

The Baoding municipality first proposed its plans to develop the China Electricity Valley in 2006. This high-tech industrial park was built to host new energy and energy equipment industries, mainly including wind power equipment, solar photovoltaic, power transmission, storage power, energy saving and power automation. In the first phase from 2006 to 2010, the project planned to invest 5.8 billion RMB for infrastructure and 18 billion RMB for enterprises covering total industrial park area of 13 km^2 (Baoding Municipal Government 2012). In the second phase from 2011 to 2015, total planned investment amounts to 35 billion RMB by 2015 and the scale of the industrial park will reach 30 km^2. The industrial value-added is estimated to reach 17.5

billion RMB by 2010 and 35 billion by 2015. In 2006-2009, the number of new energy enterprises increased from 64 to 170, while the sales revenue grew from 5.75 billion RMB to 24.3 billion RMB (Baoding Municipal Government 2012). New alternative energy and energy equipment manufacturing industry have become the fastest growing industry in Baoding, with 10.6% value-added share of total industries. Baoding, however, credits the emissions reduction potential of the clean energy equipment manufactured in the city—but likely installed elsewhere in China or overseas—as part of its own emissions reductions program. The extent to which other cities have adopted this same accounting standard may help explain the preponderance of this type of "new energy" measures in the full listing of the eight cities' low-carbon plans.

In 2007, the Baoding municipality further issued the regulation of developing a solar city. The goal of this plan is to promote the comprehensive utilization of solar photovoltaic and solar thermal energy. A total of 375 million RMB have been invested in solar application projects for buildings, traffic lights, public parks and tourism zones (Low-Carbon City China Alliance 2012). So far, 102 traffic lights and 700 street lights as well as lighting in most public parks and tourist zones have been replaced by solar energy lighting applications. Furthermore, 36 solar water heater projects provide water heating to 18,000 families with the total solar thermal collector areas of 23,370 m^2.

2.3.5 Supporting measures

Supporting measures are crucial component to the effective implementation of low carbon city plans. These supporting measures can be categorized as administrative, planning and policy, financial and tax-based, market, scientific research and other measures.

Table 7 lists the main supporting measures mentioned in low carbon city plans of the eight pilot cities. It is evident from Table 7 that local governments rely more on administrative, planning and policy measures rather than market-based measures to implement low carbon city plans. All eight municipalities created a low carbon advisory group to plan and implement its low carbon city plans and most have incorporated the plan's targets into the performance evaluation system for government officials. Even though the establishment of GHG emission statistics, verification and management is a prerequisite to the implementation and evaluation of low carbon city plans, there is actually little available information on detailed arrangements for this task, such as the allocation of personnel, funding or task timeline. Similarly, almost all low carbon plans have emphasized the need for relevant supporting plans but most municipal governments have not defined the role for special plans in supporting the low carbon city plan or laid out a process for comprehensive planning and implementation. Xiamen has developed the most comprehensive supporting plans for low carbon city development while Chongqing and Shenzhen are pioneers in regulations. Both Shenzhen and Chongqing issued regulations on building energy conservation prior to finalizing their low carbon city plans, with Chongqing's regulation being published as early as 2007.

The financial and tax measures aimed at promoting the implementation of low carbon programs are generally ambiguous and lack program diversity. Tianjin, Chongqing and Nanchang have committed to establishing special funding for low carbon city development in their plans, but have not released any follow-up documents on the total amount or allocation of the special funding. Hangzhou stated that it will provide financial incentives of 0.5 to 1 million RMB for exemplar government institutions (rather than enterprises) that have applied and successfully chosen to be a national low-carbon industrial park pilot project authorized by the State Council or ministries. This financial incentive will come from special funding of industrial plan but it is unclear how effective this financial incentive will be and if potential financial conflicts exist with other projects in the industrial plan. In addition, the low carbon plan encourages diversifying financial sources for low carbon projects such as asset financing, venture capital/private equity investment, public stock as well as low bank interest rates. Guiyang has promised to lower the consumption tax for low carbon products but there have been no other regulations or preferential policies for ensuring that low carbon projects can enjoy financial and tax benefits.

The establishment of market mechanisms in support of low carbon development is still at the trial stage. In October 2005, carbon trading under the Clean Development Mechanism began in China, administered at the national level by the NDRC. In 2008, several environmental and carbon exchanges were established, including the Tianjin Climate Exchange, China Beijing Environment Exchange and Shanghai Environment and Energy Exchanges. In 2009 to 2010, more environmental and carbon exchanges were created, covering Wuhan, Hangzhou, Kunming, and Guiyang. In August 2010, the NDRC encouraged low carbon pilot provinces and cities to include carbon trading as part of the overall development strategy. In November 2011, China approved pilot carbon trading in seven provinces and cities – Beijing, Chongqing, Guangdong, Hunan, Shanghai, Shenzhen and Tianjin. Some of the pilot regions can start trading as early as 2013 to 2014 and a national trading scheme is expected by 2016. Given that the pilots are all under design and will not be operational for some time, it is impossible to evaluate the contribution of carbon trading to low carbon city development. Moreover, there are no signs that environmental or carbon tax schemes are being considered at the municipal level.

Scientific research, international collaboration and information dissemination are other important aspects of supporting measures in low carbon city plans. Tianjin, Baoding, Chongqing and Nanchang have plans to establish low carbon research centers, while Nanchang and Shenzhen are interested in building low carbon service centers to provide technical support for enterprises. All pilot cities also mentioned strengthening international collaboration in terms of scientific research, technology transfer, and information sharing and financial resources. For example, Tianjin has been collaborating with Singapore to build an eco-city since September 2008, and further established low carbon economic demonstration district through collaboration with Japan in the beginning of 2009. Nanchang has also initiated cooperation projects with the U.S., UK and Austria.

Table 7. Comparison of Main Supporting Measures in Low Carbon City Plans

Measure	Tianjin	Baoding	Hangzhou	Chongqing	Nanchang	Guiyang	Xiamen	Shenzhen
Administrative								
Advisory group	×	×	×	×	×	×	×	×
Performance evaluation system	×	×	×		×			×
GHG emission statistics, verification and management	×	×	×	×	×			
Energy audit and label	×		×	×	×			
Permission threshold							×	
Planning and Policy								
Special planning	×	×	×	×	×	×	×	×
Regulation				×				×
Preferential policy			×	×	×			×
Financial and Tax-Based								
Low-carbon fund	×			×	×			
Financial incentives			×					
Financial sources	×		×	×	×			
Consumption tax						×		
Energy price	×							
Market								
CDM				×	×		×	
Energy and carbon trading market	×		×	×		×	×	×
Industry and technology trading center								×
Scientific research								
Low carbon research center	×	×		×	×			
Low carbon service center					×			×
Talent introduction			×	×	×			
Other								
Information disclosure	×		×	×	×			
International collaboration	×	×	×	×	×	×	×	×
Propaganda	×	×	×	×			×	

2.4 Key Findings

In this section, we reviewed the background, parallel programs and practice of the low carbon city pilot program launched by the NDRC in July of 2010. In evaluating low carbon city plans, an in-depth comparison of the eight pilot cities was conducted in terms of their low carbon city plans' target, scope, planning and implementation procedure and supporting measures. To date, no official assessments of the programs have been conducted by NDRC. Several conclusions can be drawn as follows:

- The absence of explicit definitions for low carbon city and the multitude of parallel programs have created complexity, confusion, and overlaps in the development of low carbon cities. Some cities belong to several pilot programs, and while it might be beneficial to receive technical and financial support through different programs, the overlap of programs has resulted in unclear focus, repetitive planning processes, and ineffective implementation of low carbon development planning.
- There is a need to provide explicit definitions, guidelines and methodologies for municipal low carbon plans from the national level. From the above analysis, we found large divergence among the low carbon plans in terms of targets, scope, content and planning and implementation procedures. Clear definitions, guidelines and methodologies would help provide a much needed comprehensive framework with clear targets and focused scope for low carbon development planning for municipal governments, particularly those that are relatively new to the energy and carbon field.
- The overall targets of the low carbon city plan should include both carbon emission and energy consumption targets, which correspond to 12th FYP and 2020 targets. Besides, the roadmap of the low carbon city plan needs to be formulated and sector-based targets should be decomposed from the overall targets to enable better implementation, performance evaluation and policy adjustment.
- A series of supportive special plans need to be developed under the guidance of the low carbon city plan. The sector targets in the low carbon city plan can serve as the overall target for each special plan, while special projects and measures proposed in the special plan can help ensure effective implementation of low carbon city plan.
- Existing regulations and policies are insufficient for implementing low carbon city plans and more relevant regulations and policies on energy conservation, efficiency, energy audit and monitoring need to be established.
- More market-based, rather than administrative, instruments need to be introduced in order to facilitate greater participation and implementation of the low carbon city plan.
- Third-party surveillance and evaluation of low carbon city plan implementation at the different levels of governments are needed. Public disclosure and information

dissemination should be more consistent and comprehensive, allowing the public to participate and oversee implementation of the low carbon city plan.

3. Recent Developments in China's Coal Industry

3.1 Achievements under 11th Five Year Plan and Remaining Challenges

3.1.1 Achievements during 2006-2010

Under the 11th FYP, the major achievements of the coal industry can be generally categorized into improved coal production productivity, expanded scales of coal mines and enterprises, enhanced resource utilization and conservation and strengthened mining safety.

In terms of improved coal production output and productivity, total coal production increased by 38% from 2005, reaching 3.24 billion metric tons[4] (Bt) of raw coal in 2010. The rate of coal dressing increased from 31.9% in 2005 to 50.9% in 2010, while an overall coal mine mechanization rate of 65% was achieved for the coal industry in 2010.

Another important achievement during 2006-2010 is the concurrent expansion in the formation of large-scale coal bases and large coal enterprises and closure of small inefficient coal mines. The consolidation of the coal production industry—first promoted in the late 1990s—continued under the 11th FYP, with notable changes in the relative share of coal production by mine size. During the 11th FYP, 14 large-scale coal bases produced a total of 2.8 Bt of coal in 2010, accounting for 87% of total coal production. The number of coal enterprises with production capacity of above 100 Mt increased from only 1 in 2005 to a total of 5 in 2010, comprising 25% of total production in 2010. Similarly, the number of coal enterprises with production capacity of at least 50 Mt increased from 3 to 10 between 2005 and 2010, resulting in 19% share of 2010 production. In retiring and phasing out small inefficient mines, a total of 9,616 small coal mines with total production capacity of 540 Mt were phased out during 2006-2010. This led the production share of small coal mines with capacity below 0.3 Mt to decrease from 45% in 2005 to 22% in 2010 (NDRC 2012).

Regarding resource utilization and environmental protection, 11 coal enterprises were selected as pilots under the national eco-industrial circular economy program, which recognizes industrial initiatives that link the chains of resource and energy utilization so waste from one process can be captured and used as raw material input for another process (e.g., combined heat and power projects). Coal-bed methane production and utilization development has also

---

[4] Unless otherwise noted, tons is used to represent metric tons, the equivalent of 1000 kilograms. Mt is shortened for million metrics tons and Bt is shortened for billion metric tons. In reference to coal, Mt generally refers to million metric tons of raw coal unless otherwise specified.

advanced under the 11th FYP with total utilization and production increasing to 3,500 million m^3 and 8,800 million m^3, respectively, in 2010. In addition, the installation of 26 GW of power generation capacity using coal gangue and slimes was completed under the 11th FYP, leading to the successful utilization of 130 Mt of coal gangue and slime equivalents to 42 Mt of standard coal. Additionally, the utilization rate of coal mine water reached 59% and the land reclamation rate reached 40% by 2010 (NDRC 2012).

Finally, there has also been notable progress in raising the overall safety conditions of coal mining and production and reducing employee mortality rates. For example, coal-related accidental deaths decreased by 59% from 2005 to 2,433 deaths in 2010. At the same time, the coal industry's mortality rate (person/Mt output) decreased from 2.81 in 2005 to 0.749 in 2010 (NDRC 2012).

In sum, the Chinese coal industry has continued to address two remaining areas of concern, namely outdated inefficient production and safety challenges. Over the last five years, the industry has followed a development path of increasing productivity and efficiency through production consolidation and economies of scale and accomplished new milestones over the last five years. At the same time, the industry is also expanding its activities in new emerging areas such as coal seam methane (CSM) utilization and comprehensive resource utilization through eco-industrial initiatives while improving the safety and quality of working conditions.

3.1.2 Remaining challenges

The coal industry's progress and development under the 11th FYP period has not been sufficient in resolving some of the severe challenges that remain. As recognized in the 12th FYP, China's current mode of coal resource development and management cannot sustain the country's long-term social and economic development. As the world's largest coal producer, China's coal resource per capita is merely two thirds of the world's average. The reserves-to-production (R/P) ratio of 35 years in China is very low compared to the global ratio of 118 years. From an environmental perspective, current coal resource exploitation and utilization methods are not sustainable due to worsening impacts on water resources, ecology, air pollution in the absence of timely and effective mitigation and treatment options.

In addition, conflicts caused by the spatial mismatch between energy production and consumption, particularly in the case of coal, are increasingly exacerbated and becoming more difficult to ignore. As coal resources in the eastern regions become exhausted over time, production has shifted towards the western regions and soaring demand for transporting coal from the west to the east is creating new challenges for the coal and rail industry. Coal already accounts for 40% of China's railway capacity; the continual production shift towards the west will inevitably add to the already heavily burdened railway system and pose a risk to further environmental degradation in western regions. Third, despite significant improvements in the last five years, China's level of coal productivity and management is still much lower than that of developed countries, which further intensifies resource scarcity and environmental concerns. Likewise, the safety conditions of coal production remain dire; one third of coal mines are awaiting safety retrofits while another third needs to be completely eliminated to prevent major accidents. Last but not least, there is an absence of efficient industrial management and clear administrative functions, which results in disorganized and inefficient resource exploitation.

3.2 Review of 12th Five Year Plan for Coal Industry

3.2.1 Context of National 12th FYP for Development

As the world's top energy consumer and energy-related CO_2 emitter, China is confronting challenges of sustainable economic development, environmental health, energy security and greenhouse gas mitigation with increasing international and domestic pressure. In its development planning, the Chinese government is placing greater emphasis on scientific research and development related to energy, the environment and sustainability. On March 14, 2011, China's National People's Congress approved the 12th FYP for National Economic and Social Development for 2011 to 2015, which provides overall objectives and goals related to social and economic growth and industrial planning in key sectors and regions. The overarching goal of the plan is to address rising income inequality and create an environment for more sustainable growth by prioritizing more equitable wealth distribution, increased domestic consumption, and improved social infrastructure and social safety nets. Specifically, the 12th FYP emphasizes "higher quality growth" with a lower annual GDP target of 7% aimed at the development of seven priority industries, including new and alternative energy, energy conservation and environmental protection, biotechnology, new materials, new information technology, high-end equipment manufacturing and clean energy vehicles (KPMG 2011).

Regarding energy and environmental issues, the plan calls for 16% reduction in energy intensity per unit of GDP and 17% reduction in CO_2 emissions per unit of GDP by 2015, compared to 2010. This target is consistent with China's target of reducing carbon intensity by 40-45% by 2020, relative to 2005 levels. The 12th FYP also reflects China's pledge to have 15% of its primary energy consumption derived from non-fossil fuels by 2020, with an intermediate non-fossil share target of 11.4% by 2015. Furthermore, the plan includes a domestic coal production cap and significant support for other forms of alternative energy such as nuclear, hydropower and wind, in order to mitigate energy-related CO_2 emissions and transform the current coal-dominated energy mix. In conjunction with the 12th FYP for national economic and social development, China released for the first time the 12th FYP for Environmental Protection, under which local government officials will be held accountable for meeting green indicators such as water consumption per unit of GDP and proportion of GDP invested in environmental protection.

3.2.2 12th Five Year Plan for Coal Industry

The coal industry will play a critical role in helping China achieve its energy and carbon targets for the 12th FYP period and for 2020. Under the umbrella of the 12th FYP for national economic and social development, the National Development and Reform Commission officially released the 12th FYP for Development of the Coal Industry on March 22, 2012. This coal industry-specific plan first summarizes the industry's ten key areas of achievements during the 11th FYP period from 2006 to 2010. It then sets targets on coal production, capacity expansion, enterprise development, technology improvement, safety, comprehensive resource utilization, ecological and environmental protection, resource conservation, inter-provincial transportation.

- **Coal production cap**: coal production capacity should reach 4.1 Bt of coal per year by 2015, and total coal production and consumption should be controlled at 3.9 Bt of coal, or 20.4% higher than the total coal production in 2010.
- **Industry consolidation**: the development of large-scale coal bases and large coal enterprises are promoted alongside the continual retirement and closure of small inefficient mines. The total number of coal mine enterprises should not exceed 4000 and an average annual production capacity of 1 million metric tons (Mt) of coal should be reached through mergers and acquisitions. The top 20 coal enterprises (with annual production capacity of above 50 Mt) will produce 60% of the national coal production.
- **Technology improvement:** the dressing rate of raw coal will increase from 50.9% in 2010 to 65% by 2015; the national average mechanization rate will improve from 65% in 2010 to 75% by 2015; open-pit coal mines will reach a total of 60 mines with annual production capacity of 0.8 Bt ; safe and high efficiency coal mines will reach 800 mines and produce 64% of total coal production.
- **Improve safety in coal production:** the number of accidental deaths and major accidents will decrease by at least 12.5% and 15%, respectively, in 2015 compared to the 2010 level; the mortality rate per Mt ton of coal produced will decrease by at least 28% by 2015.
- **Comprehensive resource utilization and conservation:** newly increased reserves of coal seam methane[5] (CSM) will reach 1 trillion m^3; CSM production is expected to reach 30

---

[5] Coal seam methane is defined as coal mine methane and coal bed methane. Because coal mine methane and coal bed methane are not always clearly distinguished in Chinese usage, coal seam methane is used to generally refer to both unless otherwise specified. More details on coal seam methane in China can be found in section 4.5.

billion m^3 with the utilization rate[6] increasing from 39% in 2010 to 81% by 2015; the installed capacity of CSM power generation will exceed 2.85 GW; the installed capacity of comprehensive power plants for coal gangue and slimes will reach 76 GW; the utilization rate of coal gangue and coal mine water will reach 75%.

- **Ecological and environmental protection:** land reclamation rate will increase from 40% in 2010 to 60% by 2015; coalfield fire treatment will be completed by 2015 and emissions of major pollutants will not exceed environmental standards.
- **Regional production shift:** the western region will become the focus area of coal production in the next five years, accounting for 53% of national coal production by 2015, while the eastern and central regions will have respective shares of 12% and 35%.
- **Inter-provincial coal transport:** total net inter-provincial coal transport is estimated to reach 1.66 Bt of coal by 2015. Shanxi, Shaanxi, Inner Mongolia, Gansu and Ningxia will contribute total provincial exports of 1.58 Bt, mainly transported to eastern regions including Beijing, Tianjin, Hebei, central south and the northeast areas. Coal demand for rail transport is expected to reach 2.6 Bt and coal railway transport capacity will likely reach 3 Bt per year.

Table 8 summarizes specific targets set in the 12th FYP for the coal industry compared to the level achieved in the previous ten years.

Table 8. Major Targets in the 12th FYP for Coal Industry

Target	2005	2010	2015
Coal production (Bt)	2.35	3.24	3.9
Raw coal dressing rate	31.9%	50.9%	65%
Total number of large coal mines (≥50Mt)	100 Mt: 1 50 Mt: 3	100 Mt: 5 50 Mt: 10	100 Mt: 10 50 Mt: 10
Production share of large coal mines (≥50Mt)	14%	44%	60%
Production share of open pit mines	5%	10%	60 mines 800 Mt/yr
Number of safe and efficient mines	197	359 mines 1,020 Mt/yr	800 mines 2,500 Mt/yr
Mechanization rate	-	65%	75%
Installed capacity of comprehensive power generation plants for coal gangue and slimes (GW)	9.57	26	75
Utilized coal gangue and slimes (Mt)	29	130 (saving 40 Mtce)	610 (saving 95 Mtce)

---

[6] Utilization rate refers to the proportion of total CSM that is recovered and used as an energy source. The remaining portion of CSM (i.e., non-utilized CSM) is typically vented into the atmosphere due to lack of recovery.

Utilization rate of coal gangue	-	61%	75%
CSM production (million m^3)	2,300	8,800 surface: 1450 underground: 7350	30,000 surface: 16000 underground: 14000
CSM utilization (million m^3)	1,000	3,500	24,400
Utilization rate of CSM	43%	39%	81%
Mine water production (million m^3)	4,500	-	7,092
Mine water utilization (million m^3)	2,000	-	5,400
Utilization rate of mine water	44%	59%	75%
Land reclamation rate	-	40%	60%
Accident deaths	5,938	2,433	2,129
Mortality rate (person·Mt^{-1})	2.53	0.75	0.54

Source: NDRC, 2012, 12th Five-Year Plan for Coal Industry Development.

3.3 International Context of Chinese Coal Industry

As a coal-intensive economy, China is and has remained highly dependent on coal as a primary source of energy, especially when compared to other large economies in the world. Figure 5 shows that while coal comprised of 70% of China’s total primary energy consumption in 2010, coal only accounted for 23% of primary energy consumption in the U.S. (second-largest coal consumer) and 53% in India (third-largest coal consumer).

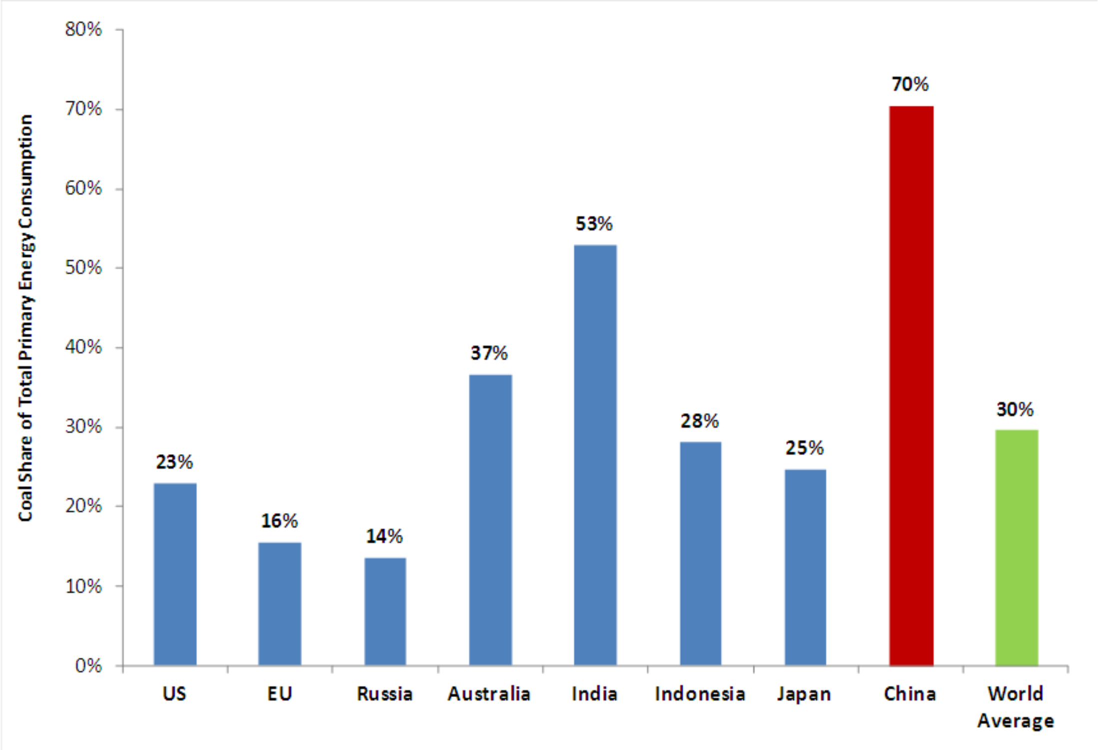


Figure 5. 2010 Coal Share of Total Primary Energy Consumption for Selected Countries
Source: IEA 2012. Coal Information 2011.

China's high coal dependency and soaring coal consumption has resulted in growing imports from overseas, with net imports accounting for 5% of total coal consumption in 2010. As shown in Figure 6, China's dependence on coal imports is relatively low given its substantial coal resources when compared to other leading coal consumers. India's coal import dependence is three times greater than China, while Japan's coal consumption is 100% import dependent in the absence of any domestic coal resources. In contrast, the major regional exporters Indonesia and Australia consume little coal compared to their export volumes.

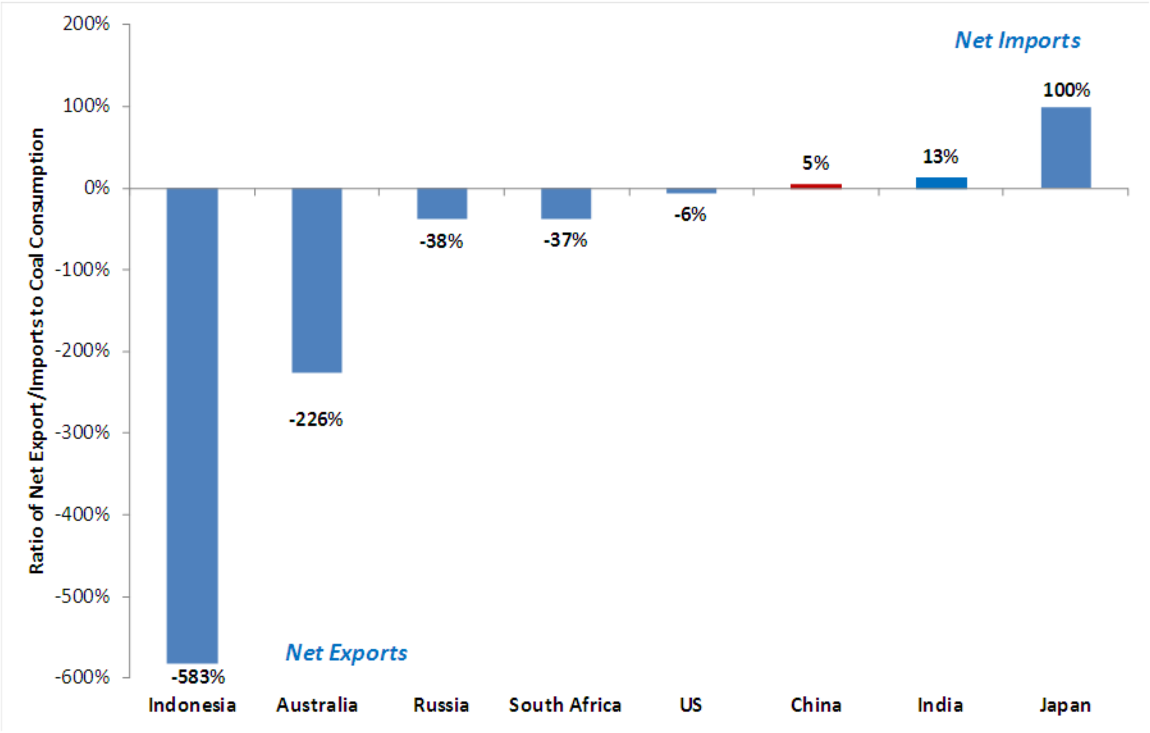


Figure 6. 2010 Ratio of Net Export/Import to Coal Consumption for Selected Countries
Source: IEA 2012. Coal Information 2011.

Figure 7 highlights Indonesia's and Australia's role as major commodity exporters, with their net exports accounting for 85% and 71%, respectively, of their domestic production. However, this role may begin to shift in the near future and could potentially impact global coal supplies and coal trade flows. With oil and gas production falling or stagnant, Indonesia is turning to coal for power generation, so domestic demand may eat into Indonesia's exportable surplus. At the same time, Australia's environmental concerns with coal mining and its contribution to global emissions may limit future production increases. These trends are explored further in section 6.2.2.

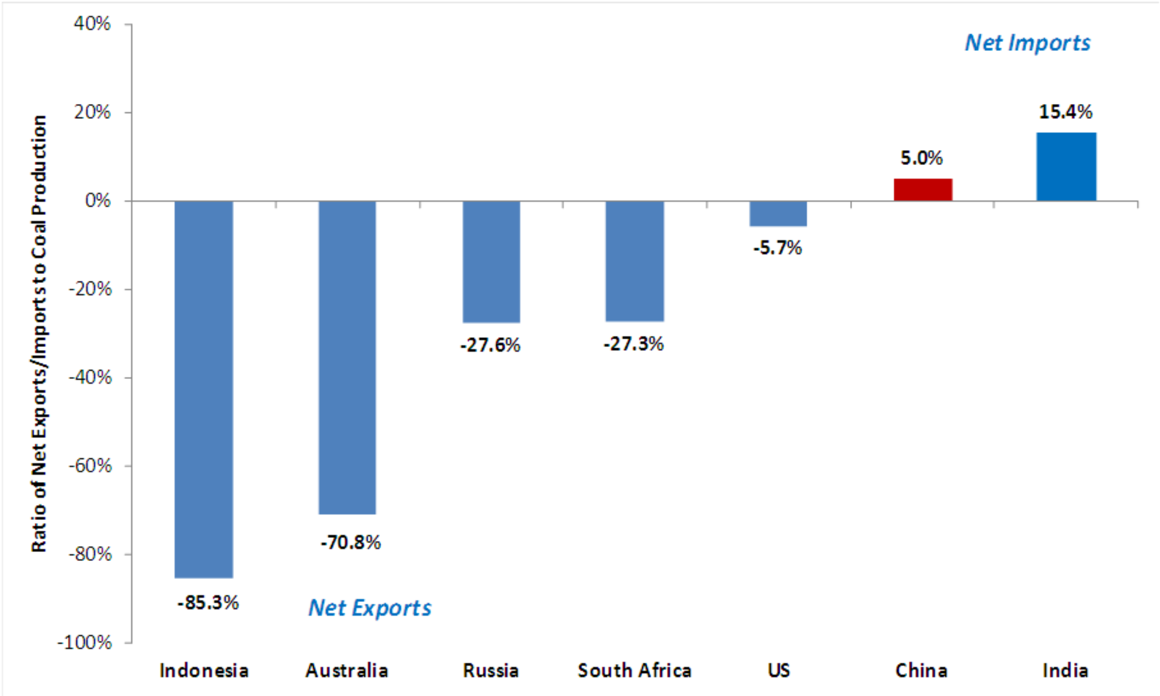


Figure 7. 2010 Ratio for Net Export/Import to Coal Production for Selected Countries
Source: IEA 2012. Coal Information 2011.

4. Coal Production Trends in China

As suggested by the high proportion of coal in total primary energy consumption compared to other countries, coal has consistently dominated primary energy production in China. Despite increasing government and policy focus on low carbon fuel sources and renewable energy sources, coal remains by far the largest energy source for China. Over the last thirty years, coal's share of total primary energy production has continued to rise, from a low of 69% in 1980 to 73% in 2000 and most recently to 77% in 2010 (Figure 8). In absolute terms, Chinese coal production tripled from 771 million metric tons of coal equivalent (Mtce[7]) in 1990 to 2271 Mtce in 2010 with an annual average growth rate of 5.6%.

---

[7] Mtce, or million metric tons of coal equivalent, is the standard energy unit used in Chinese statistics. 1 Mtce = 29.27 million GJ.

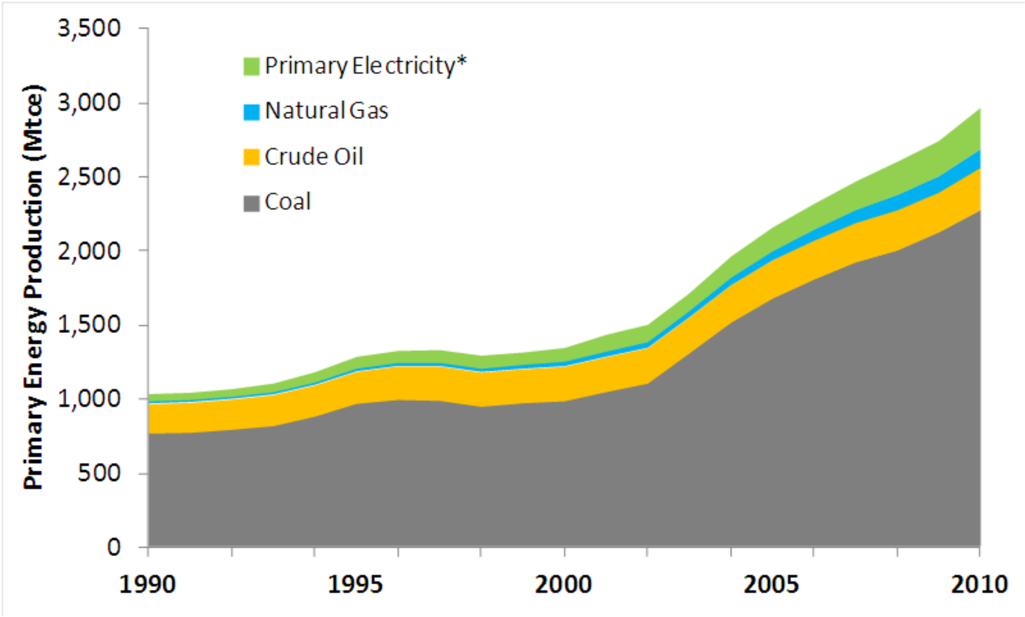


Figure 8. China's Primary Energy Production by Fuel Source, 1990 to 2010

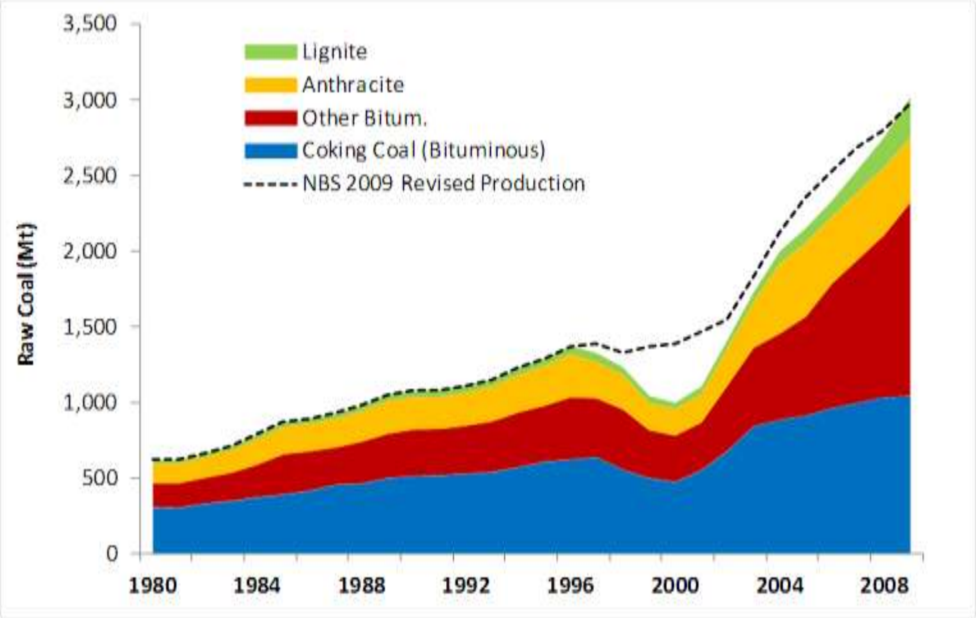
*Note: Primary electricity includes nuclear, hydropower, wind, solar and other renewable expressed at calorific equivalent for conversion. 1 Mtce = 29.27 million GJ.

Source: China Statistical Yearbook 2011.

This section provides a closer look at different characteristics and trends in China's coal mining industry to better understand the underlying factors enabling coal production growth over the last few decades. Specifically, four specific areas are evaluated in terms of recent trends in coal production: type of coal produced, mine ownership, mine size, and geographic and spatial distribution. In addition, an overview of coal-related production of coal-bed and coal mine methane is provided to highlight the widening scope and emerging areas in Chinese coal production.

4.1 Raw Coal Production by Coal Type

Prior to 2005, China had focused its coal mining efforts in maximizing the extraction and production of high-quality bituminous coal alongside rising production volume of all types of coal. During this period, each coal type's relative share of total coal production remained relatively constant with nearly half from coking (bituminous) coal, a quarter from other bituminous coal (primarily steam coal for power generation) and the remaining quarter from anthracite and lignite coal. After 2005, however, notable changes emerged in the composition of coal types produced, characterized by a rapid increase in low-quality lignite production and declining output of high-quality anthracite, as seen in both the total production and relative shares of coal production by coal type, as illustrated in the two following figures.



Source: China Coal Industry Yearbooks, various years. 2009 China Energy Statistical Yearbook.

Figure 9. Raw Coal Production by Coal Type, 1980 – 2009[8]

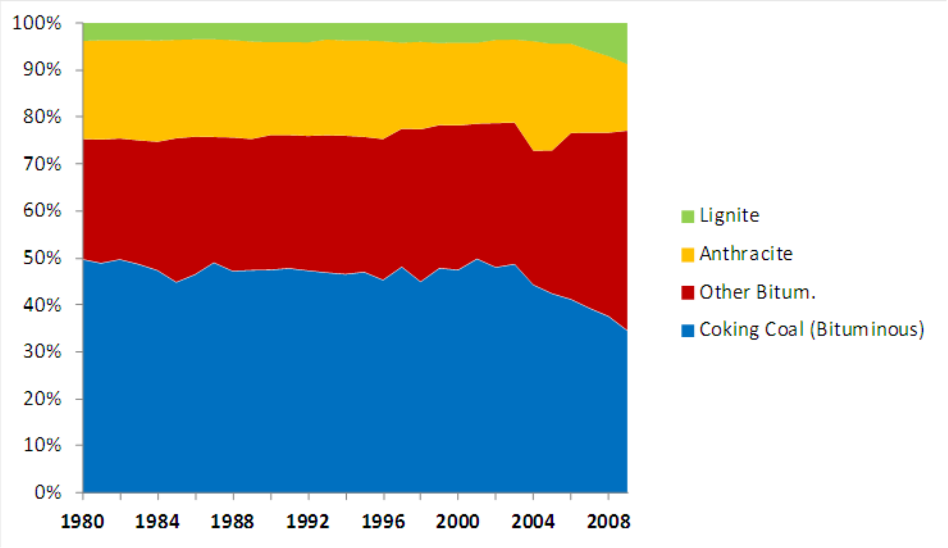


Figure 10. Shares of Coal Production by Coal Type

---

[8] Data on coal production by coal type is collected and published by the coal industry. In 2004, and again in 2008, China's National Bureau of Statistics extensively revised historical coal production and consumption figures back to 1996, but these revisions to coal production totals have not been reflected in revisions to the data on coal production by type published by the coal industry.

Figure 9 illustrates the slowing growth in coking coal production after 2005, despite accelerating growth in the output of other bituminous coal for power and industrial use. As a result, , the relative share of coking coal has continued to decline from half of total production to only 35% in 2009 while the share of other bituminous coal has increased from 30% to 42% in 2009 (Figure 10). Bituminous coal in total, however, has remained at about 75% of total production.

The decline in domestic production of coking coal can be linked to the relative scarcity of the resource base in China and insatiable growth in demand from rapidly growing iron and steel production. Only one-quarter of China's total coal resources is coking coal, the bulk of which is located in western Shanxi province. Because coking coal is a critical input to iron and steel manufacturing, China's recent rapid industrialization and growth of iron and steel production capacity has accelerated depletion of coking coal resources.

Another notable production trend is the decline in higher quality bituminous and anthracite coal and rise in low quality lignite coal. As the coal type with the lowest energy content, lignite production volume remained negligible throughout the 1980s, 1990s and early 2000s. Over the last few years, however, lignite coal production volume has ramped up significantly while anthracite production volume has declined. Total lignite production grew at an annual average rate of 22% from 98 Mt in 2005 to 266 Mt in 2009, while anthracite production fell from 487 Mt to 426 Mt during the same period. As a result, lignite share of total coal production reached an all-time high of 9% in 2009 as anthracite production reached an all-time low of 14%.

These new trends in coal production by coal types shed light on one possible factor driving total production: the declining production of high quality coal and subsequent rise in production of more low quality coal implies that greater volumes of coal are needed to provide the coal supply to meet the same energy demand.

4.2 Coal Production by Mine Ownership

Over the last ten years, changes in coal production by mine ownership have demonstrated the changing trends in the structure of the coal mining industry. From the late 1990s to early 2000, government reform of the coal mining industry sought to rein in the uncontrolled growth of small collectively-owned and private mines that had marked the mid-1990s. The unregulated growth of these collective and private mines, often township and village-owned and operated, not only forced centrally administered and state-owned mines to operate far below designed capacities but also resulted in massive resource waste, environmental degradation, high accident and mortality incidences and supply-demand imbalance from 1992 to 1997 (Shen et al. 2012). Thus, the 1998 reforms led to widespread closures of small individually licensed mines and illegal mines, with 58,000 small coal mines shut from 1998 to 2001. As reported at the time, these closures resulted in a sharp absolute decline in reported production from collective and private mines between 1998 and 2002 as shown in Figure 11 and Figure 12. However, as seen in Figure 11, the extensive revisions to total national coal production data in 2008, as reported by the National Bureau of Statistics in 2009, suggests, as was suspected at the time, that many of the officially closed mines continued to produce but failed to report their production.

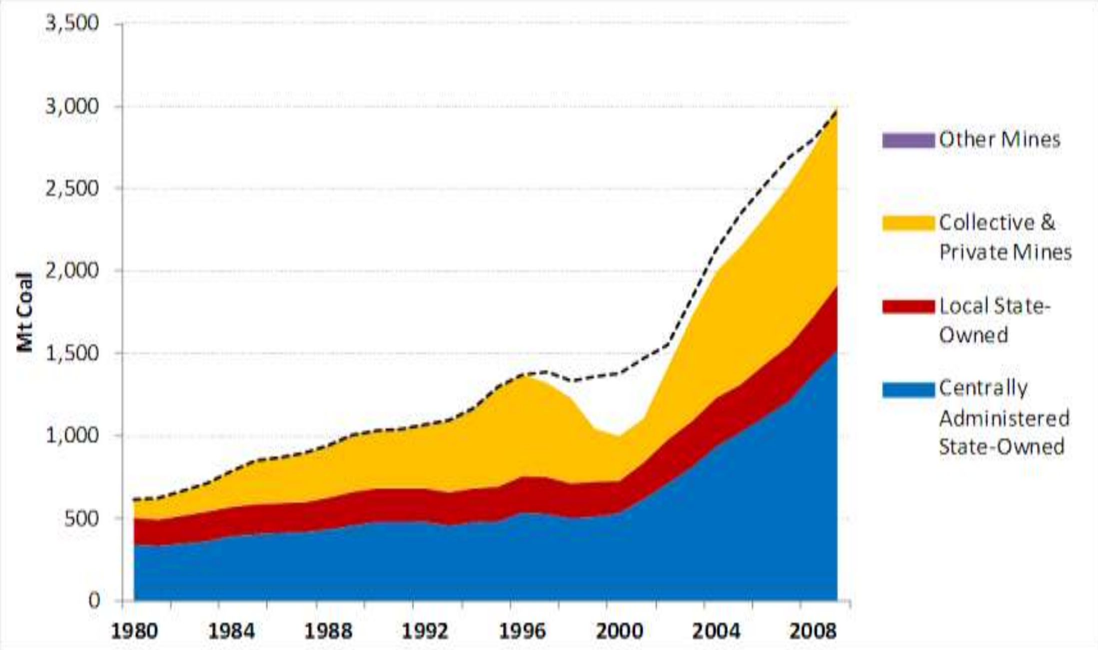


Figure 11. Coal Production by Mine Ownership, 1980 - 2009

Note: dotted line shows 2009 revised NBS production values.
Source: China Coal Industry Yearbooks, various years. 2009 China Energy Statistical Yearbook.

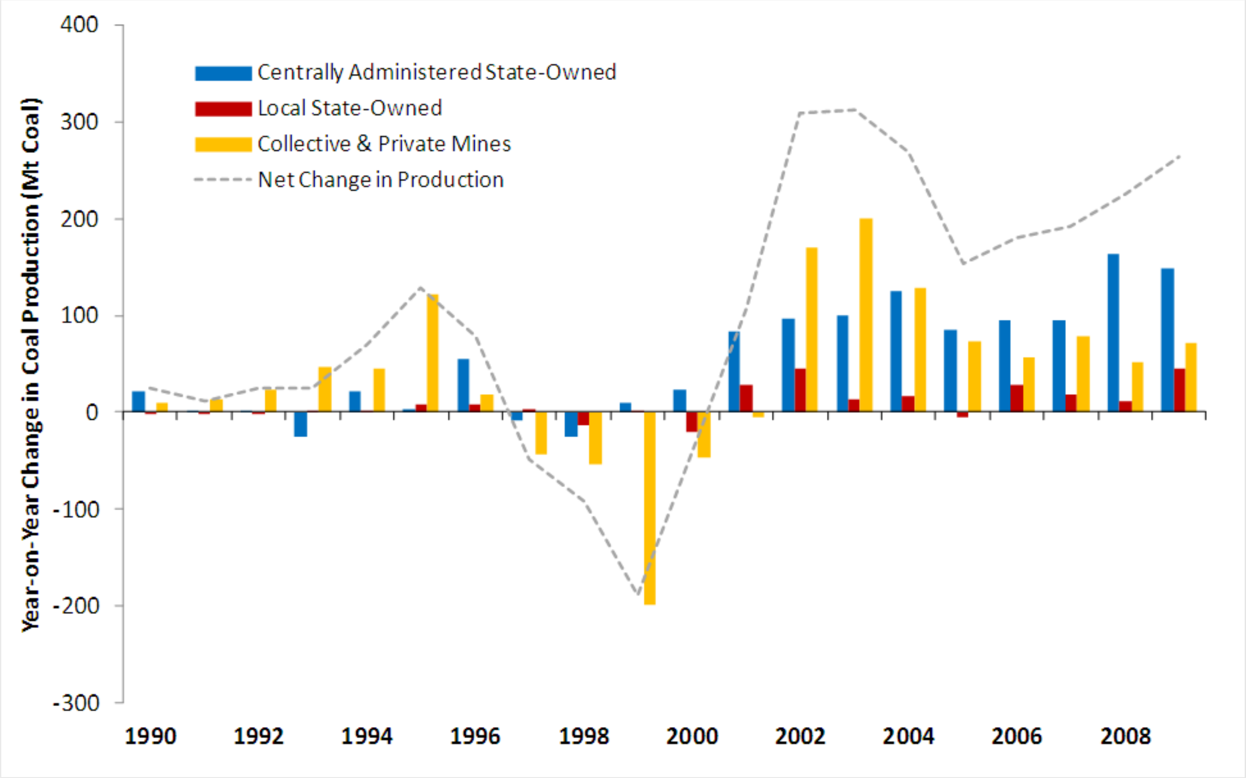


Figure 12. Incremental Change in Coal Production by Mine Ownership Type, 1990 to 2009

In 2002, as coal production by centrally administered state-owned mines returned to expansion in light of the 1998 regulatory reforms, changes in economic conditions led to a resurgence of coal production by collective and private mines. Specifically, the 2002 and 2003 world economic recessions coupled with severe power shortages and engendered by a sense of complacency in the need to expand power generation capacity led to growing concerns about energy shortages (Shen et al. 2012). The central government in turn began emphasizing national energy supply security, with the domestic coal industry as a target supply industry. As a result, many officially closed mines returned to production and production reporting, and output from these collective and private mines provided the largest increment in coal supply from 2002 to 2004.

From 2005 to present, renewed and strengthened policy emphasis on restructuring the domestic coal industry in order to compete internationally with a small group of powerful international mining mega-corporations have led to production changes similar to those from 1998 to 2002. As seen in the 11th and more recently the 12th FYP, the closure of small, inefficient local coal mines that are inefficiently managed, insufficiently invested, poorly equipped and operated without necessary safety precautions has been a major theme and overarching development goal for the coal industry (Shen et al. 2012). Concurrently, the central government has actively promoted the consolidation, merger and collaboration of coal mining enterprises across different sectors, different regions and counties with plans to build large coal bases, gigantic and large coal mine groups. Against this policy backdrop, growth in coal production over the last few years have primarily been driven by centrally administered state-owned mines with collective and private mines once again playing a secondary role

4.3 Coal Production by Mine Size

As reflected in the changing coal mine ownership trends, coal production is increasingly shifting away from small mines and towards larger mines as a result of the government-mandated coal industry restructuring and consolidation. Specifically, in the 11th FYP, production targets by coal mine size were set for 2010 with 56% of production targeted to be from large mines, 17% from medium mines and 27% from small mines (Shen et al. 2012). Shifting coal production away from small mines represented significant gains in economies of scale, as the recovery rate of poorly operated coal mines were only 10 to 20% compared to average rates of 50 to 70% for medium and large mines. In fact, overproduction from small local coal mines caused losses of more than 4 Bt of coal reserves on an annual basis (Shen et al. 2012). The policy emphasis on increasing production from large mines also reflected the government's strategic encouragement of the formation of large mining groups capable of comprehensive management of coal, power, chemical, and railway and port transportation.

This policy-driven shift away from small mines can be seen in subsequent coal production shares in 2006, 2008 and 2009 in Figure 13. Production from the smallest mines with capacity of less than 30,000 tons per year dramatically decreased from 20% in 2003 to only 2% in 2008. Similarly, the total share of small mines (including the smallest mines) continued to decrease from 48% in 2003 to 44% in 2006 to only 35% in 2008 and 29% in 2009. By 2010, the share of coal production from small mines was further lowered to only 22%, below the original 11th FYP target of 27% (NDRC 2012). At the same time, the share of coal production from large mines increased by 10 percentage points from 2003 to 2009, rising from 38% in 2003 to nearly half of total production by 2009. Coal production from medium mines has stayed relatively constant, accounting for less than one-fifth of total production.

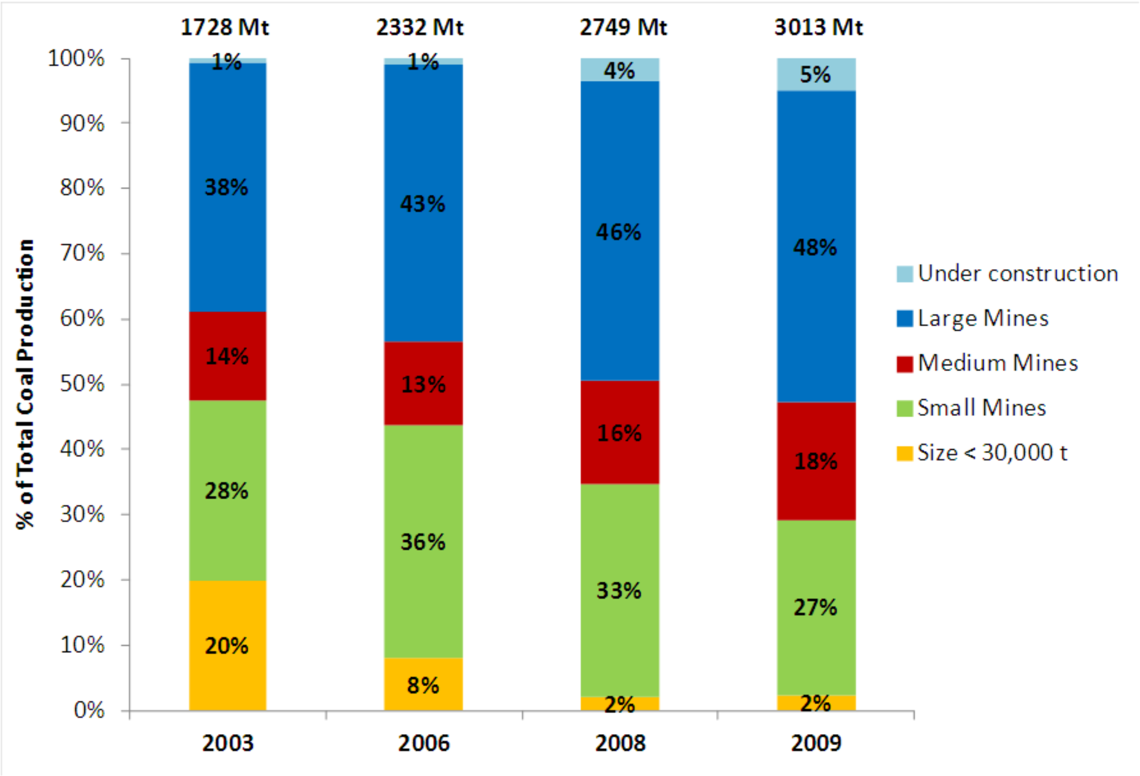


Figure 13. Coal Production by Mine Size for Selected Years

4.4 Coal Production by Geographic Region

The evolution of the spatial distribution of coal production in China over the last twenty years has followed a progressive shift towards greater production in the western region, where the vast majority of coal resources are located. This has meant shifting production away from the coal consumption centers of middle China and the eastern coastal region, which accounts for a majority of national coal consumption but very limited coal resources and production. Between 1995 and 2005, the relative shares of coal production in Eastern and Middle China both declined from 29% to 22% and 44% to 42%, respectively, while the share of production in Western China jumped from 28% to 36%. In absolute terms, Figure 14 shows coal production in Western China more than doubled while production in Middle China increased by a factor of 1.5 and Eastern China increased by a factor of only 1.2 during the same period.

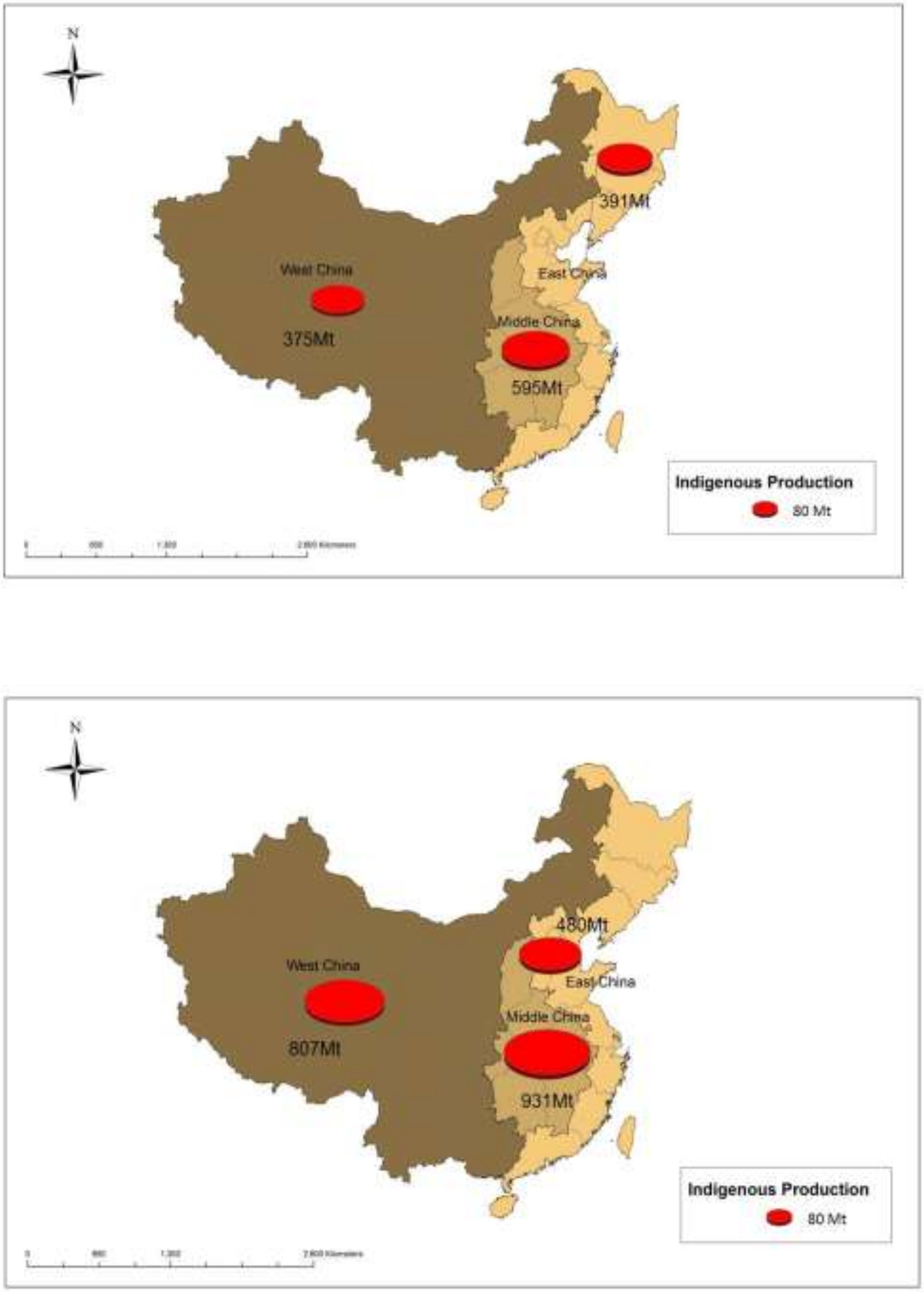


Figure 14. Coal Production by Geographic Region in 1995 (top) and 2005 (bottom)

Table 9 shows the provincial breakdown of regional coal production for 1995 and 2005. Within the Eastern China region, coal production has and will continue to be concentrated in the provinces of Shandong, Liaoning, Heilongjiang, and Hebei, which together accounts for 80% of the region's coal production. For the 12th FYP period, coal mining surveys will focus on deep and peripheral surveys in these four provinces as well as in Jilin and Fujian. Coal production in Middle China is dominated by the two provinces of Shanxi and Henan, which account for more than three-quarters of regional coal production. As the major coal production bases of the region, Shanxi and Henan will also be the focus of supplementary mining surveys to be conducted for the 12th FYP period along with new surveys in Anhui province. In addition, the 12th FYP also calls for focus on construction of coal mines with production capacity of greater than 3 Mt/year in Shanxi and capacity of greater than 1.6 Mt/year in Henan and Anhui (NDRC 2012). In Western China, Inner Mongolia (now China's largest coal producer) and Shaanxi – which accounts for nearly 70% of total proven coal reserves along with Shanxi province - have been the two fastest growing coal producers with annual average growth rates of 14% between 1995 and 2005. Inner Mongolia and Shaanxi, as well as Shanxi, is also home to China's richest and highest quality coal with high calorific value and low sulfur and ash content (Peng 2011). The production growth in these two western provinces will continue under the 12th FYP period with planned efforts to build new coal mines with capacity above 3 Mt/year in these provinces, as well as in Ningxia and Gansu.

Table 9. Actual and Target Coal Production by Region and Province

Unit: Mt Coal	1995 Actual	2005 Actual	2015 Target
Eastern China	**391**	**480**	**460**
Beijing	10	9	
Fujian	11	20	
Guangdong	11	5	
Hainan	0		
Hebei	81	86	
Heilongjiang	79	97	
Jiangsu	26	28	
Jilin	26	27	
Liaoning	56	66	
Shandong	88	140	
Zhejiang	1	0	
Middle China	**595**	**931**	**1350**
Anhui	44	86	
Henan	103	188	
Hubei	15	8	
Hunan	56	69	
Jiangxi	29	26	
Shanxi	347	554	
Western China	**375**	**807**	**2090**
Chongqing		34	
Gansu	25	36	
Guangxi	14	7	
Guizhou	55	106	
Inner Mongolia	71	256	
Ningxia	15	27	
Qinghai	3	6	
Shaanxi	42	152	
Sichuan	96	79	
Xinjiang	27	39	
Yunnan	28	65	
National Total	**1361**	**2218**	**3900**

Source: actual data from China Energy Statistical Yearbook, 2015 targets from NDRC 2012.

This strategy of shifting coal production westwards will continue as NDRC's 12th FYP regional production targets for 2015 signify even more dramatic changes in spatial distribution. From 2005 to 2015, coal production in the west is expected to increase by 259% while production in middle China increases at a slightly slower rate of 145%. The notable difference from previous trends is that production in eastern China should actually decline by 2015, dropping from 2005 level of 480 Mt to 460 Mt. Similarly, Table 10 shows that the Eastern and Middle China's relative shares of new coal mining construction are also expected to decrease during the 12th FYP, while western construction increases dramatically to account for 87% of total new construction by 2015. These regional production targets, as well as the different proposed targets of new coal mine construction for each region, illustrate the government's three-pronged geographic approach to coal development: controlling development in the east, promoting steady development in the middle region and accelerating coal development rapidly in the west.

Table 10. Coal Mining Construction Trends and Targets by Geographic Region

	East China		**Middle China**		**West China**	
	New Capacity	***% of Total***	***New Capacity***	***% of Total***	***New Capacity***	***% of Total***
11th FYP New Construction	20 Mt/year	6%	110 Mt/year	31%	230 Mt/year	63%
12th FYP New Construction Target	25 Mt/year	3%	185 Mt/year	25%	530 Mt/year	87%

Source: NDRC 2012.

While this geographic shift in coal production is in line with the spatial concentration of coal resources within China, the new spatial distribution of coal mining and production nevertheless have important implications for coal transportation issues discussed in a later section.

4.5 Emerging Coal Production Area: Coal Seam Methane

In addition to the changing trends of direct coal production in China, a new area related to coal production is the recovery and use of coal seam methane (CSM) to supplement natural gas resources. CSM methane includes, among others, two major categories of production defined by production process and methane quality. In China, the most prevalent type of CSM is Coal Mine Methane (CMM), which refers to methane drained from active mines (primarily for safety reasons) with methane concentrations of 25% to 60%. Less developed in China is Coal Bed Methane (CBM), which refers to methane extracted from a coal seam prior to mining, often from the surface, with methane concentrations above 90% (Wang 2010). In China, these two types are sometimes referred to as underground drainage and surface production; in some cases, however, the two are lumped together and considered more broadly as CSM (煤层气).

4.5.1 CSM Recovery and Utilization

CSM recovery and utilization started in China in the early 1990s as a strategy to improve coal mining safety, diversify energy resources and take advantage of a fuel that was previously wasted (IEA 2009). Prior to the 1990s, most of the CSM captured was vented and only a small portion was used for on-site heating and cooking. In the early 1990s, collaboration and technical assistance from the U.S. Environmental Protection Agency and the World Bank's Global Environment Facility led to increased CSM recovery and use. In recent years, the Chinese government has recognized the environmental benefits of using CSM as a clean energy source and by 2007, 40 projects were in place with estimated 8.6 Mt CO_2e emissions avoided per year (IEA 2009).

CSM capture can occur through either pre-mining drainage (CBM) or post-mining drainage (CMM). Pre-mining drainage involves drilling vertical wells or horizontal boreholes into the coal seam before mining occurs in order to preemptively release methane and prevent explosions (World Coal Association 2012). Post-mining drainage focuses on recovering methane released during coal mining by capturing it, diluting it below the explosive range of 5-15% and removing it using large ventilation systems. In China, low gas permeability, high gas pressure and relatively low concentrations of methane in recovered CMM have all influenced the drainage technologies and methods being applied. Most of the CMM drained and recovered have been located in Shanxi Province with a 44% share of the national total in 2007, with smaller shares of 4% in Shaanxi, Liaoning, Anhui, Henan, Guizhou and Chongqing.

CMM utilization is determined in large part by the methane concentration of the recovered CMM. China's CMM utilization is mostly medium concentration with methane content of 30% to 80% or low concentration with methane content of less than 30%. Low concentration methane is rarely utilized because methane is explosive with concentrations in the range of 5% to 15% and project developers and vendors have avoided projects that would require transporting, distributing and using low concentration methane. Lastly, ventilation air methane constitute the largest source of CMM emissions in China as the large volume of air with methane concentrations of less than 1% are emitted directly from mine ventilation shafts. In China, research into developing the technologies to capture and utilize ventilation air methane began only recently but ventilated air methane has been used to generate heat or electricity in the U.S., Australia and Canada (IEA 2009).

Medium-concentration CMM with methane content of at least 40% can be used as a household fuel, industrial fuel or for power generation. As a household fuel, CMM is used directly as a gas for residential and commercial energy demand within coal mining districts in Liaoning and Shanxi provinces. Underground drained CMM has the same heat value as coke gas and as an industrial fuel; it can replace coal gas, natural gas, LPG or coal as fuel input to industrial boilers in Shanxi and Anhui provinces (CMBC 2004, IEA 2009). Because significant investment and time are needed to construct the infrastructure needed to transport and distribute CMM from the mines to point of use, its application as a household or industrial fuel is relatively limited to sites close to coal mines. Lastly, CMM with methane content of at least 30% can be used to power gas combustion turbines with 30% efficiency and gas combustion engines with 40% efficiency to generate electricity. CMM utilization for power generation has increased rapidly over the last few years, with installed capacity growing from 200 MW in 2005 to 920 MW with a total of 1,400 generators by the end of 2008 (Zhao 2011).

The influence of government policy and pace of technological development on CMM drainage and utilization over time can be seen in Figure 15. In the 1990s as China began to develop the technologies and methods for CMM drainage, total drainage began to rise steadily but at a relatively slow rate, growing only from 536 million m^3 (mcm) in 1993 to 858 mcm in 2000. After 2000 with the commercialization of CMM drainage and increased government attention on CMM as a clean energy resource under the 10th FYP, the drainage amount increased rapidly from 1,146 mcm in 2001 to 2,614 mcm in 2006. During the last five years with greater policy emphasis under the 11th FYP, CMM drainage has accelerated and tripled between 2007 and 2011, from 4,735 to 11,500 mcm. At the same time, the setting of utilization targets and policy focus on comprehensive resource utilization under the 11th FYP has greatly increased CMM utilization rates from 21% in 2006 to 40% in 2010.

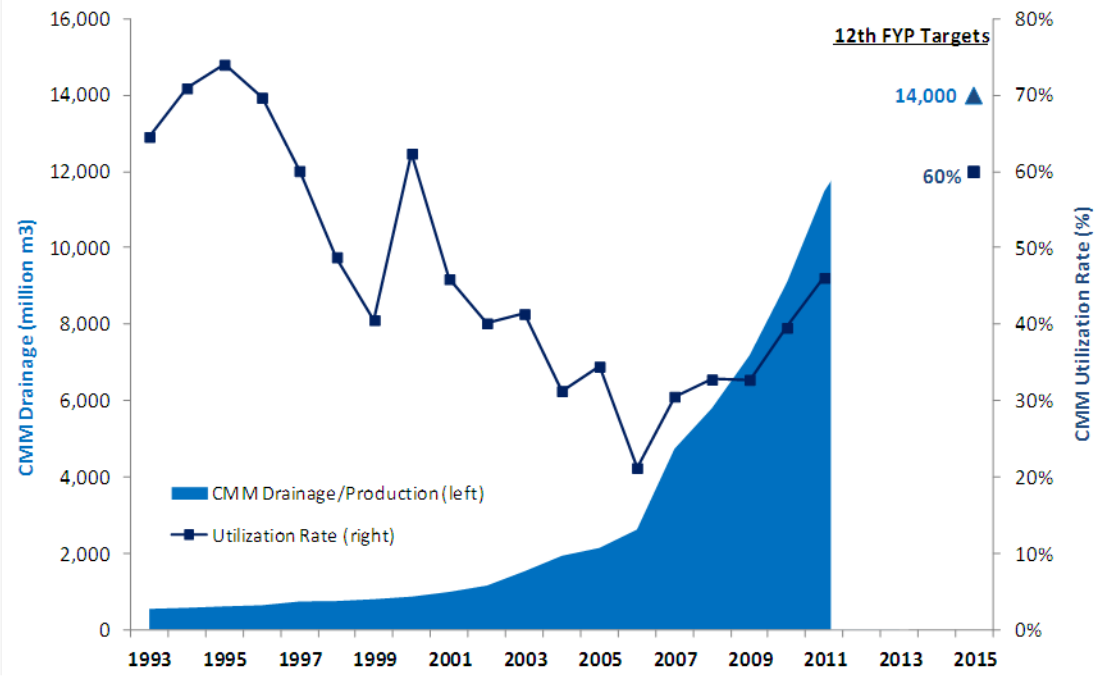


Figure 15. Coal Mine Methane Drainage and Utilization Rate in China, 1993 – 2011
Source: China Coal Statistical Yearbook , various years.

4.5.2 CSM Reserves, Extraction and Utilization

China has the world's third largest reserves of CSM, with estimates of 36.8 tcm of resources in coal fields at depths of above 2,000 meters (Zhao 2011). However, actual recoverable CSM reserves at depths of less than 1,500 meters are only 10.9 tcm (Equity Research 2010). The vast majority of China's CSM resources are located in large basins in Northern China, with 56% in North China, 28% in Northwest China and 1% in Northeast China (Equity Research 201). Within Northern China, half of the CSM resources are concentrated across three large basins - Qinshui in Shanxi, Ordos in Inner Mongolia and Junggar in Xinjiang – and 40% of the resources in these three basins are recoverable at depths of less than 1,500 meters. The other half of China's CSM resources is distributed across 11 other basins as shown in Figure 16.

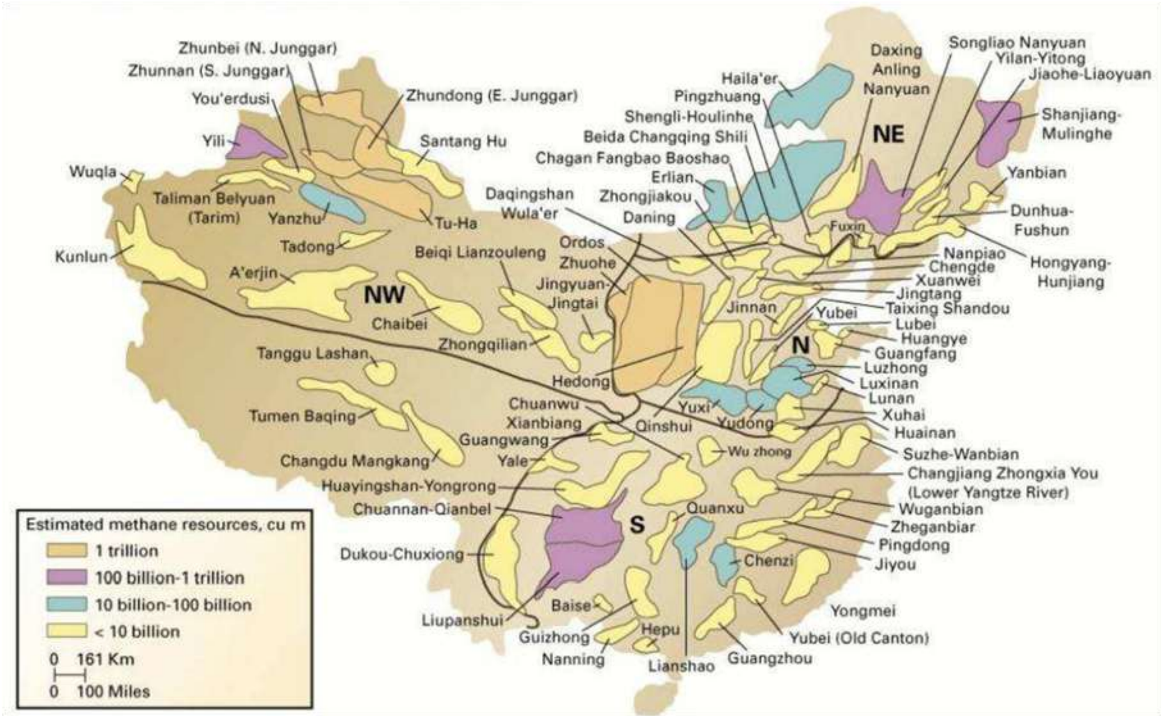


Figure 16: Distribution of China's CSM Resources by Basin

Source: Wang 2010.

Although China has extensive experience in the technologies used in CMM drainage, surface production of CBM using surface standard wells or surface gob wells[9] into collapsed mined-out parts of coal mines is still relatively new. Surface development is advantageous over underground drainage as it produces gas with higher concentrations of methane and the gas is easier to collect, transmit and utilize. However, there are still barriers to large-scale CBM

---

[9] Gob wells refer to a type of recovery well where methane is extracted from the gob areas of a mine after the mining has caved the overlying strata.

commercial development including insufficient gas utilization and pipeline infrastructure and limited exploration in the majority of undeveloped fields (CMBC 2004). In addition, China's distinct reservoir conditions of low pressure and permeability have limited high CBM yield through surface development. Nevertheless, the Chinese government has promoted surface production of CBM since the 1990s and surface volumes have increased greatly over the last decade. The high concentration level of methane in recovered CBM, makes it a viable alternative for conventional natural gas. However, natural gas pipeline networks are needed to transport the gas to demand centers away from the coal mining sites.

4.5.3 Recent CSM Policies

The recent growth of CSM recovery and utilization have been spurred by variety of policies that include financial subsidies, preferential tax policies, coal mining safety regulations and standards on low concentration CMM transportation and utilization. More specifically, the central government has offered a financial subsidy of 0.2 RMB per m^3 of CBM gas produced in addition to local government subsidies that may have existed since the early 2000s. The government also provides a 3 to 5 year tax holiday period during CBM production phase. Other preferential tax breaks and fiscal policies for CSM projects are listed in Table 11.

Table 11. Early Preferential Fiscal Policies for CSM Projects in China

Category	Preferential Item
Enterprise Income Tax	30% and 3% local tax, total income tax rate is 33% Tax rate is 0% from 1st -2nd year, 16.5% from 3rd -5th year Other local preferential policies Preferential policies on depreciation calculation
Value-added tax	5%
Resource tax	0
Royalty	0 to 3% varies with the location and gas production
Tariffs	0% except those listed in the not exemption category
Exploration right acquisition	100 RMB/km/yr, but can be exempt
Mining right	100 RMB/km/yr, but can be exempt
Other tax	<1% vehicle and ship license tax and urban real estate tax etc.

Source: CMBC 2004.

In addition to preferential fiscal policies, the State Council also issued "Opinions on Speeding Up CSM Extraction and Utilization" in 2006 to strengthen mine safety while promoting CSM extraction. This policy mandates that CMM must be drained prior to initiating coal mining; coal mines must implement CMM measurement and monitoring measures; coal mining activity must be suspended if significant problems are caused by CMM; and coal mine owners and operators are legally responsible for following safety standards (IEA 2009). In April 2008, an emission standard prohibiting CBM and CMM drainage systems from emitting gas with 30% or higher concentration of methane was adopted by the Ministry of Environmental Protection (Zhao 2011). This standard went into effect for new coal mines and surface drainage systems on July 1, 2008 and also applied to existing mines and systems as of January 1, 2010.

The 11th FYP further ushered in a variety of policies and measures promoting the greater utilization of CBM and CMM in China. In April 2007, NDRC issued two notices on CSM price management and prioritization of electricity generation from CSM. For price management, NDRC specified that the price of methane gas can be determined through negotiations if it is not distributed via city pipelines. To promote CSM power generation, NDRC exempts CSM power plant owners from market price competition and responsibility for grid stability and also required that the power generated from CSM plants be given priority by grid operators (IEA 2009).

4.5.4 CSM Outlook and Challenges

CSM extraction and utilization is expected to grow rapidly over the next three years, with aggressive targets and policies set out for the 12th FYP. From 2011 to 2015, newly increased proven reserves of CSM are expected to increase to 1,000 billion m^3 (bcm), with total production to reach 30 bcm by 2015. Of the 30 bcm of CSM production targeted for 2015, 16 bcm should come from surface drainage and extraction while 14 bcm should come from underground drainage. The 12th FYP also sets targets of 60% utilization rate for CSM and total installed capacity of 2.85 GW for CSM power generation.

While the 12th FYP and supporting policies present an optimistic future for the CSM industry in China, there are also several major challenges and barriers that could hamper or slow CBM and CMM development. For CMM, there is limited technical knowledge on how to mitigate or recover ventilation air methane with very low concentrations given the relatively nascent stage of technologies worldwide. Likewise, knowledge and technical capacity gaps about methane recovery and utilization and CMM power generation still persist in smaller mines. For CBM, despite recent increase in surface drainage, existing technological limitations with surface development still result in high extraction costs and limited yield. Both areas thus require greater technological research and development and possibly technology transfer and information exchange.

In terms of utilization, there are also limitations to expanding the amount of CMM and CBM being utilized for household and industrial fuels and power generation. On one hand, because most of China's coal mines are located in isolated rural areas with sparse population, there is very limited local demand for methane gas. In some cases, it is not even feasible for large mine operators to supply methane to households beyond the immediate border of the mine (IEA 2009). On the other hand, it is not financially viable to transmit methane via long-distance pipelines to large coastal cities that have unmet demand for methane gas. This geographic imbalance between CSM extraction and utilization thus caps the CSM gas use opportunities in China. Furthermore, similar to renewable generation, there have been problems in implementing subsidies for CSM power generation and enforcing the priority grid access policies passed in April 2007. For example, many mine operators are not aware of the subsidy for CSM generated power and for those who are aware and interested, there are still hurdles to connecting to the grid (IEA 2009).

The Chinese government has started to address some of these challenges and barriers with the launch of new supporting policies for CSM extraction and utilization in the 12th FYP. For example, the CSM industry is expected to receive total investment of 120 billion RMB to help increase CMM and CBM production during the 12th FYP period. This investment will be used to build 36 large-scale gas extraction mining areas with capacity exceeding 0.1 bcm per year. In addition, 13 CSM transmission pipelines with total length of 2,054 kilometers and transport capacity of 12 bcm will be constructed across the Qinshui basin, eastern Ordos basin and northern Henan province. The rapid growth and possibly commercialization of surface drainage technologies will also be supported by 58.1 billion RMB of investment in advancing CBM surface drainage in two demonstration basins - Qinshui in Shanxi Province and Ordos in Inner Mongolia - which are expected to produce 10.4 bcm and 5 bcm, respectively, by 2015 (NDRC 2012). Additional financial support will be provided to increase CSM utilization, with a doubling from current levels of 0.2 RMB per m^3 to 0.4 RMB per m^3 and increased payment for CSM power generation from 0.25 RMB per kWh to 0.35 RMB per kWh. The degree to which these new policies can mitigate existing barriers to CMM and CBM development remains to be seen.

5. Coal Consumption Trends in China

As China’s most abundant and relatively cheap energy resource, as well as the bulk of domestic energy production and by far the largest fuel input to the power sector, coal has held a relatively constant share of total primary energy consumption. From 1990 through 2010, Figure 17 shows how coal has dominated China’s primary energy consumption with coal shares ranging from a low of 68% in to a high of 76%. In absolute primary energy terms, coal consumption has tripled from 752 Mtce in 1990 to 2,210 Mtce in 2010. This section will explore the drivers of coal consumption in China and review changing trends in future coal consumption forecasts and demand outlooks.

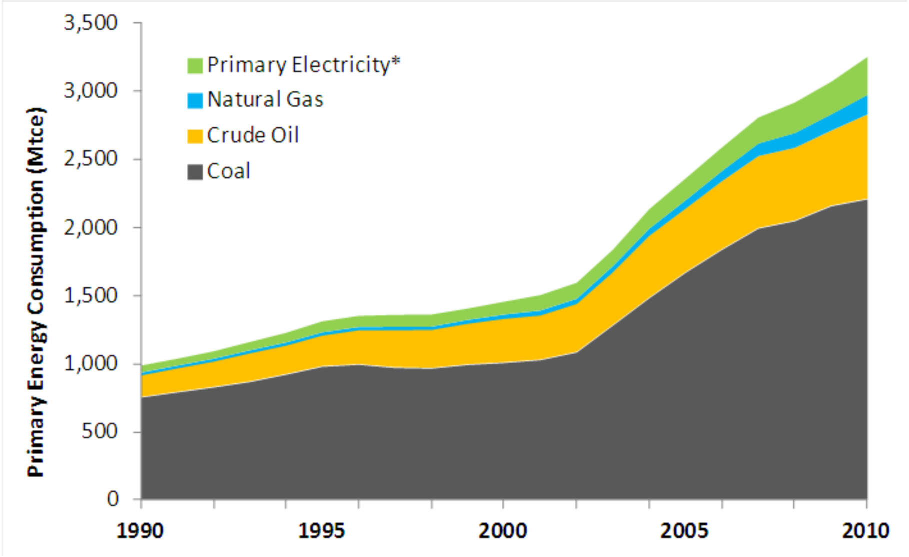


Figure 17. Primary Energy Consumption by Fuel, 1990-2010

*Note: Primary electricity includes hydro, nuclear, wind, solar and other renewable power at calorific equivalent conversion.

Source: China Statistical Yearbook 2011.

5.1 Drivers of Coal Demand: Electricity, Coking

As seen in Figure 18, total coal consumption remained relatively flat from 1995 to 2001 but surged from 2002 through 2010. The rapid growth of coal demand is primarily driven by the transformation sector, particularly by coal use for power generation and for coke production, while total coal consumption in the industrial sector also rose from 2002 to 2010.

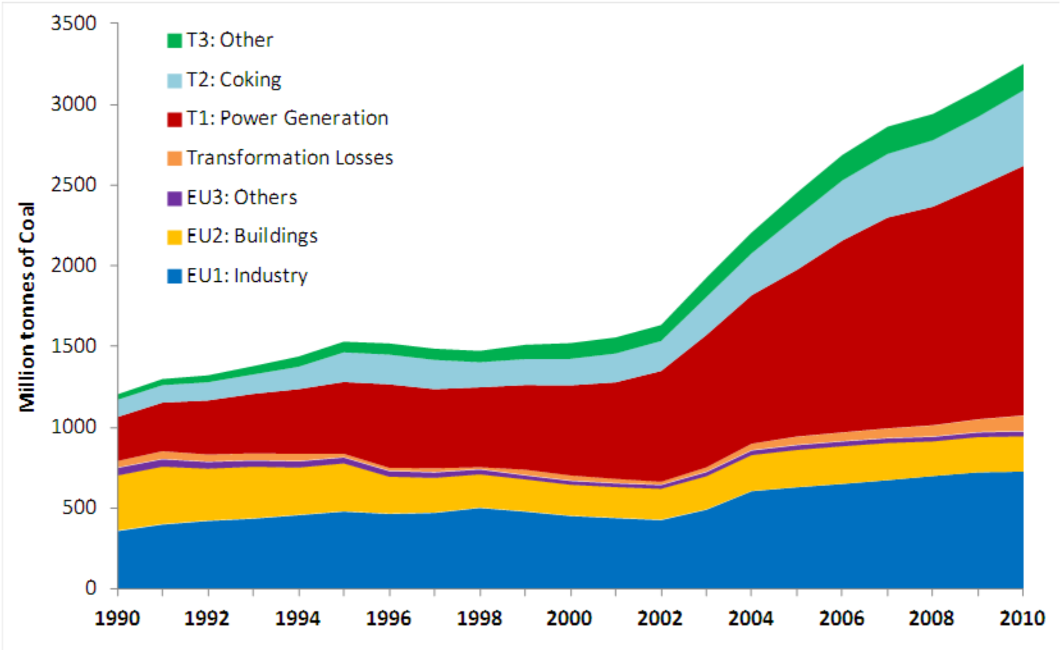


Figure 18. Coal Consumption by End-Use
Source: China Energy Statistical Yearbook, various years.

The key drivers of the coal demand are more readily apparent in Figure 19, which shows changes in the each end-use's relative share of coal consumption. Between 1990 and 2010, the relative share of direct coal consumption by buildings decreased dramatically from 29% to only 7% as coal was displaced by electricity and natural gas/LPG. Industry's relative share of coal consumption also declined slightly during the same period from 30% to 22%. In contrast, the share of coal consumed for power generation skyrocketed from 23% in 1990 to 38% in 2000 and 48% in 2010, accounting for nearly half of all coal consumed by 2010. At the same time, the share of coal use for coke production – the vast majority of which is used in the iron and steel industry—also increased from 9% to 14% between 1990 and 2010.

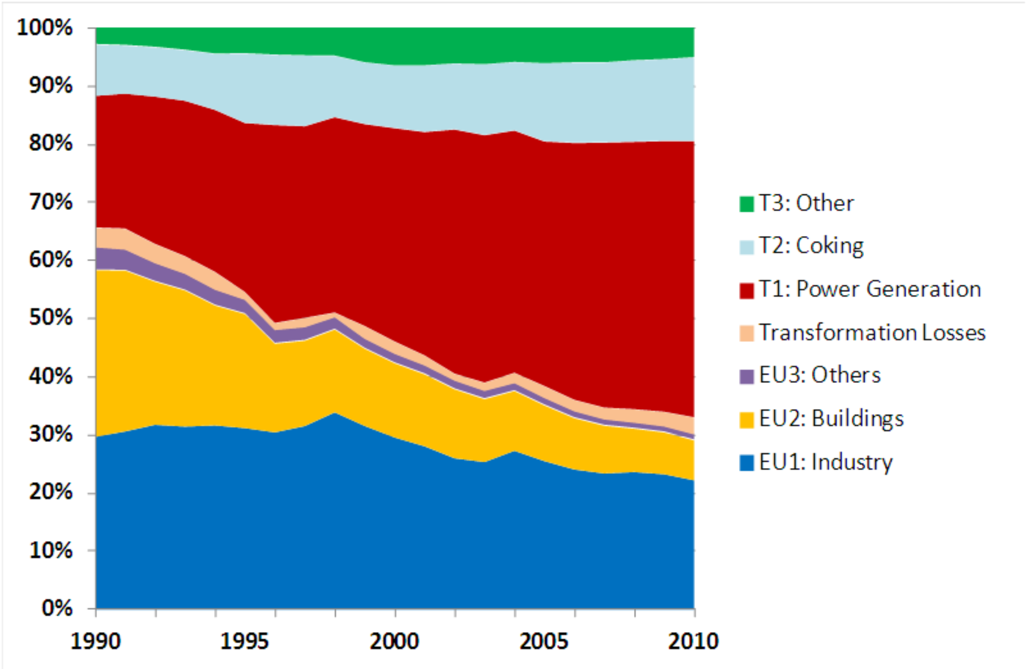


Figure 19. End-Use Shares of Coal Consumption

These trends show that almost all of the recent rapid rise in coal demand can be attributed to China's surging power demand, as power generation has contributed to the majority of incremental change in coal consumption in the last twenty years (Figure 20). In the last five years, for example, over 60% of the marginal increase in coal use has been to support China's power generation which has grown at annual average rates of over 13% to nearly 4,700 TWh of total output in 2011. Electricity demand, in turn, has been driven by dual forces of urbanization – with growing residential and commercial electricity demand from China's burgeoning urban population – and continued industrialization and the use of electricity in iron and steel, cement and aluminum production. In 2009, for instance, residential and commercial buildings and industry accounted for 88% of total electricity demand.

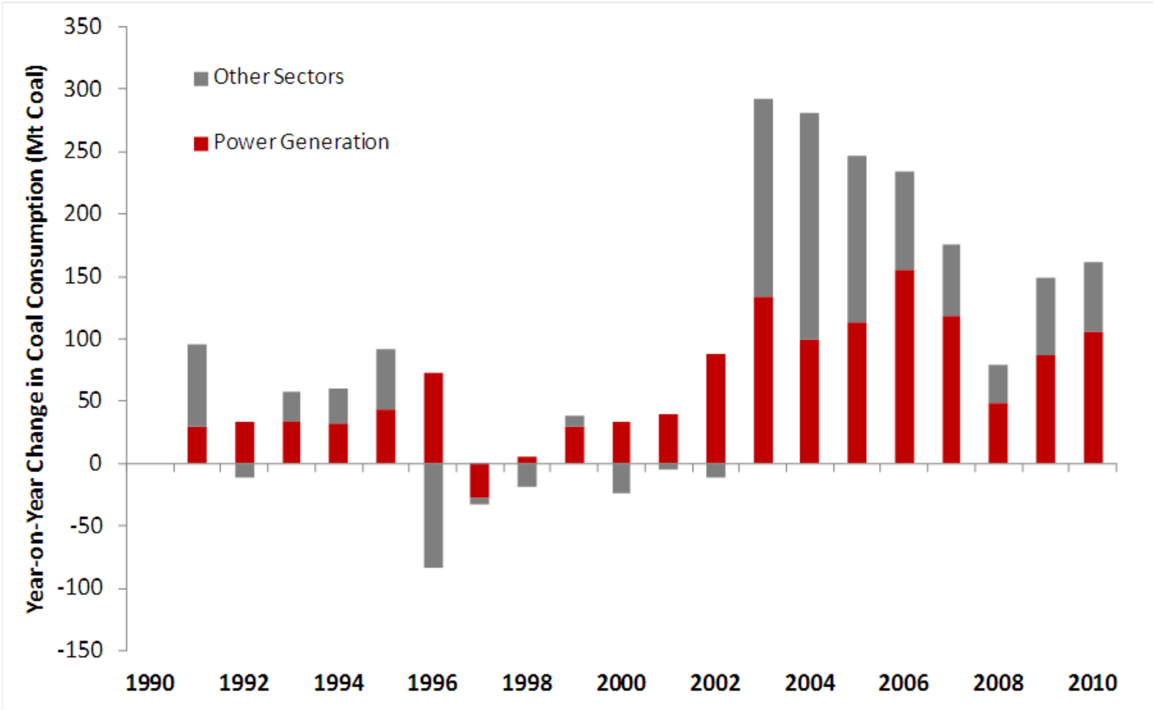


Figure 20. Incremental Change in Coal Consumption from Power Generation and Other Sectors

The integral role of the power sector in driving current Chinese coal demand and its future potential for reducing total coal consumption suggest that the evolving relationship between the coal and power sectors will be a key determinant in China's future coal consumption trends.

5.2 China's Coal-Power Conflict

As the two largest and most important energy industries in China, the coal and power industry have undergone very different phases of regulatory and price reform. Historically, fuel and power prices have increased at a faster rate than the general price index as shown in Figure 21, but this aggregate price index masks very different price trajectories of each energy type (petroleum, natural gas, coal, and electricity). Prior to 1993, the prices in China's coal and power industries were both controlled by the central government and were set at a low level below production costs. In 1993, following the initiation of China's overall energy price reform, the coal price of major state-owned mines were liberalized in order to force these mines to be more economically competitive (Peng 2011). However, coal sold to power companies to generate electricity was not liberalized but rather, still subject to a government-set price. The Annual Coal Conference has traditionally been the mechanism through which prices for electricity coal are set through the signing of supply contracts between coal and power companies and the allocation of transportation quotas for contracted coal by the Ministry of Railways. In 2002, China's power industry was also introduced to market-oriented reform through restructuring that formed 11 state-owned companies, including five key power generation companies. However, because electricity is a critical input to many key economic outputs from industry and foreign manufacturers and is also a basic need of residential households, power prices remained tightly controlled by the government even after the restructuring. These two different paths of market reform – and price reform in particular - have created a "coal-power" conflict with rising market coal prices but fixed electricity and thus essentially fixed electricity coal prices.

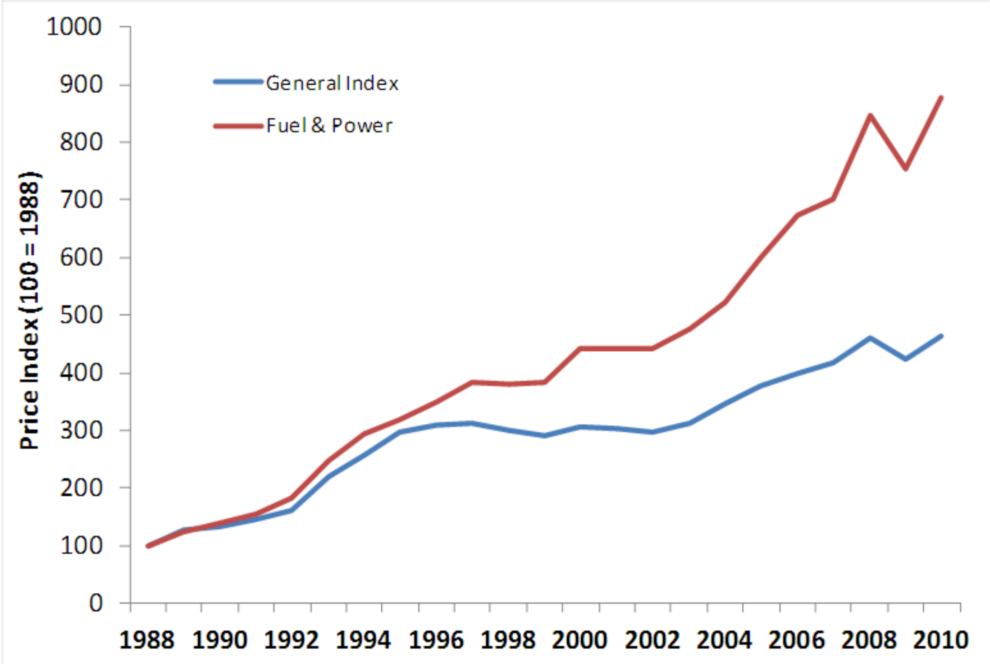


Figure 21. Comparison of Fuel & Power Prices and General Price Indices
Source: China Statistical Yearbook, various years.

Since 2002, rising domestic and international coal prices have exacerbated the coal-power conflict as coal producers' push for higher electricity coal prices have been met with resistance from power producers that cannot pass rising costs to their consumers with the government's fixed electricity prices (Rui et al. 2010). The increasing gap between rising spot market coal prices and planned flat electricity prices can be seen by comparing the price indices of these two industries in Figure 22.

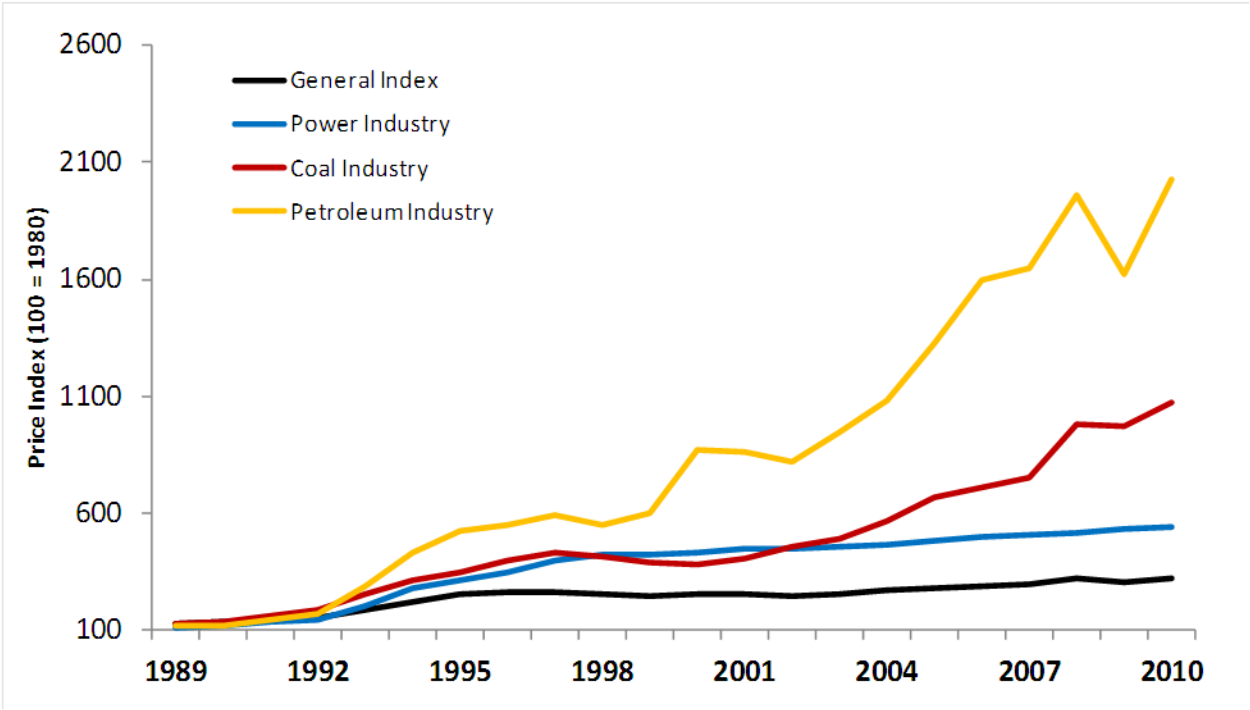


Figure 22. Comparison of Power, Coal, Petroleum Industry Price Indices
Source: China Statistical Yearbook 2011.

As the gap between coal and electricity price have widened over recent years, the coal-power conflict has resulted in fewer and fewer contracts being successfully negotiated and enforced between coal and power producers. In 2003, for instance, 50% of contracts were not signed and fulfilled because coal producers chose to sell their coal on the free market rather than at a fixed price with only a 5% increase to power producers (Peng 2010). The subsequent electricity shortages in 2004 led the government to introduce a price linkage mechanism between power prices and coal price increases but concerns over inflation from rising coal and power prices ended attempts to link prices. In 2008, coal-power negotiations broke down with almost no agreements reached on coal prices at the 2009 Coal Conference and many thermal power producers began importing coal from overseas markets including Indonesia, Vietnam and Australia (Rui et al. 2010). The example of coal cost and electricity prices in Shanghai shown in Figure 23 illustrates the wide disparity in power generation costs and revenues, with over 40 billion RMB of losses accrued by the power sector in 2008 alone. In 2011, NDRC raised electricity prices three times to target different end-users and provinces and imposed price caps on coal for power generation in attempts to rein in power sector losses. Despite these price hikes, combined losses from the five large power companies still totaled 15.1 billion yuan in 2011, with four out of the five suffering net losses (Liu 2012).

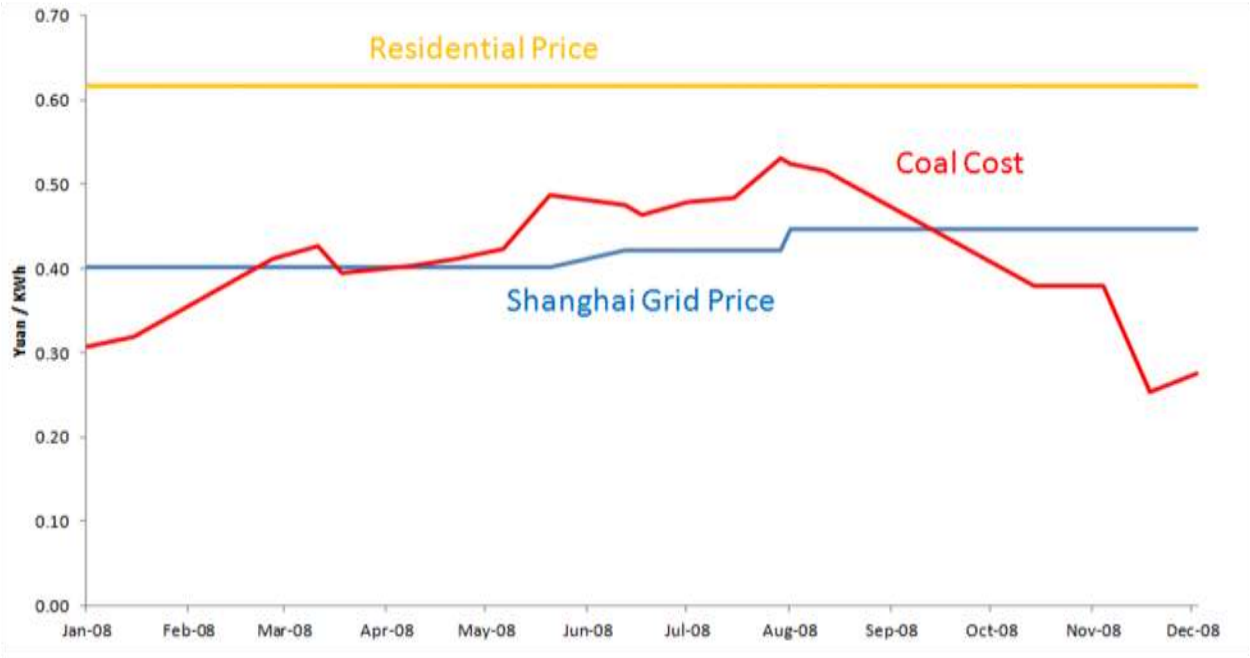


Figure 23. Shanghai Electricity Prices and Coal Cost

Note: coal cost is expressed in Yuan/kWh equivalent.

Source: He 2012b.

In addition to economics that have instigated the persistent conflict between coal and power producers, there are also regulatory and structural causes to the coal-power conflict. In addition to a market-based economy, the coal industry is highly fragmented because coal mines responsible for 85 to 90% of coal production in China are administered by local provincial governments (Peng 2011). In contrast, the power sector is highly regulated, and key national power producers that purchase half of all coal for power generation are owned by the central government. Thus, the existing tension between coal and power sectors and potential resolution of the conflict cross not only industrial boundaries, but also different levels of government.

In order to address the coal-power conflict, the Chinese government proposed the formation of 13 coal-power bases in late 2005 and set out plans to build 13 bases throughout northwestern, western and central China. These coal-power bases are to be coordinated and developed in a centralized manner by one company with emphasis on research and development and innovation and optimal coal production structure emphasizing mine consolidation (Rui et al. 2010). The coal-power bases are also intended to promote the coordinated and integrated development of coal and power, coal and chemical and coal and railways. However, plans to establish the proposed coal-power bases have continued to change while the 12th FYP continues to encourage cross-regional, cross-sectoral and cross-ownership mergers and acquisitions and comprehensive operation of coal, electricity and transport.

5.3 Emerging Area for Coal Demand: Polygeneration Development in China

While power generation has and is likely to continue to dominate coal consumption in China in upcoming years, a new emerging area of demand for coal is in polygeneration which allows for the comprehensive utilization of coal to co-produce chemicals, liquid fuels and power. As a complex engineering system that targets system optimization and flexible cross-industry production, polygeneration has been considered a promising technology for the more efficient and clean utilization of coal. It has benefits in flexible output product mix; low production costs; high energy conversion efficiency; the treatment and reuse of pollutants as resources. For example, the recovery and utilization of sulfur, and utilization and sequestration of high-concentration carbon dioxide (CO_2) can produce near-zero greenhouse gas emissions.

Figure 24 illustrates the different processes and potential outputs of a typical integrated coal polygeneration system. In a typical polygeneration system, coal is burned through oxygen-blown gasification to produce a syngas composed of CO and H_2, which can then be used for multiple purposes. First, the syngas can be used as town gas for cooking and heating, as well as inputs to distributed power, heat and cooling. Second, the syngas can be used for large scale power generation with gas/steam combined cycle or fuel cell technologies. Third, the syngas can be used to produce methanol or liquid fuels, including synthetic fuels and dimethyl ether. Fourth, syngas can serve as a feedstock for other chemical products like NH_3, urea, tar or middle distillates. Lastly, syngas can also be reformed to produce hydrogen.

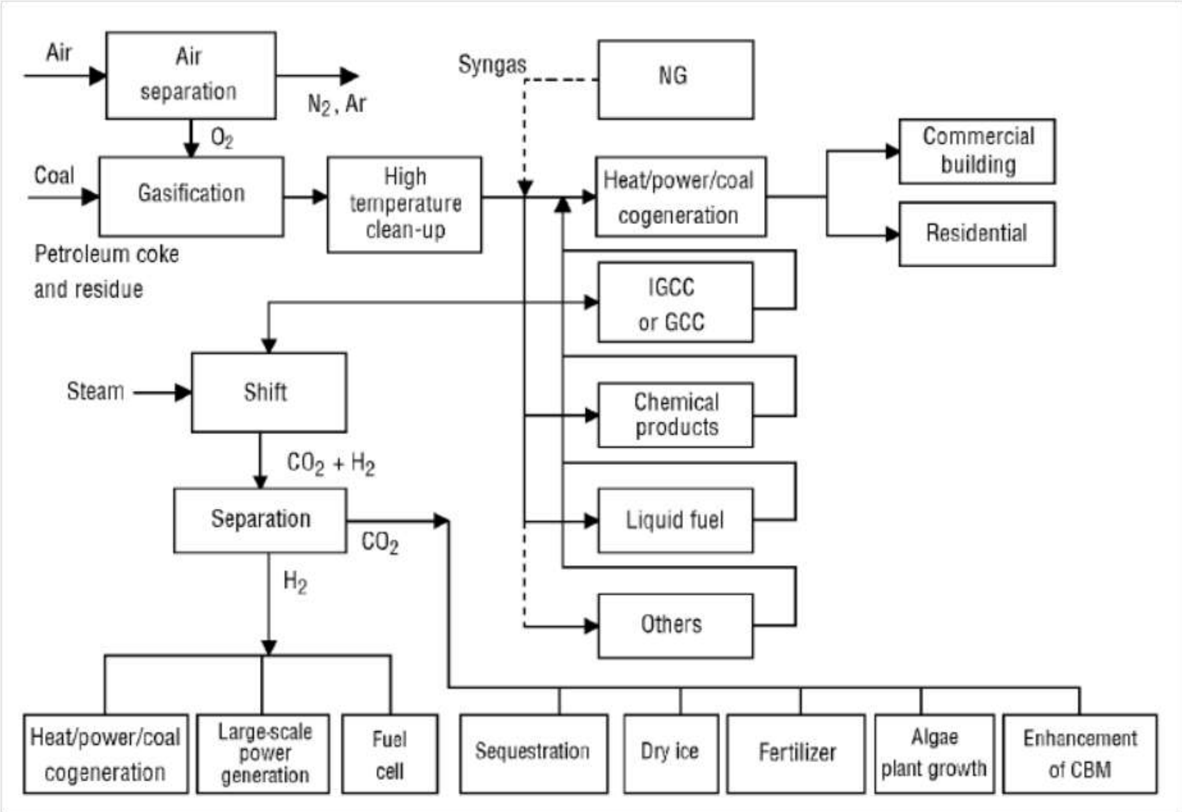


Figure 24. Sample Schematic of Integrated Polygeneration System
Source: Li et al. 2003.

Polygeneration development has also followed the expansion of coal chemical development in China, with polygeneration featured in some planned coal-to-liquid projects. For example, the *Report of China's Oil and Chemical Industries in 2011* reported that by the end of 2011, the total capacity of proposed CTL production capacity exceeded 40 Mt with 14.1 Mt additional production capacity per year for methanol to olefins (MTO) planned or already under construction. By end of 2010, four polygeneration projects were already completed and in operation, with plans for constructing another seven IGCC project with polygeneration (Cai 2010).

5.1.1 Drivers of Polygeneration Development

Energy security and its related goals of fuel supply security, availability of reliable electricity supply and access to the latest energy technologies has been one of the key drivers for China's interest in exploring and demonstration coal-based polygeneration applications. If successfully developed and commercialized, polygeneration can provide a buffer to China's shortage and import dependence of liquid fuels with large scale co-production of alternative fuels such as methanol, DME, F-T liquid and hydrogen (Cai 2010). At the same time, because polygeneration systems will be located near thermal generation sites in small town and rural areas, it can also serve as an important energy resource for distributed energy supply. For example, polygeneration can help provide clean town gas to urban areas that lack natural gas supply and DME as an alternative to LPG for small towns and rural areas. Polygeneration would also allow China to better utilize its coal resources with higher efficiency in producing multiple products.

Another major motivation for pursuing polygeneration development in China is economics, as the co-production of different energy products can increase exports and reduce capital investment costs of new coal-fired generation units. Compared to standalone thermal power production, the polygeneration of power, heat, methanol and syngas in the U.S. can reduce capital investment by 38%, unit cost of energy by 31% and coal consumption by 22.6% (Robert 2001)[10]. If applied to China, a polygeneration system with partial recycling scheme can achieve optimal cost savings of more than 10% when compared to single-product systems with the same product outputs (Lin et al. 2011). China's coal exporting provinces are pursuing high value-added development path and are motivated to build industry parks that have comprehensive industries including coal mining, power generation, polygeneration and coal chemicals near where the coal is located and benefit directly from the value-added of coal and multiple products. At the same time, local processing reduces the increasing transport burden of moving raw coal to consumers in the East.

The improved environmental performance of polygeneration systems, including its ability to use high sulfur coal while controlling air pollutants, further makes it an attractive energy technology for China. Coal-gasification based polygeneration systems have superior environmental controls capable of eliminating large volume of conventional pollutants such as heavy metals, dust and particles with lower incremental costs. Polygeneration also have the potential to meet future CO_2 reduction requirements as the system can be converted to capture CO_2 with lower incremental costs. Compared to a pulverized coal system and methanol single production system with costs of $35 per ton of carbon captured (tC) and $15.9/tC, respectively, a polygeneration system with CO_2 recovery can achieve the lowest cost with only $3.1/tC (Lin et al. 2011).

5.1.2 Policies Enabling Polygeneration Development

In light of the energy security, economic and environmental benefits that coal-based polygeneration development can bring to China, the central government has increasingly adopted policies to promote the research, development and demonstration of polygeneration over the last decade. Beginning in 2006 with the National Medium and Long-term Science &

---

[10] Despite substantial increases in capital costs in the U.S. electricity power sector in recent years, the cost savings for should still be valid because the savings are compared to a standalone, single-product coal power plant and increases in capital costs in the electric power sector would affect both standalone and polygeneration plants. The more recent Chinese study also shows that cost savings are possible under polygeneration due to higher efficiency, higher equipment utilization and greater product flexibility.

Technology Development Plan (2006-2020), polygeneration was formally designated as a key area of priority in the pursuit of clean and high-efficiency development and utilization of coal. China's Science & Technology Action on Climate Change in 2007 then established that polygeneration efforts will focus on research development and demonstration (RD&D), capacity building, and demonstration projects of polygeneration technologies. Polygeneration has also been considered a new area for addressing China's environmental and climate change challenges. *China's National Climate Change Programme* proposes that China should vigorously develop coal-to-liquids, coal gasification, coal-to-chemicals conversion, coal-based polygeneration and CO_2 capture, utilization and storage to increase the capacity of its response to climate change (NDRC 2007). In 2007, the China Council for International Cooperation on Environment and Development (CCICED), the top environmental think-tank, created a task force on Sustainable Use of Coal and Pollution Control Policy in China. In its report, CCICED proposes that the R&D and demonstration of CCS, IGCC and polygeneration should be promoted as part of the national strategy and that policy support should be given to promote coal/biomass co-firing power generation (CCICED 2009).

In terms of supporting polygeneration research and development, China's National Basic Research Program, the 973 program, listed three basic research projects on coal gasification as well as a polygeneration project by the Taiyuan Institute of Technology on using coal gasification gas and pyrolysis coal gas to produce synthesis. China's High-Tech Development Plan, the 863 program, supported five types of gasification technologies in the 10th FYP period (2001-2005) as well as the demonstration design projects of IGCC and polygeneration. The program allocated 346 million RMB (49 million USD) to polygeneration and related technology development from 2006 to 2010 and further formalized China's pursuit of coal-based polygeneration technologies. Most recently in the 12th FYP for National Science and Technology Development and 12th FYP for Energy Science and Technology, coal-based polygeneration demonstration and the system integration of coal gasification technology are listed as areas to be promoted by the government from 2011-2015 (NEA 2011).

5.1.3 Current Status of Coal-based Polygeneration Technology in China: Examples from Existing Projects

After several years of government-based R&D support and policy emphasis, demonstrations of coal-based polygeneration systems now exist at a moderate scale in China. The status of current technologies for four different types of polygeneration systems are highlighted through a review of three major demonstration projects in China.

Shanghai Coking and Chemical Corporation's Coal-Methanol-Town Gas Polygeneration Project

As early as the 1980s, Shanghai Coking and Chemical Corporation began developing the idea of using polygeneration to enhance its ability to supply town gas for Shanghai while extending the coal value chain by producing coal chemical products. A technology roadmap and feasibility study was then conducted by Bechtel Corporation with a proposed coal-methanol-town gas polygeneration schematic as shown in Figure 25. The plant has been in operation since 1995.

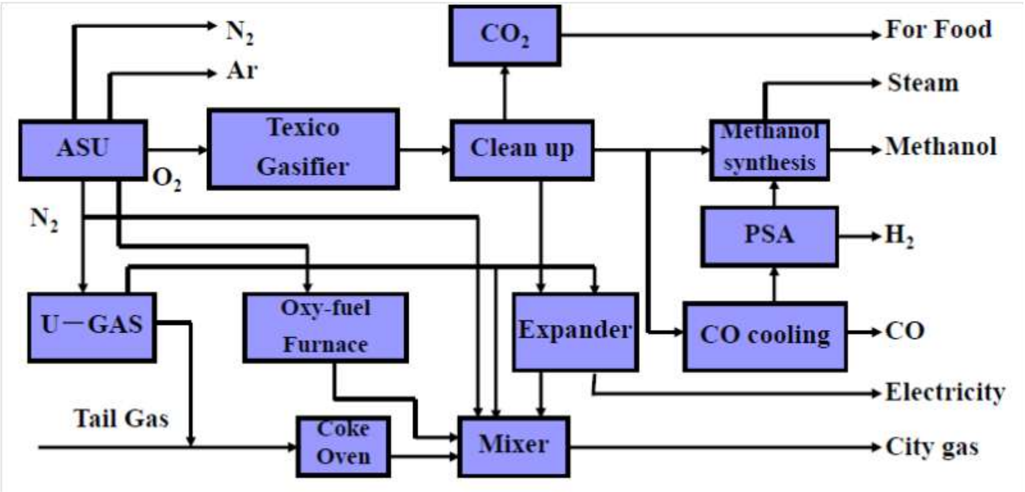


Figure 25. Energy Flow Diagram of Coal-Methanol-Town Gas Polygeneration

The total investment of the project was 1.4 billon RMB with a 5 year payback period. The plant has 1 MW of electricity generation capacity and can produce 1.7 mcm of town gas per day and 200,000 tons of methanol per year. Compared to old technology, the polygeneration system can reduce coal input by 1 Mt annually. Additionally, water pollution was reduced by using waste water to create coal water slurry as an input to the coal gasification process.

Shandong Tengzhou Yankuang Group's Methanol Polygeneration Joint Demonstration Project

In 2005, China Yankuang Group and the Institute of Process Engineering received support from the Chinese Academy of Science under the national 863 Program to build an efficient and clean coal-based methanol power polygeneration demonstration system in the city of Tengzhou in Shandong province. The resulting polygeneration project's investment totaled approximately 1.58 billion RMB and became China's first coal gasification power generation and polygeneration demonstration project.

A schematic of the Shandong Tengzhou polygeneration system is shown in Figure 26. This plant is equipped with two coal water slurry gasifiers capable of processing 1,150 tons of coal each, and produces 240,000 tons of methanol, 200,000 tons of acetic acid per year with 80 MW of power generation capacity. The system has a designed efficiency of 51.3% and an estimated efficiency of 67.2% (Lu'an Group 2011). The Yankuang Group in Tengzhou has recently completed the second phase of the system with expanded production of 300, 000 tons of acetic acid, 100,000 tons of ethyl acetate and is beginning construction of the third phrase with 350,000 tons of methanol and 400,000 tons of acetic acid production.

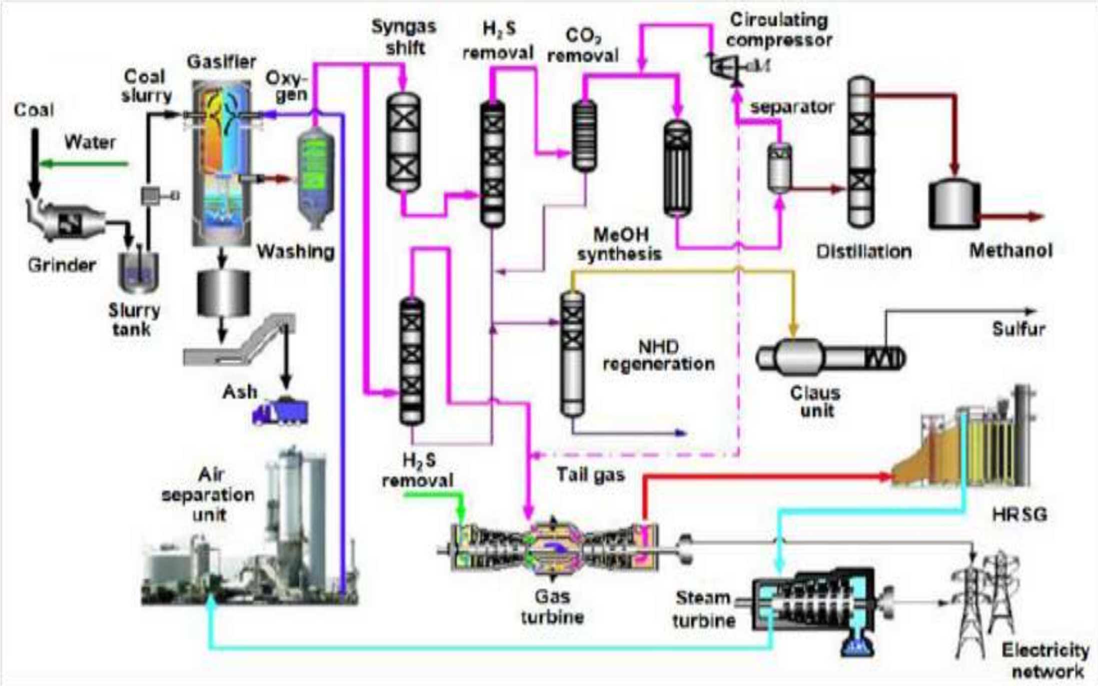


Figure 26. Energy Flow Diagram of Electricity and Methanol Polygeneration System
Source: Cai 2011.

Shanxi Lu'an Group's Synthetic Fuel Polygeneration

Lu'an coal-based synthetic fuel, heat and power polygeneration projects was developed with support from the national 863 program for key projects in advanced energy technologies and has been in operation since 2008. This coal-based synthetic fuel polygeneration project is based on the comprehensive utilization of power generation, coal-based synthetic integrated coal conversion and utilization and clean production of oil and electricity. As seen in Figure 27, the system features a gas turbine, waste heat recovery boiler and supporting power generation devices and access systems and has an estimated efficiency of 36.9%. It produces 160,000 tons of liquid fuel annually, about 3,200 barrels per day (b/d), and includes 60 MW of electricity generation capacity.

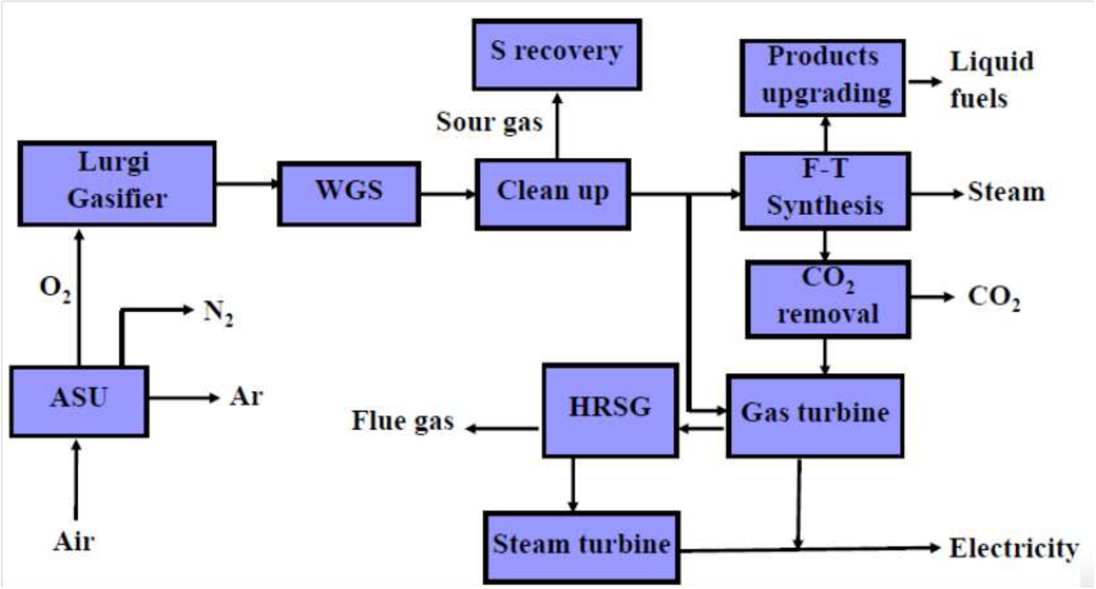


Figure 27. Energy Flow Diagram of Coal-based Synthetic Fuel Polygeneration
Source: Cai 2011.

These three existing coal-based polygeneration projects demonstrate that China has developed polygeneration systems capable of producing different combinations of energy products, including coal-methanol-town gas, coal-methanol-acetum and synthetic fuel polygeneration.

5.1.4 Challenges and Barriers to Future Polygeneration Development in China

The main challenges and barriers to large-scale polygeneration deployment in China fall into four major areas: technology, market, regulatory and water constraints.

First, technological knowledge and capacity remains a barrier to further coal-based polygeneration development and deployment since there is relatively limited information and understanding of the basic technology. While the national research programs and R&D funded demonstration projects have helped narrow the knowledge gap, China still lacks the capacity to develop its own gasifier technology, a core technology in polygeneration systems. Instead, the import dependence of gasifier technology raises initial investment costs and creates uncertainty in polygeneration technology development. China still faces technical challenges in integrating the different parts of polygeneration systems and needs further technical assistance and capacity building through more demonstration projects.

Second, the market barrier stems from two primary factors, funding constraints and market uncertainty. Despite some economically favorable demonstration projects, the high initial investment cost of coal-fired polygeneration is still preventing many companies from directly investing in polygeneration projects. With the current stage of the technology, it is not realistic to expect that a polygeneration demonstration project can achieve the same economic benefits as conventional power or chemical technologies. Therefore, the government needs to continue promoting polygeneration as a strategic energy technology and invest to support RD&D and ultimately lower the costs to facilitate the technology's full commercialization. Moreover, the economic benefits of polygeneration are not guaranteed as profitability is highly dependent on the dynamic competitiveness between coal prices and oil prices and the market for the output products.

Third, regulatory constraints also exist in the form of strong but fragmented bureaucracy and decision making (Anderson 2003; Li et al. 2003). While the structural uncertainty of fragmented bureaucracy allows local governments and companies to move quickly and develop polygeneration projects, it also poses barriers to the cross-sector and cross-industry coordination needed for large-scale system as complex as polygeneration. For example, the successful development of polygeneration involves the support and coordination of different sectors and industries along the value chain such as coal mining, power generation, chemical, and petroleum products. There is also significant need for integration and coordination between conventional industries and different levels of government in order to expand polygeneration development. For example, grid connection regulations needs to be changed in order for polygeneration project developers to sell the electricity they generate to the grid at reasonable prices, or that the systems be given grid access priority in recognition of their energy and emission reduction benefits.

Fourth, water constraint poses another challenge to the large-scale expansion of coal-based polygeneration technologies as water consumption is quite significant on the order of 0.91 to 1.32 tons per GJ (Lin et al. 2011). As China's coal mines and polygeneration systems are located in the water-scarce regions of China, water availability could become a limiting factor for the development of more polygeneration projects. If water constraints are not properly addressed in developing new polygeneration projects, there could be negative impacts on the local ecosystems and the living conditions of local residents.

6. Coal Trade Flows and Emerging Constraints

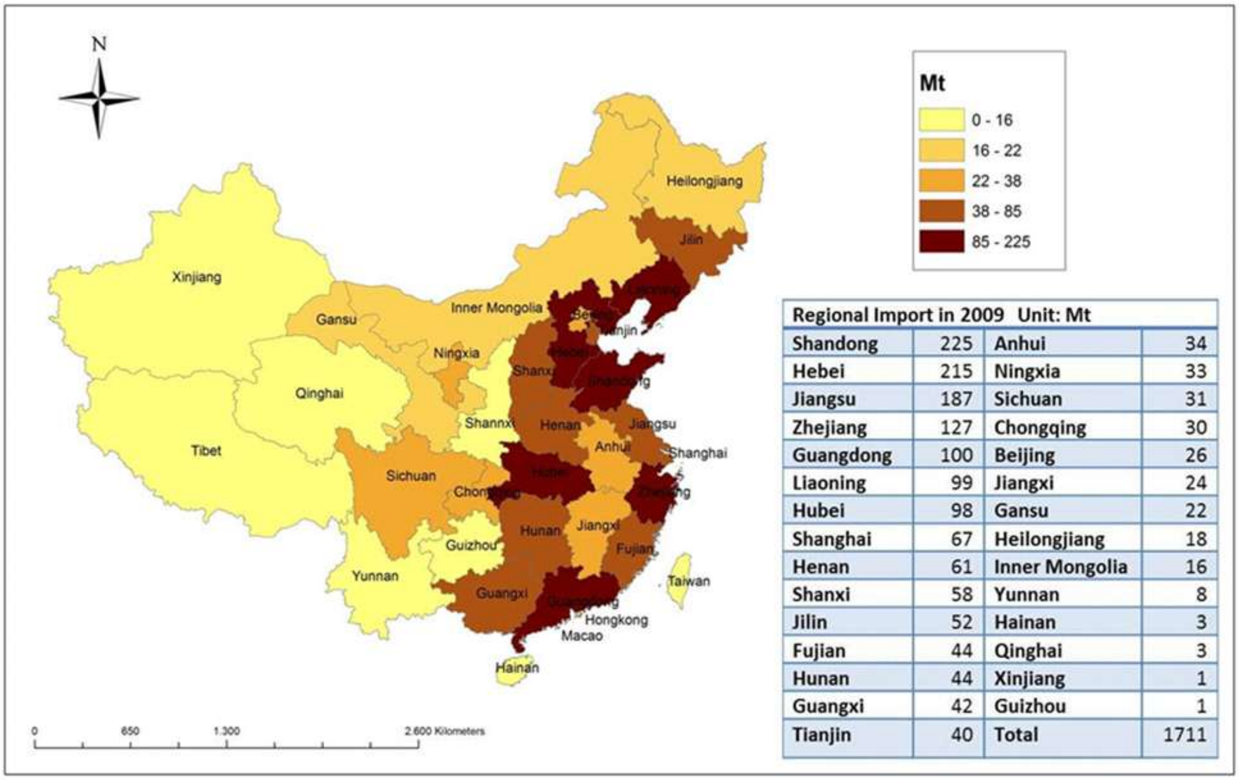
As suggested by shifting coal production trends, the uneven spatial distribution of China's coal resources and production activity makes transportation a key element in sustaining the growth of the coal industry. Different modes of domestic transportation modes, particularly long distance railways, waterways and roadways, have facilitated China's inter-regional coal trade by moving coal from its point of production to its point of use. However, the continual growth of domestic coal demand is pushing the bounds of transport capacity, with constraints in rail transportation emerging amidst growing competition from transport demand of other freight and rail transport volume outpacing rail capacity growth. Internationally, China's dependence on a few Asia-Pacific countries for its growing anthracite and bituminous coal imports could face growing competition from other large coal importers within Asia, including Japan, India and South Korea.

The first part of this section reviews the spatial mismatch between coal imports and exports within each of the three major regions as the underlying driver for coal's rising demand for all modes of transport. It will then discuss constraints in rail transport despite the recent stimulus-driven spike in rail investment and capacity growth. The second part will explore China's coal import flows to understand the importance of coal trade within Asia-Pacific and its future implications.

6.1 Domestic Coal Trade Flows and Transportation Bottlenecks

6.1.1 China's Inter-regional Coal Trade and Transport Implications

As the population centers and home to China's mega-cities, the heavily populated eastern and southern coastline of China dominate coal consumption. This region is estimated to hold less than 5% of the total proven coal reserves but consume nearly 40% of national coal consumption in 2010 (Tu and Johnson-Reiser 2012). As a result of the unbalanced coal resource distribution and consumption, Figure 28 shows most of the domestic coal imports in 2009 are heavily concentrated in provinces along the eastern coastline and a few inland provinces in middle China. Specifically, the densely populated and some of the fastest economically growing eastern and southern provinces of China such as Shandong, Hebei, Jiangsu, Zhejiang and Guangdong are largest provincial importers of domestically traded coal. Together, these five provinces imported half of the total 1.7 Bt of coal traded within China in 2009.

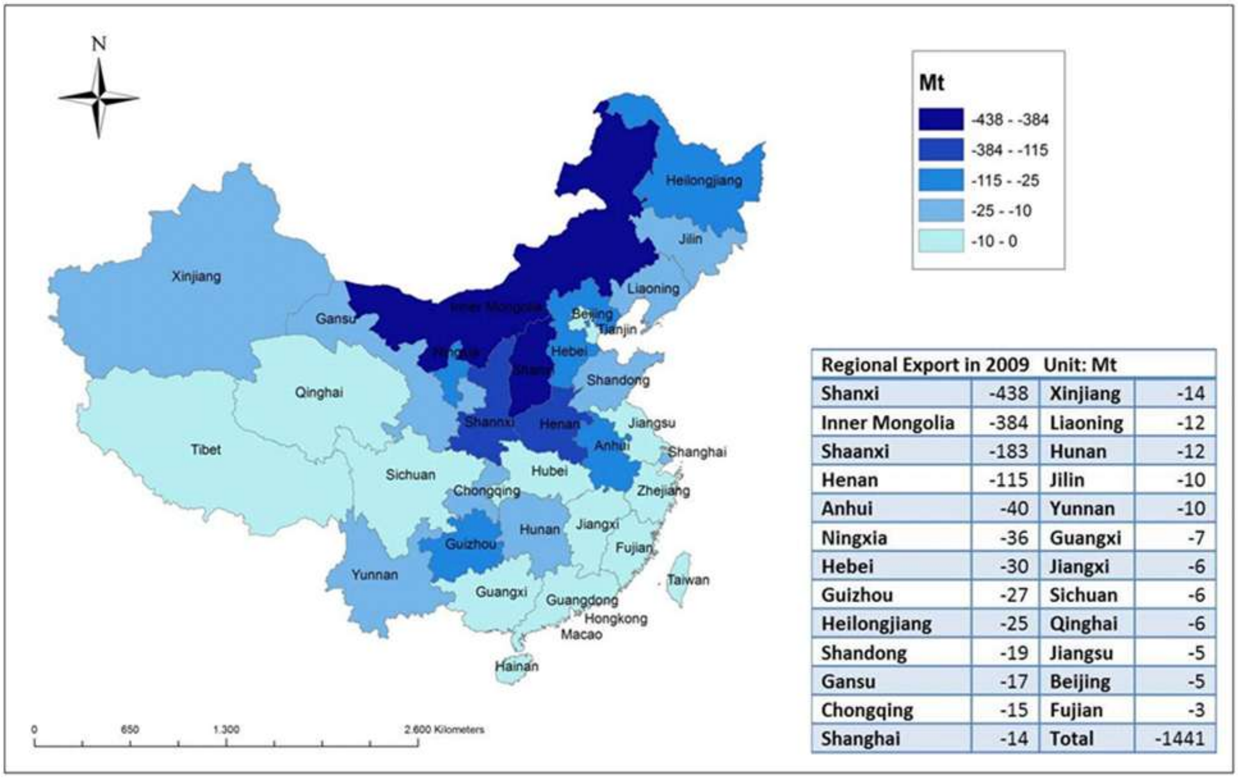


Regional Import in 2009 Unit: Mt

Shandong	225	Anhui	34
Hebei	215	Ningxia	33
Jiangsu	187	Sichuan	31
Zhejiang	127	Chongqing	30
Guangdong	100	Beijing	26
Liaoning	99	Jiangxi	24
Hubei	98	Gansu	22
Shanghai	67	Heilongjiang	18
Henan	61	Inner Mongolia	16
Shanxi	58	Yunnan	8
Jilin	52	Hainan	3
Fujian	44	Qinghai	3
Hunan	44	Xinjiang	1
Guangxi	42	Guizhou	1
Tianjin	40	Total	1711

Figure 28. China's 2009 Inter-regional Coal Imports by Province
Source: China Energy Statistical Yearbook 2010.

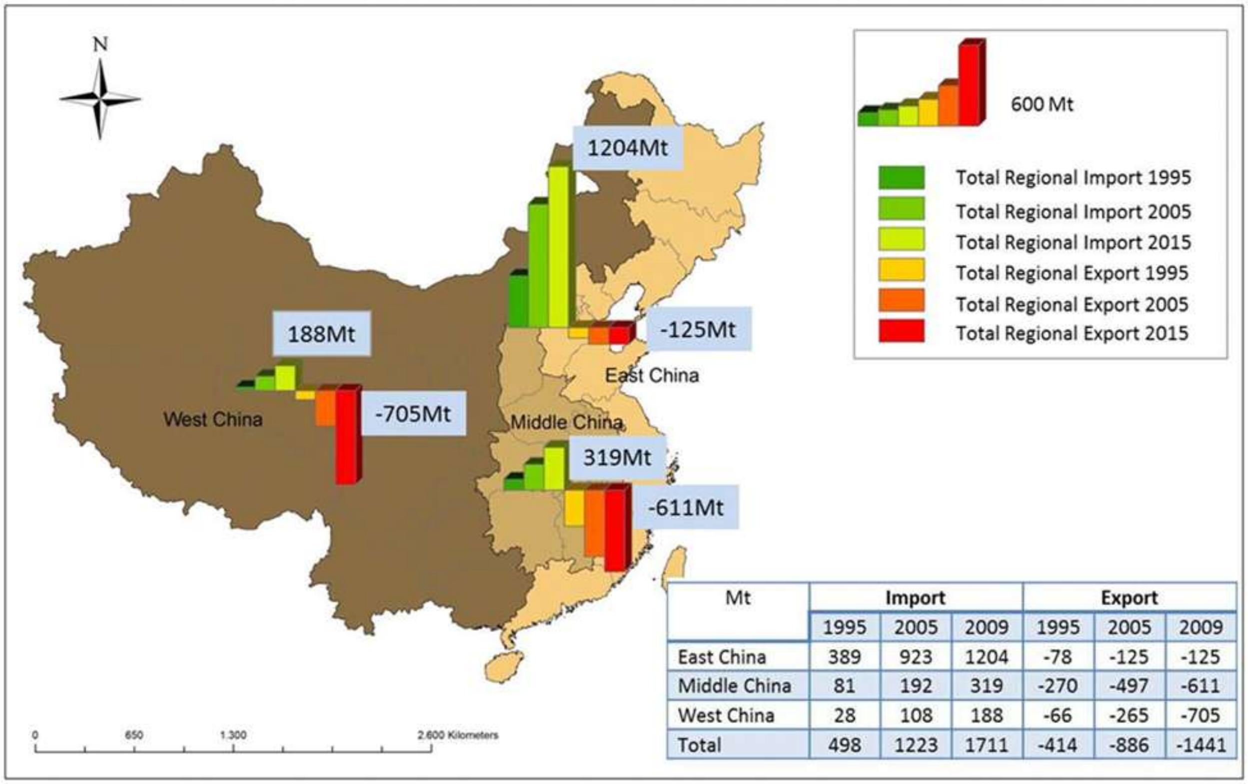
As expected from domestic coal production trends, China’s interregional coal exports present a very different picture with 2009 coal exports dominated by northern and western provinces as seen in Figure 29. The consolidation of exports from major coal producing regions are even more apparent, with 78% of coal exports concentrated in the four largest exporting provinces of Shanxi, Inner Mongolia, Shaanxi and Henan. In 2009, Shanxi alone exported 30% of total exported coal in 2009, followed closely by Inner Mongolia with 27%, Shaanxi with 13% and Henan with 8%.



Regional Export in 2009		Unit: Mt	
Shanxi	-438	Xinjiang	-14
Inner Mongolia	-384	Liaoning	-12
Shaanxi	-183	Hunan	-12
Henan	-115	Jilin	-10
Anhui	-40	Yunnan	-10
Ningxia	-36	Guangxi	-7
Hebei	-30	Jiangxi	-6
Guizhou	-27	Sichuan	-6
Heilongjiang	-25	Qinghai	-6
Shandong	-19	Jiangsu	-5
Gansu	-17	Beijing	-5
Chongqing	-15	Fujian	-3
Shanghai	-14	Total	-1441

Figure 29. China's 2009 Inter-regional Coal Exports by Province
Source: China Energy Statistical Yearbook 2010.

Figure 30 aggregates provinces into the three pre-defined geographic regions and compares regional imports and exports over time. It highlights East China's role as a net coal importer and West China (and Middle China to a lesser degree) as net coal exporters. Moreover, a comparison of regional coal exports and imports in 1995, 2005, and 2009 further reveal that the unbalanced distribution of coal production for exports and consumption through imports has intensified over time. In 2005, for instance, net coal exports from West China totaled only 157 Mt while net coal imports in East China totaled nearly 800 Mt. By 2009, West China's net coal exports have grown three-fold to 517 Mt while East China had net coal imports of 1,079 Mt. Growth in coal imports and exports have remained fairly steady in Middle China, with net exports staying relatively constant at approximately 300 Mt between 2005 and 2009.



Mt	Import			Export		
	1995	2005	2009	1995	2005	2009
East China	389	923	1204	-78	-125	-125
Middle China	81	192	319	-270	-497	-611
West China	28	108	188	-66	-265	-705
Total	498	1223	1711	-414	-886	-1441

Figure 30. China's Regional Coal Import and Exports for 1995, 2005 and 2009

6.1.2 Rising Demand for All Coal Transport Modes

The provincial and regional coal import and export imbalances dictate that long distance transport is needed to move coal through two key corridors: from the west (e.g., Shanxi, Shaanxi, and west Inner Mongolia) to the east and from the north to the south. Earlier estimates have shown that coal transport from north to south accounted for 53.5% of total coal freight, while transport from the west to east accounted for 21% (Duan 2007).

In order to transport coal along these corridors, three major modes of transport are used: rail, water and road transport. As seen in Figure 31, the volume of coal and coal products moved by each transport mode has grown dramatically since 2000, with coal transported by rail growing at average 8% per year and coal transported by water growing at 14% per year between 2000 and 2009. In terms of transport volume, rail transport still dominates with 1,560 Mt of coal transported in 2010, compared to 1,323 Mt of coal throughput for coastal and inland ports and 520 Mt transported on roadways in 2007.

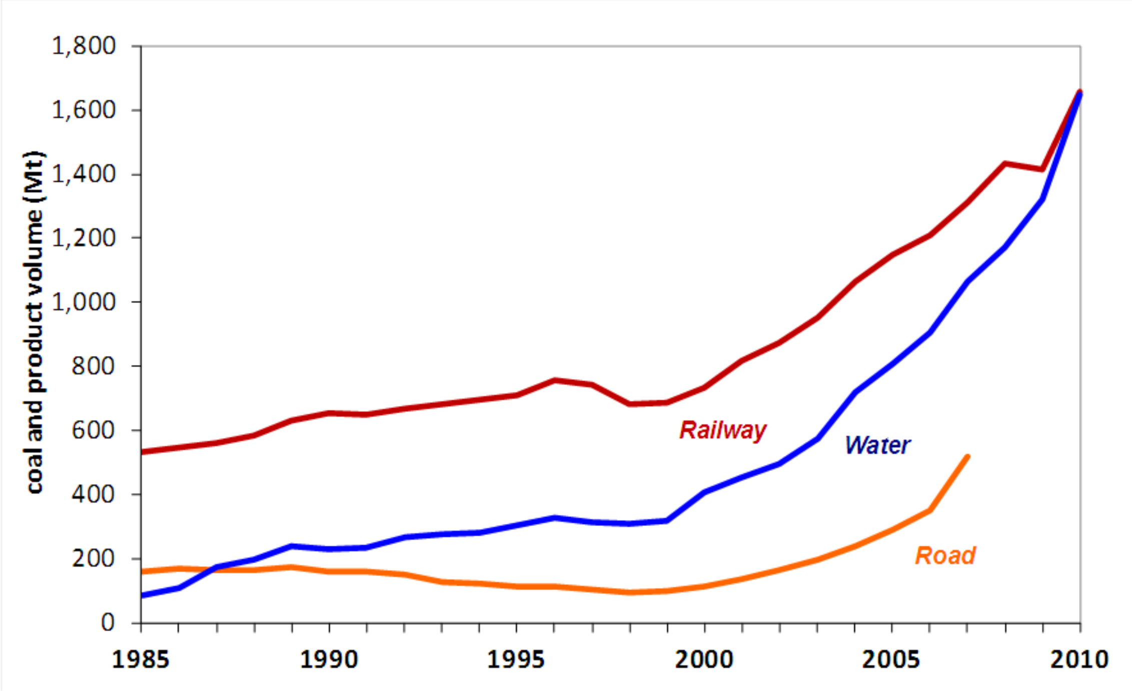


Figure 31. Coal Transport Volume by Transport Mode (Rail, Water, Road)
Source: NBS, various years. China Communications Press, various years.

Railways remain the most important coal transport mode in China, transporting around half of all coal and coal products produced in China. Coal railways include 12 railway lines along three interconnected routes (north, central, south) on the west to east coal transport corridor (Tu 2011). These routes and railway lines connect the major coal producing regions of West Inner Mongolia, Northern Shaanxi and Shanxi with major cities such as Beijing and Tianjin as well as major coastal ports. Figure 32 shows the origins, major stops and destinations of three major north, central and south rail routes and the 12 accompanying rail lines for coal transport in China.

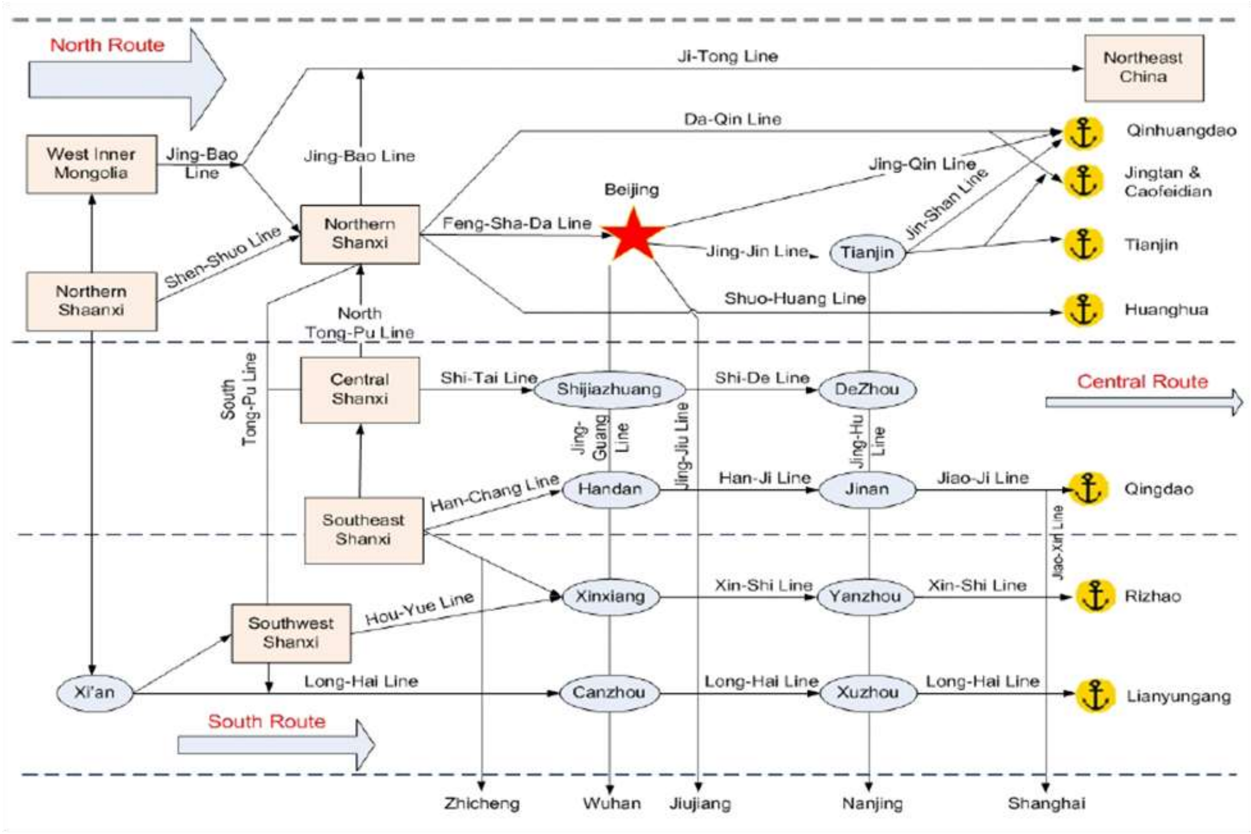


Figure 32. Major Coal Rail Transport Routes in China

Source: Taken from Tu 2011. Original sources cited as Sagawa et al. 2003, Ministry of Railways 2008, and interviews with Chinese academia and officials in 2009.

For the north to south transport corridor, rail transport is supplemented by water transport in the absence of dedicated southbound rail lines. Specifically, rail is used to move coal from western regions to seven major northeastern seaports around the Bohai Bay for transfer to southeastern China. These "Northern Seven" coastal ports include Qinhuangdao, Jintang and Huanghua Ports in Hebei; Tianjin Port in Tianjin; and Qingdao, Rizhao and Lianyungang Ports in Shandong. Together, these seven ports are responsible for handling nearly 90% of all coastal port throughout (Tu 2011). From these seven ports, coal is then shipped to various discharge ports along the southeastern coastline including the major discharge ports of Shanghai, Ningbo-Zhoushan and Guangzhou Ports (Tu and Johnson-Reiser 2012).

The important role that water transport play in facilitating the north to south transfer of coal, especially given existing railway bottlenecks, has resulted in water transport surpassing rail as the transport mode with the largest coal transport volume in 2010. Although it was traditionally the second largest transport mode for coal, the volume of coal transported through coastal and inland ports has soared in recent years with total coal throughput in coastal marine ports quadrupling from 325 Mt in 2000 to 1,163 Mt in 2010 and increasing by six-fold from 80 Mt to

484 Mt in inland river ports during the same period (Table 12). At the same time, the water transport shares of total coal produced rose from 29% in 2000 to 52% in 2010, with coal throughput in ports and waterways surpassing the coal volume transported by rail for the first time.

Table 12. Coal Transport Volume by Mode for Selected Years

Unit: Mt	Rail Total	Water Total	Coastal Ports	Inland Ports
1985	519	85	85	0
1990	629	232	169	63
1995	674	302	232	70
2000	685	406	325	80
2005	1,071	807	635	172
2010	1,560	1,646	1,163	484

Source: NBS, various years. China Communications Press, various years.

Coal transport by road has also grown over the last decade, but roadways remain a supplemental, rather than primary, mode of coal transport as it is used mostly for the local distribution of coal. Compared to rail and water transport, the use of trucks for long-distance coal transport is both economically unattractive given its higher transport costs and environmentally undesirable given the fuel mix and efficiency of China's truck fleet (Tu 2011). Thus, road transport is typically used for the delivery of coal within a province or short-distance transfer of coal from point of production to point of consumption. Data on road transport of coal are not collected and published on the same basis as those for rail or water transport owing to the fragmented nature of the road logistics industry and mixture of public and private ownership. Estimates for 2009 put road transport of coal as high as 3,000 Mt, but this likely included both short-haul and longer-haul transfers as well as single-mode transport. Anecdotal evidence suggests that single-mode road transport has expanded greatly since 2007, particularly from Inner Mongolia to eastern destinations.

6.1.3 Coal by Rail Transport in Focus: Emerging Constraints

As the largest mode of coal transport, rail transport has inherent advantages in its economies of scale for transporting large volume of freight such as raw coal. Besides its large transport capacity, freight transport by rail also benefit from higher fuel efficiency and has subsequently lower freight cost. Rail freight transport (not specific to coal) has relatively lower cost of 10.31 cents per ton-kilometer in 2009 compared to nearly 60 cents per ton-kilometer for freight transport by truck, but slightly higher than coastal marine transport with average freight rates of 6 to 8 cents per ton-kilometer (Tu 2011).

As a result of its favorable conditions for high volume freight transport, freight demand for rail transport has increased dramatically in recent years accompanying continued rapid economic growth and demand for raw materials. Most noticeably, both the freight density of China's railway network measured in terms of annual freight cars per kilometer of track and the daily number of freight cars spiked after 2000, as seen in Figure 33 and Figure 34. The freight density of rail, for instance, went from net negative growth between 1986 and 2000 to annual average growth of 2.5% per year from 2000 to 2009, with the decline after 2008 resulting from an accelerated pace of track length expansion. Similarly, the daily flow of total rail freight cars grew slowly from 72,400 cars per day in 1990 to 77,650 cars per days in 2000, but then grew rapidly at 5% per year to over 120,000 cars per day by 2009.

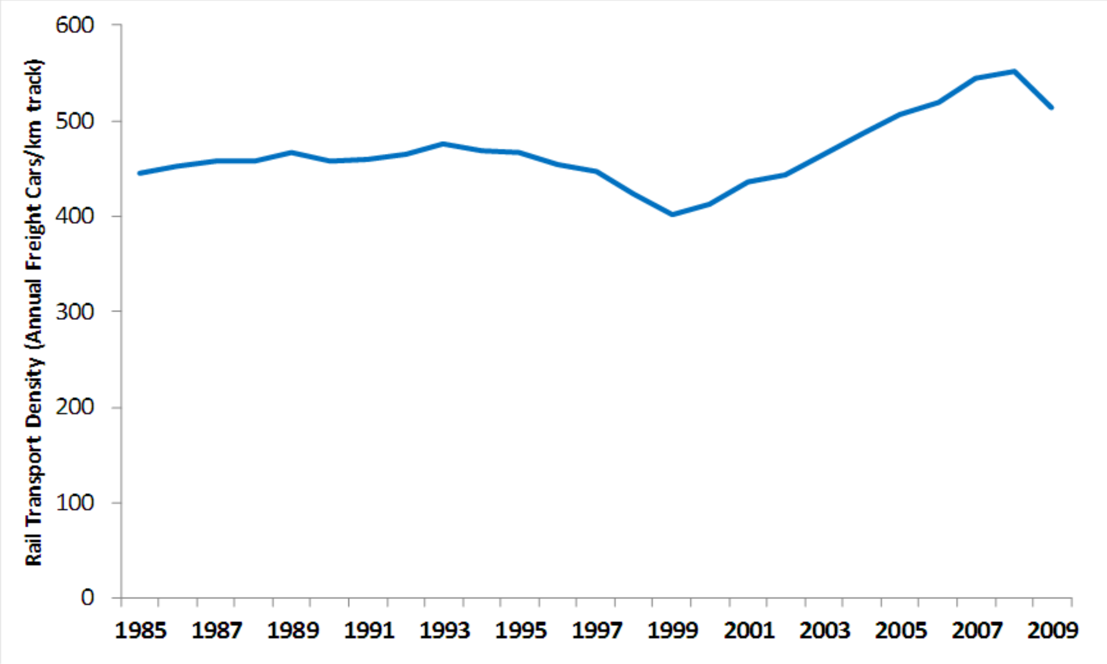


Figure 33. China Rail Freight Transport Density, 1985 to 2009

Source: NBS, various years. China Communications Press, various years.

As China's railway network is becoming denser in terms of freight transport, the average load of each freight car has also increased. At the same time, average static load of freight cars has steadily increased, with average loads increasing from 48 tons per car in 1980 to 63.1 tons per car in 2010. As seen in Figure 34, the static load of coal freight cars has remained slightly higher, growing from 52.5 tons per car in 1980 to 67 tons per car in 2010. As with the growth in the flow of total freight cars, the daily flow of coal freight cars also experienced rapid growth after 2000.

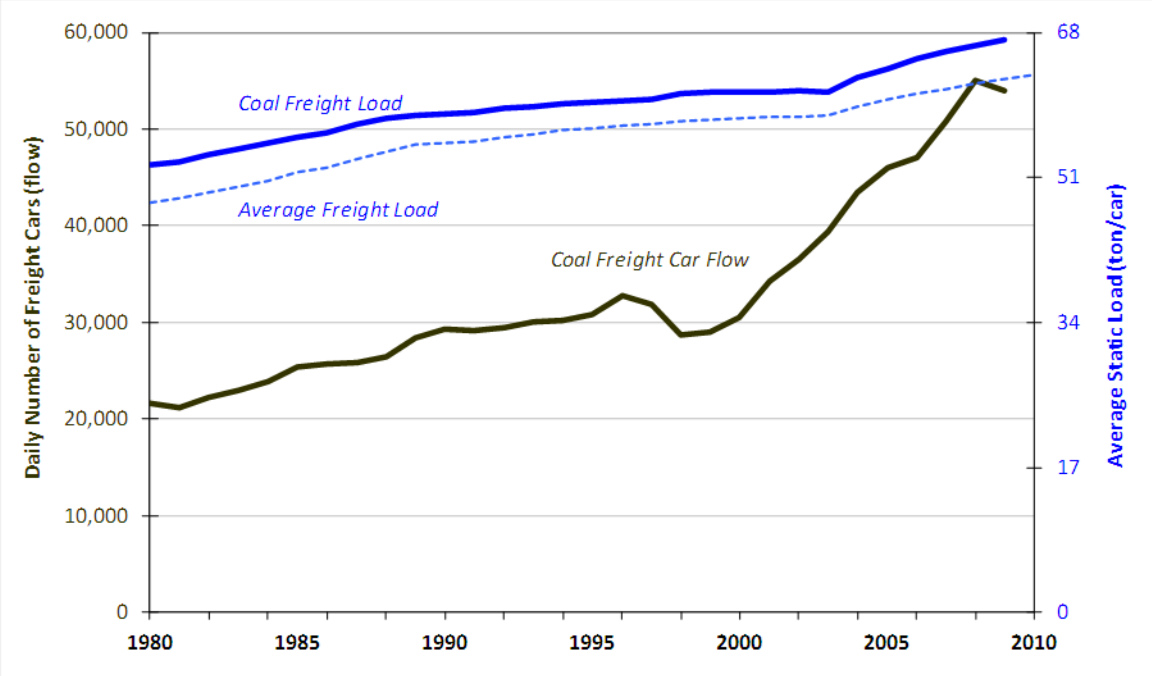


Figure 34. China Railway Daily Freight Flow and Average Loads, 1980 to 2010

Source: NBS, various years. China Communications Press, various years.

Despite growing freight density and loads, coal demand for rail transport is increasingly facing competition from other freight commodities seeking to take advantage of rail transport's lower costs and high transport capacity. Figure 35 shows that in addition to transporting coal, rail transport for building minerals and materials, steel, petroleum, metal and non-metallic ores, and agricultural products have all grown over time. While the coal transported by rail freight grew at annual average of 4.6% per year from 1990 to 2010, coke, steel and metal and non-metallic ores all grew at faster annual average rates of 6.8%, 5.1% and 5.3%, respectively. As a result, coal's share of total rail freight volume has remained relatively stable at below 50% from the late 1980s to present despite rapid growth in total volume of coal transported by rail.

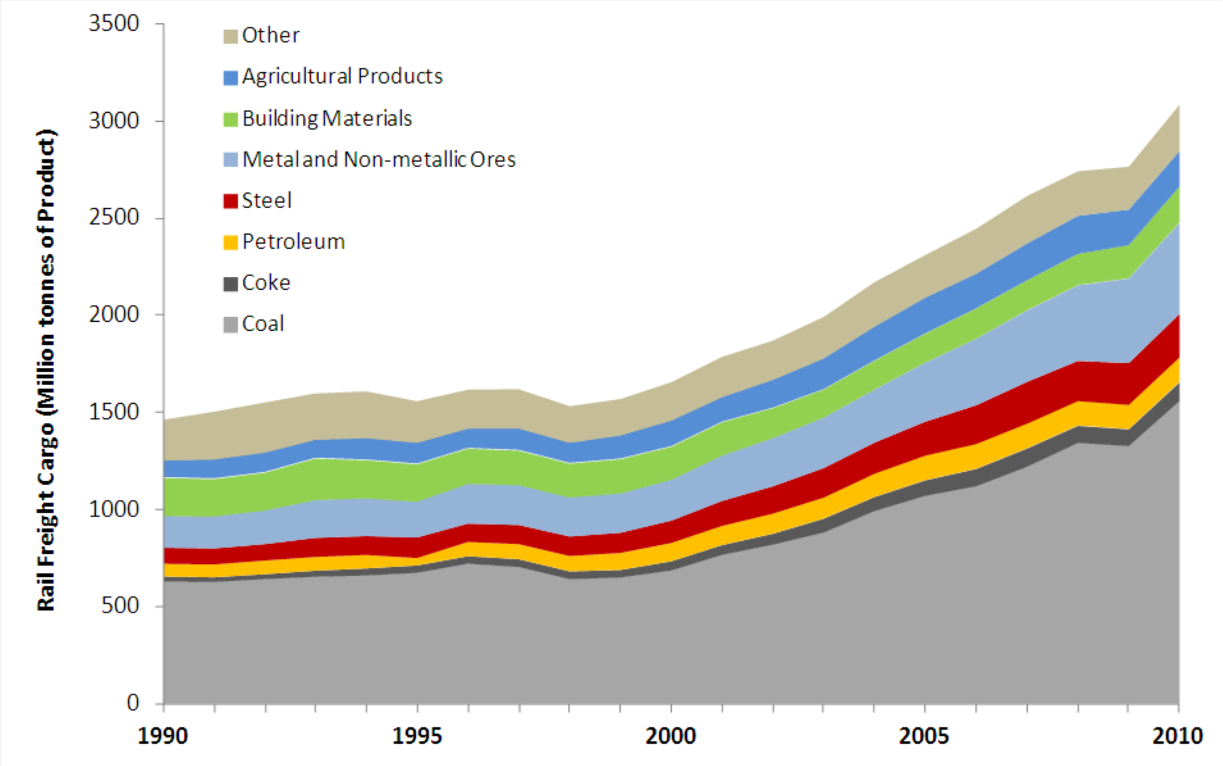


Figure 35. China Rail Freight Transport by Commodity, 1990 to 2010
Source: China Communications Press, various years.

In recognition of the rising demand for rail transport across industries, the Chinese government promulgated its Medium- and Long-term Plan for Railway Development in 2004 with a revised plan focused on extending rail coverage, improving network structure, improving service quality, boosting transport capacity and equipment upgrades released in 2008. Specific targets in the 2008 revised plan include extending total railway length to 120,000 kilometers by 2020 with 50% double-tracked lines and 60% electrified lines. The plan also identified coal transport as a priority with plans to improve its coal transport railway network between the ten major coal bases and add new high-capacity corridors from the West to coastal ports and inland areas in central-south and eastern China to provide total transport capacity of 2.3 Bt (Zhang 2009). For the 12th Five Year Plan period, the Ministry of Railways is planning to invest 2.8 trillion RMB to add 30,000 kilometers of new railways to reach the 2020 target of 120,000 kilometers (People's Daily Online 2011).

The Chinese government's concerted efforts to develop and expand its rail network over the last five years have translated into an unprecedented spike in both new rail capacity and rail investment since 2007, as shown in Figure 36. While the new rail capacity has generally ranged from 500 to 2,500 km added per year, the annual newly added capacity jumped in both 2008 and 2009 were over 5,000 kilometers. The amount of new rail capacity added over these two years is the equivalent of all new capacity added from 2000 to 2007. Likewise, rail investment has been growing at annual average rates of over 30% since 2003 with a high of nearly 600 billion RMB (2000 prices) invested in 2010.

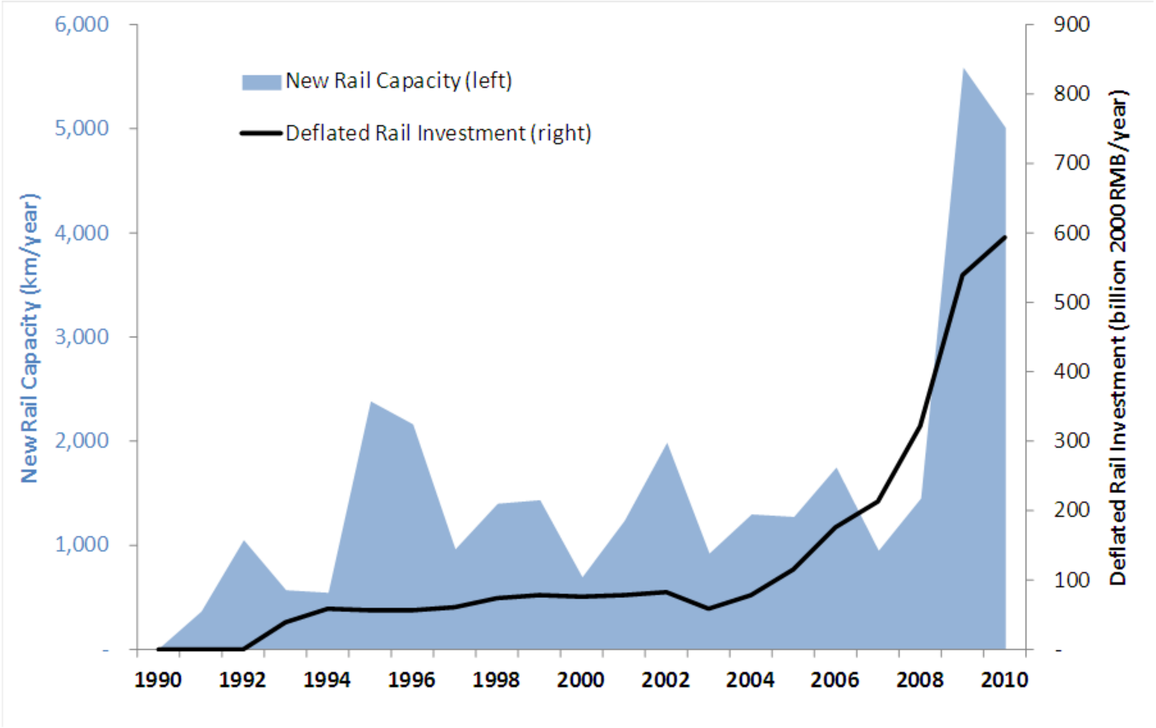


Figure 36. New Rail Capacity and Rail Investment, 1990 to 2010
Source: China Communications Press, various years.

In spite of the impressive boom in rail investment and new capacity additions in the last two years, Figure 37 shows that the incremental investment per kilometer of new track has actually declined after 2007. While the investment per kilometer of new track grew steadily from an average of 66 million RMB in 2004 to 154 million RMB in 2007, the upwards trend reverted with per kilometer investment declining to 112 million RMB in 2010. This suggests that cost increases brought on by the rapid jump in investment demand for materials have moderated, though at a level triple that of a decade ago.

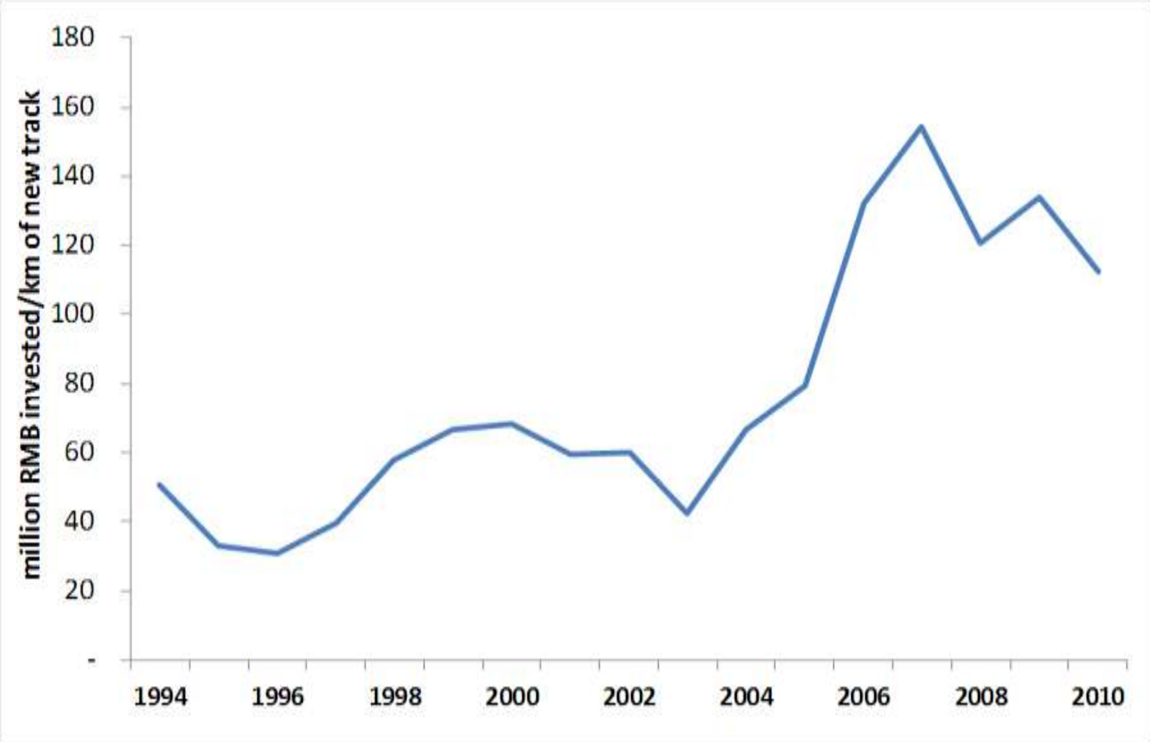


Figure 37. Incremental Rail Investment, 1994 to 2010

Moreover, while total rail track length has grown significantly in recent years, supply has lagged behind demand as Figure 38 shows rail freight volume and particularly coal rail volume far outpacing track expansion from 2000 onwards. While both rail freight volume and coal by rail volume have grown by over 250% in 2010 relative to 1986 levels, rail track length has only grown by 160% in the same period. Although increases in freight density and in average car loads have accommodated part of the disparity, the growing gap between rail capacity and volume of freight to be transported by rail underscores continued capacity constraints and railway bottlenecks.

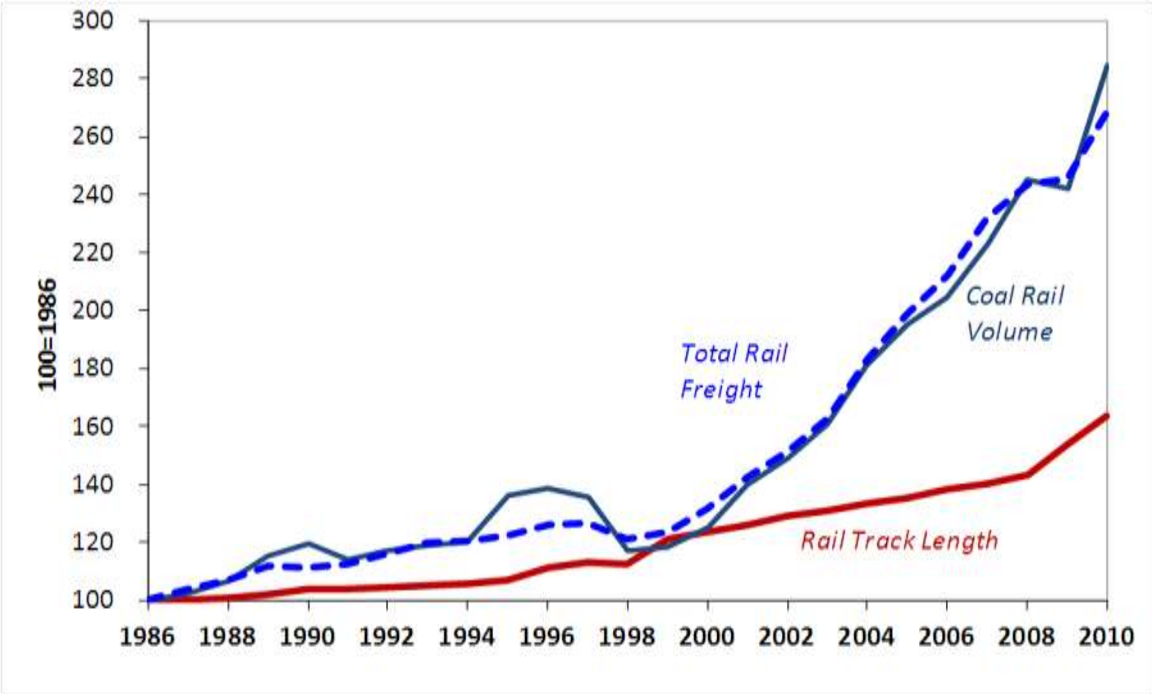


Figure 38. Indices of Total Rail Freight and Coal Freight Volume and Rail Track Length, 1986 to 2010

The imbalance between rail capacity and rail freight growth can be traced back to the persistent lack of competition in a monopolized rail system controlled solely by the Ministry of Rail. In the case of coal, insufficient response to demand and market conditions have hampered the growth of railway networks, and rail capacity growth has lagged behind the growth of coal production. Rail transportation bottlenecks are particularly acute in the major coal producing regions of Western China, which supplies the majority of coal production but only has 17% of China's rail lines (Tu 2011). As the starting point of transport for moving coal from point of production to coastal ports in northern China and end-users in central south China and eastern provinces, the congested railways in western China poses a major bottleneck for the coal supply chain. Figure 39 shows the result of a rail sector that has not been able to keep pace with rapid coal production growth, with the share of coal transported by rail continuing to decrease from 64% in 1980 to only 48% in 2010.

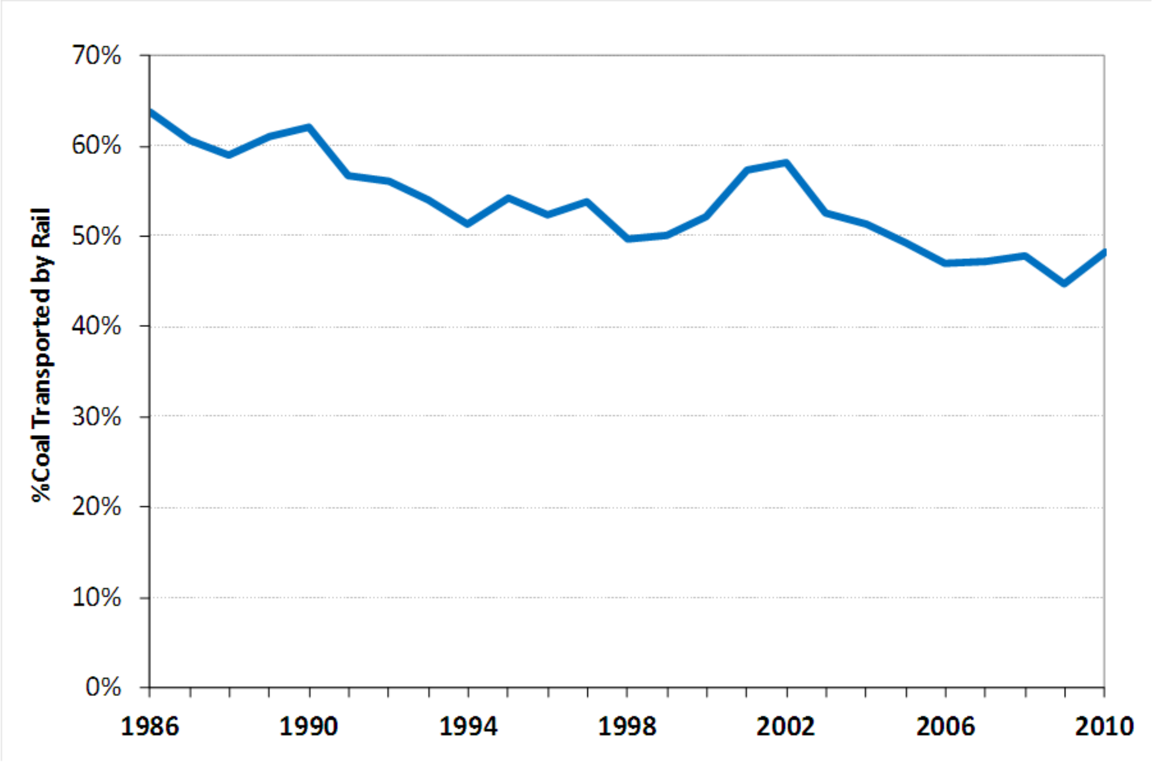


Figure 39. Share of Coal Transported By Rail, 1986 to 2010

Over the next five years, as coal production continue to shift towards western China with target share of 54% of 3,900 Mt of production by 2015, the western railway network will become increasingly critical to moving coal from point of production to point of use. In order for China's coal resources to be transferred to where it is needed, existing challenges with rail congestion and bottlenecks and emerging constraints with rail capacity will need to be quickly and effectively addressed.

6.2 International Coal Trade Flows and Resource Constraints

6.2.1 China's Coal Import Flows

In 2009, China shifted from its historic role as a major net coal exporter to Asian countries to become a net coal importer, with net imports jumping to 103 Mt of coal or the equivalent of 15% of all globally traded coal (Tu and Johnson-Reiser 2012). In 2010, China's coal imports from the world market further increased by 31% from 2009, rising to 165 Mt. Table 13 shows China's coal imports, exports and net coal trade by coal type from 2007 to 2010. During this period, China's coal exports have continued to decrease from 53 Mt in 2007 to 19 Mt in 2010 while its imports have dramatically increased from 2008 onwards.

In terms of the type of coal being imported by China, while anthracite coal imports has remained relatively steady at around 30 Mt from 2007 to 2010, its bituminous coal imports soared after 2007 following declines in domestic production of bituminous coking coal (Table

13). The 400% increase in China’s bituminous coal imports in 2009 became the driving force behind the country’s significantly higher coal imports and new status as a net coal importer. Driven by a myriad of factors including domestic transportation bottlenecks, environmental impacts and safety concerns, coking coal resource constraints and coal pricing, both the volume of China’s coal imports and its coal trade partners have increased over the last three years.

Table 13. China's Coal Imports and Exports by Coal Type, 2007 to 2010

Unit: tons	2007	2008	2009	2010
Export Total	53,187,173	45,434,186	22,395,723	19,030,369
Anthracite	5,254,814	6,074,234	3,235,108	4,255,399
Bituminous	47,856,208	39,213,207	19,113,303	14,701,286
Other	-	347	3	10
Briquettes	76,151	146,398	47,310	73,674
Import Total	51,015,854	40,340,095	125,834,394	164,568,497
Anthracite	28,414,471	19,387,245	34,332,820	26,299,889
Bituminous	19,587,561	16,598,011	72,455,773	98,387,909
Other	3,013,820	4,354,561	19,045,801	39,850,528
Briquettes	2	279	0	30,171
Net Trade	2,171,320	5,094,091	(103,438,671)	(145,538,128)

Source: UN Comtrade Database.

Figure 40 shows China’s major overseas coal suppliers in 2010. As seen in the figure, nearly all of China’s major overseas coal suppliers are located within the Asia Pacific region. Coal imports from outside of Asia, namely from Canada, the U.S., Colombia, Venezuela and South Africa, only total 12% of China’s coal imports. In contrast, some of China’s largest coal suppliers within Asia include Indonesia and Australia, which supplied China with 50% of its coal imports in 2010, followed by Vietnam and Mongolia with another 20%. While Indonesia and Australia have historically provided the bulk of China’s coal imports, other countries in Asia are also emerging as new coal trade partners as China seeks to increase its acquisition of coal from overseas. Mongolia, for example, has recently become an increasingly important overland coal supplier for China given its geographic proximity, low mining costs and abundant coking coal resources (Tu and Johnson-Reiser 2012).

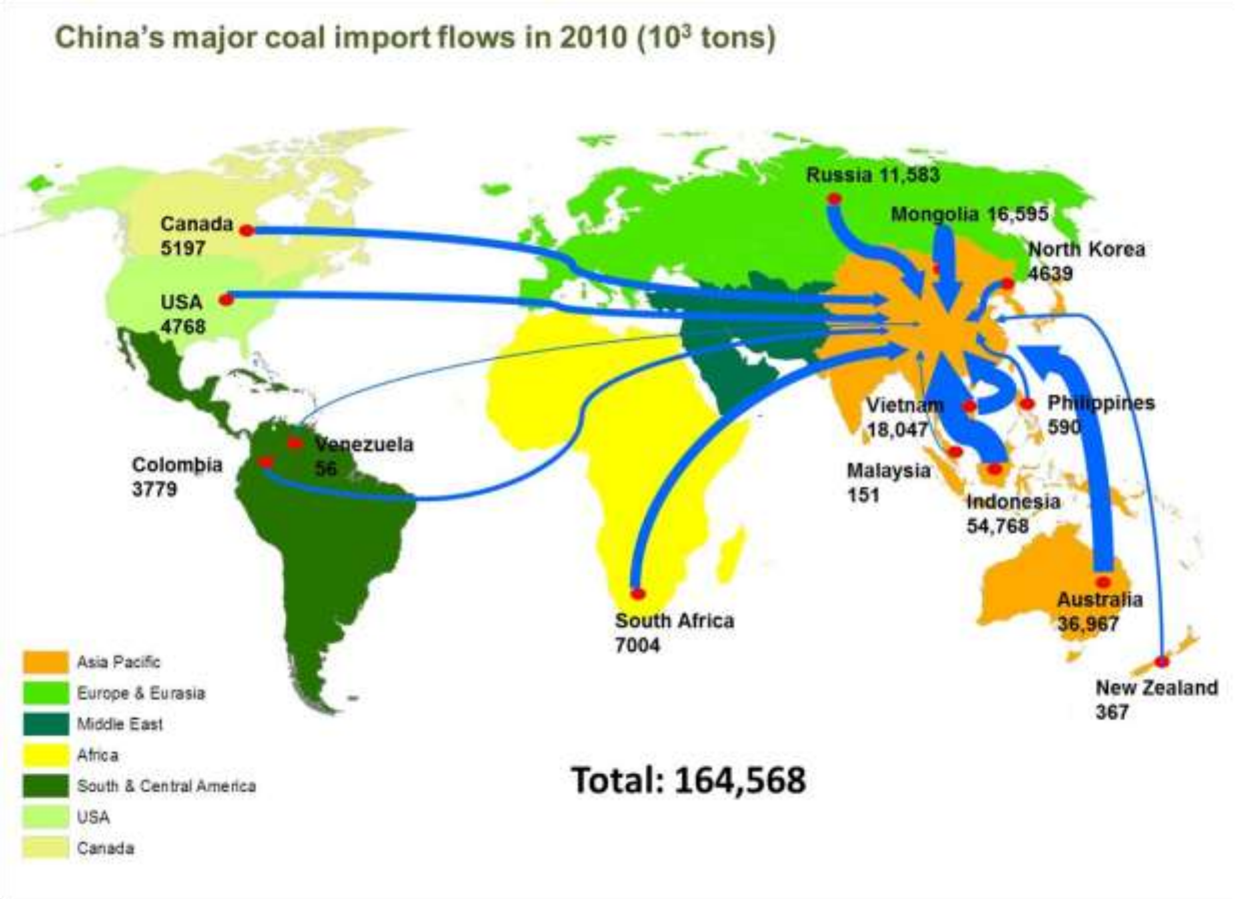


Figure 40. China's Major Coal Import Flows in 2010

Source: UN Comtrade Database 2012.

In terms of imports by coal type, Figure 41 shows that China's anthracite coal suppliers are even more concentrated in the Asia-Pacific region. Vietnam, North Korea and Australia dominate supplies for China's anthracite coal imports, accounting for 69%, 18% and 11% of imports in 2010.

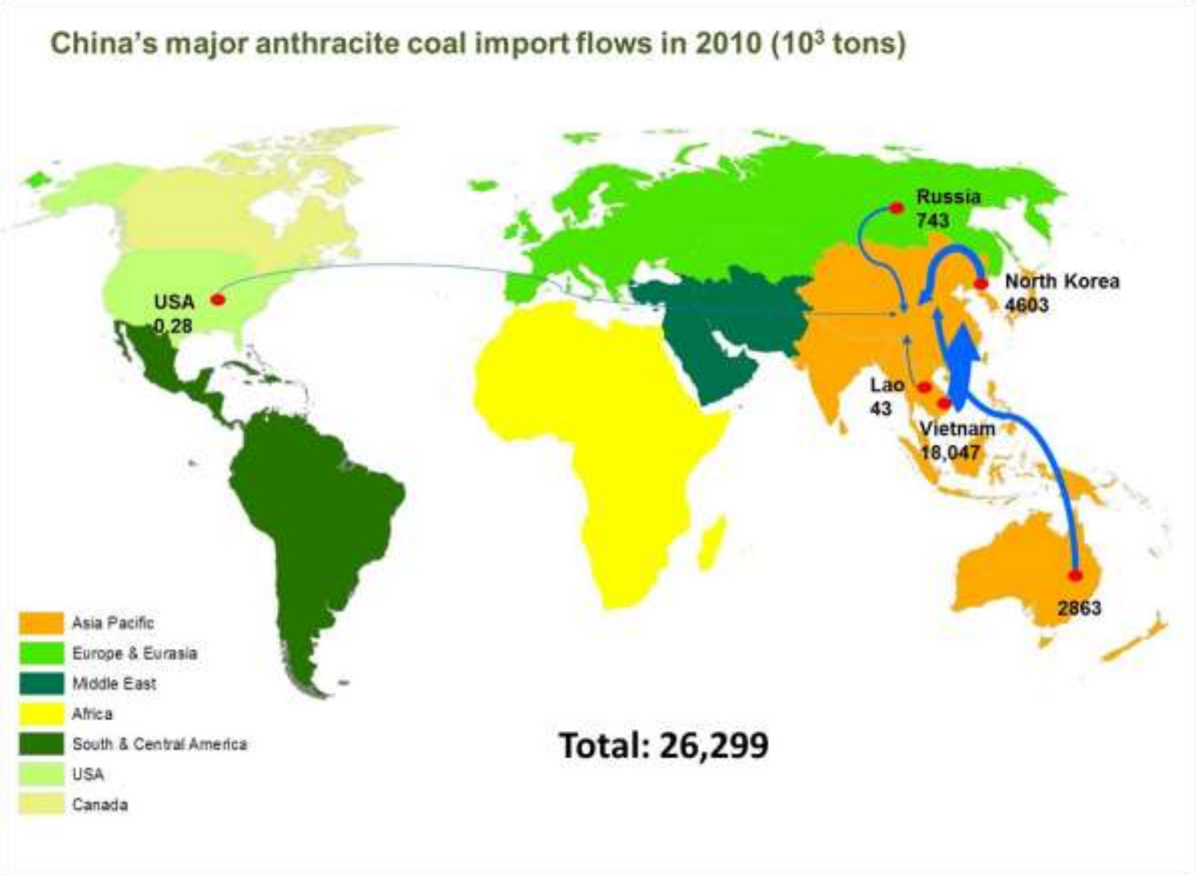


Figure 41. China's Major Anthracite Coal Import Flows in 2010

Source: UN Comtrade Database 2012.

Figure 42 shows the major suppliers of China's bituminous coal imports in 2010. While the sources of China's bituminous coal imports are more varied than anthracite coal imports, there is nevertheless a clustering of major suppliers in the Asia Pacific region. Altogether, the seven coal exporting Asian-Pacific countries supplied China with 71% of its total bituminous coal imports. Of these, Australia and Indonesia together account for more than half of China's bituminous coal supplies, although the specific type of bituminous coal supplied by each country differs. Steam coal used primarily for power generation dominates Indonesian coal exports to China, accounting for 95% of Indonesia's coal exports to China in 2010. In contrast, coking coal accounted for 63% of Australia's coal exports to China in the same year (Tu and Johnson-Reiser 2012). Coking coal also accounted for three-quarters of China's coal imports from Canada and U.S., although the coal supplied by these two countries is much smaller.

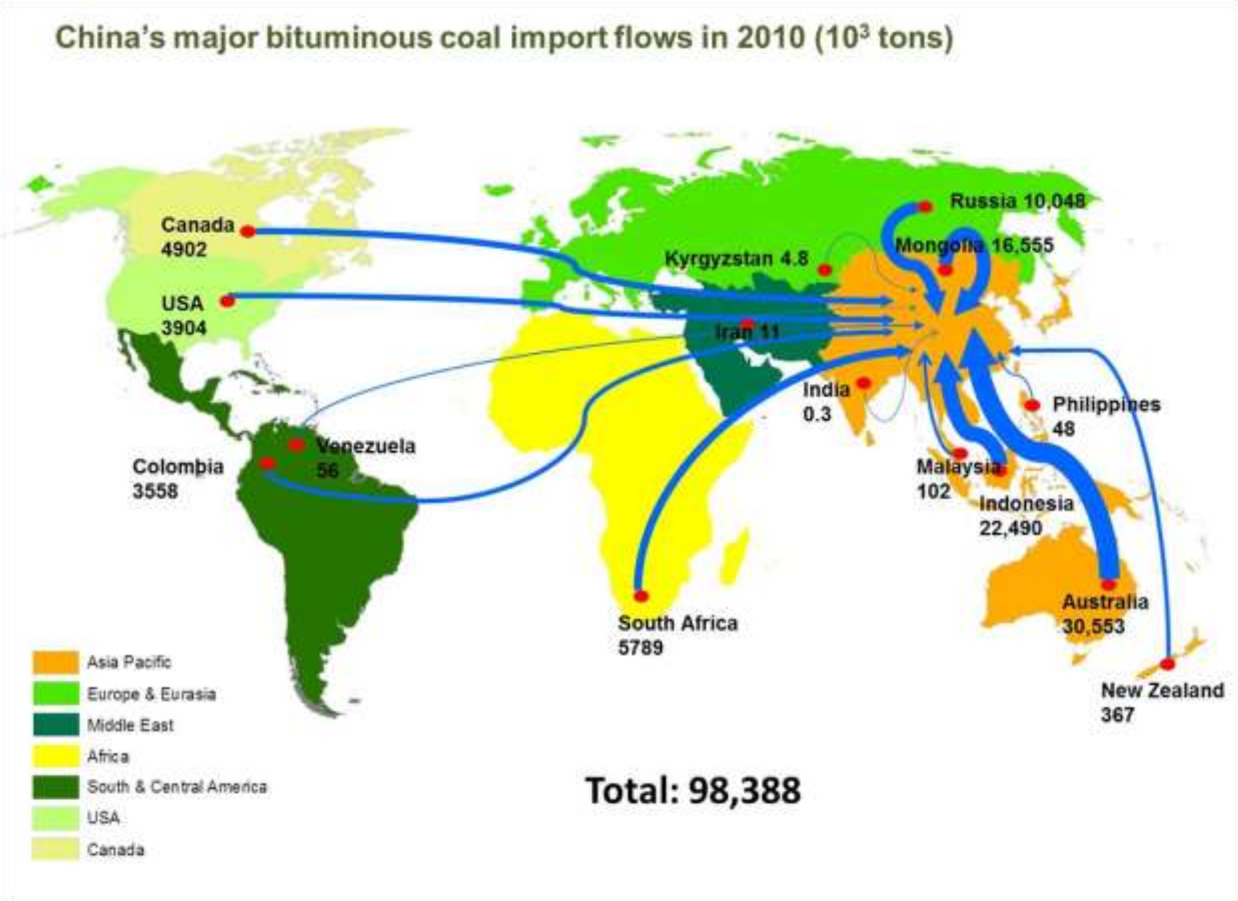


Figure 42. China's Major Bituminous Coal Import Flows in 2010

Source: UN Comtrade Database 2012.

6.2.2 Asia-Pacific Regional Demand for Coal and Implications for China

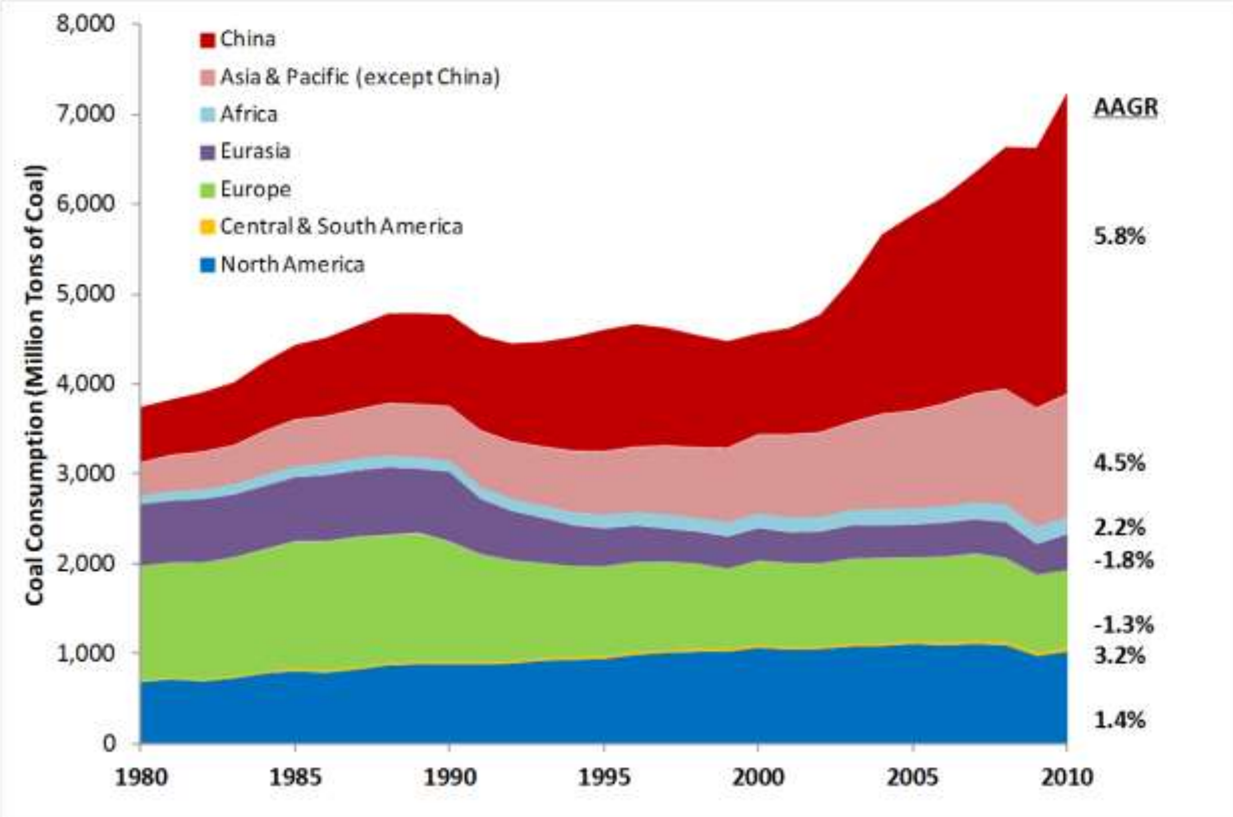


Figure 43 shows the growth in global consumption by region and clearly highlights China's large and rising share of global consumption, particularly after 2003, to a 2010 share of 46%. While China's growing demand for coal over the last thirty years has been impressive with annual average growth rates of nearly 6%, its demand for coal is followed closely by the rest of Asia, which also saw average growth in coal consumption on the order of 4.5% per year. In contrast, the OECD-dominated regions of North America and Europe have experienced slow to negative growth in coal consumption while Eurasia has also seen its coal consumption decrease over time. Over the next two decades, the bulk of growth in coal demand is expected to come from Asia as a result of faster population and economic growth and availability of low-cost and regional coal resources (IEA 2011).

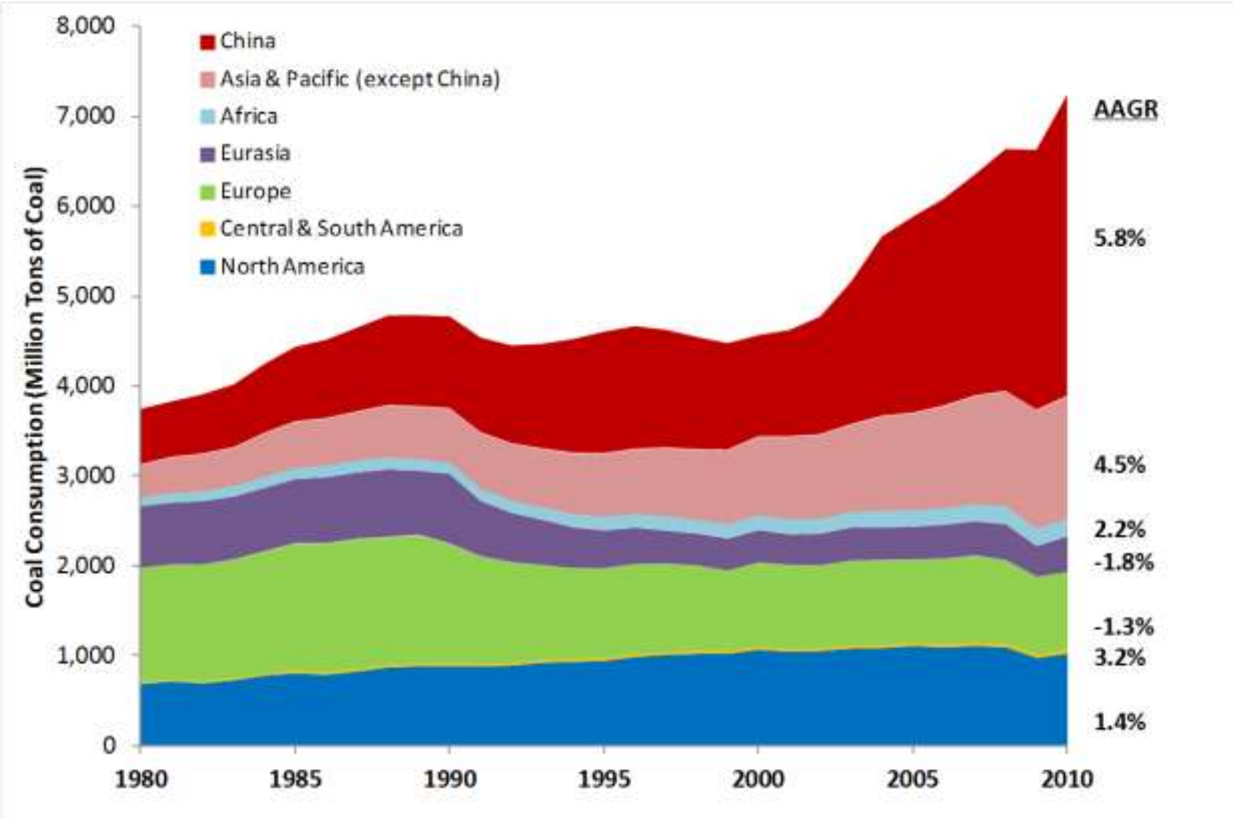


Figure 43. Global Coal Consumption by Region, 1980 – 2010

Source: EIA 2012, International Energy Statistics.

Within Asia, the largest coal consumers after China include India, Japan, Australia, South Korea, Taiwan and Indonesia. In fact, the five top consumers in Asia are also amongst the top ten coal consumers in the world in 2010. As seen in Figure 44, China, India, Japan, South Korea and Taiwan together account for 72% of total consumption by the top ten coal consumers and over 60% of global coal consumption in 2010.

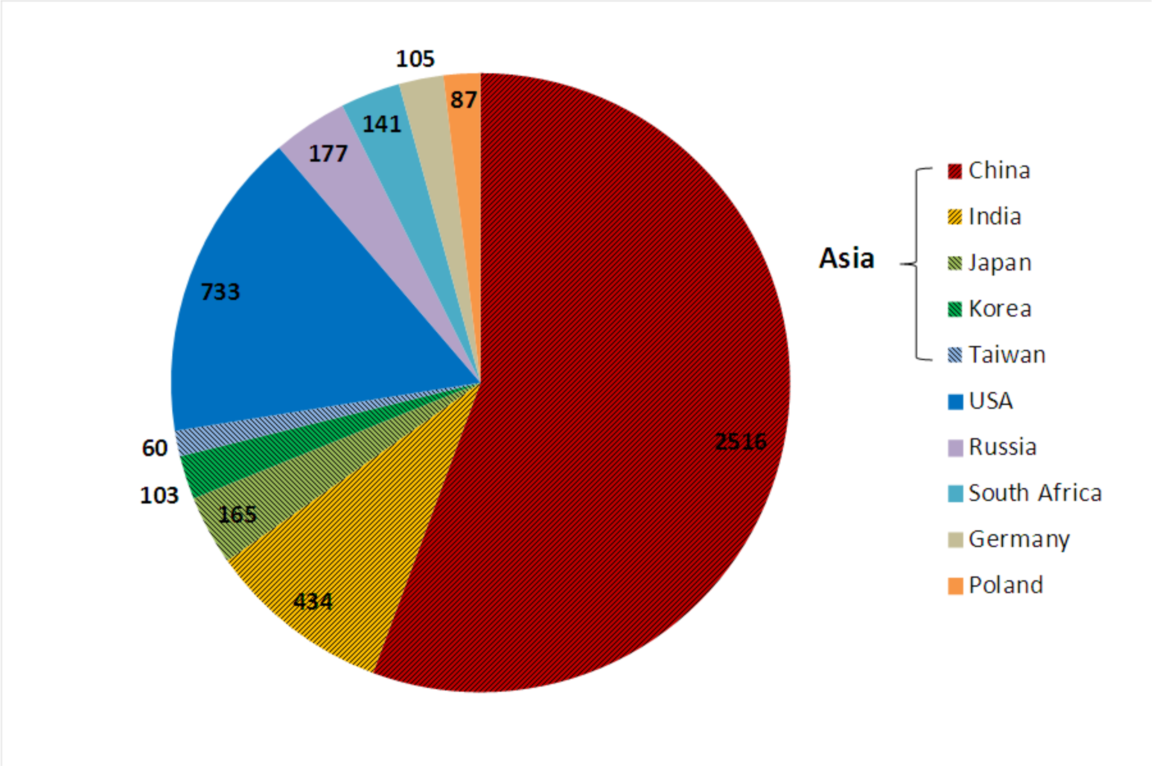


Figure 44. 2010 Coal Consumption by Top Ten Coal Consumers (Mtce)

Source: World Coal Institute 2012, Coal Statistics.

Table 14 shows that the five leading Asian coal consumers are also the top five coal importers in the world in 2010, with the majority of imports as steam coal for power generation.

Table 14. Top Coal Importers in 2010 (Mt)

Unit: Mt	**Total**	**Steam**	**Coking**
Japan	187	129	58
China	177	129	48
South Korea	119	91	28
India	90	60	30
Taiwan	63	58	5
Germany	46	38	8
Turkey	27	20	7

Source: World Coal Institute 2012, Coal Statistics.

Thus, while Asia has continued to supply China with the vast majority of its coal imports, some of China's other Asian neighbors are also importing large quantities of coal from the same coal suppliers. In the coming years, coal demand as well as coal imports from coal-dependent countries within Asia are expected to continue growing. India, for example is expected to see its share of global coal demand increase from its current level of 8% to 11% by 2020 and 15% by 2035 and overtake the U.S. as the world's second largest coal consumer by 2025 (IEA 2011). India's coal demand growth will be driven largely by expansion of its power sector to provide for increasing electrification and industry and other transformation processes. Similarly, fast-growing and coal abundant Indonesia is also expected to become a major contributor in Asia's coal demand growth, with demand also largely driven by a growing power sector (IEA 2011). Indonesia's growth will have important implications for future coal exports to China, as well as other leading coal consumers in Asia, as government policies are beginning to emphasize meeting domestic coal needs over export sales with proposals of implementing a coal export tax. In light of this expected coal demand growth within Asia in the coming years, and possible shrinking supplies from one of the largest coal exporters, China will likely face mounting competition for coal supplies from its coal-importing neighbors.

7. Coal Outlook to 2015 and Beyond

7.1 Coal Demand Outlook

Although urbanization and industrialization are expected to continue to drive China's economy and power demand in the medium-term, recent forecasts of future Chinese coal consumption show a possible flattening out in total consumption in the near term.

As Figure 45 shows, both the U.S. Energy Information Administration (EIA) and the International Energy Agency (IEA) have shifted their coal consumption forecasts for China in the 2011 International Energy Outlook (IEO) Reference Case and the 2011 World Energy Outlook (WEO) New Policies Scenario, respectively, downwards by ~800 Mt of raw coal by 2030. The IEA WEO 2011's forecast is also noteworthy in that it expects a peak in coal consumption at 4,000 Mt of raw coal in 2020. Similarly, more recent forecasts by China's Energy and CO_2 Emissions Research Group in 2009 and LBNL in 2012 also show a leveling off of total coal consumption over the next twenty years – albeit at very different levels and paces – and suggest that future coal consumption will not exceed 4,500 Mt. The LBNL scenario, which assumes that the government's strengthened efforts in improving efficiency and increasing non-fossil generation under the 11th FYP will continue at the same pace through 2030, expects the lowest future growth in future coal consumption with a maximum of around 3,500 Mt. These new forecasts – all of which feature flattening out or at least a slowdown in future coal consumption – differs from previous forecasts in 2007 and 2008 that expected coal consumption to continue rising at relatively fast pace through 2030. This change in forecasted consumption trends may reflect China's recent policy emphasis on reducing coal and suggest that demand could slow as a result of aggressive and effective policy actions.

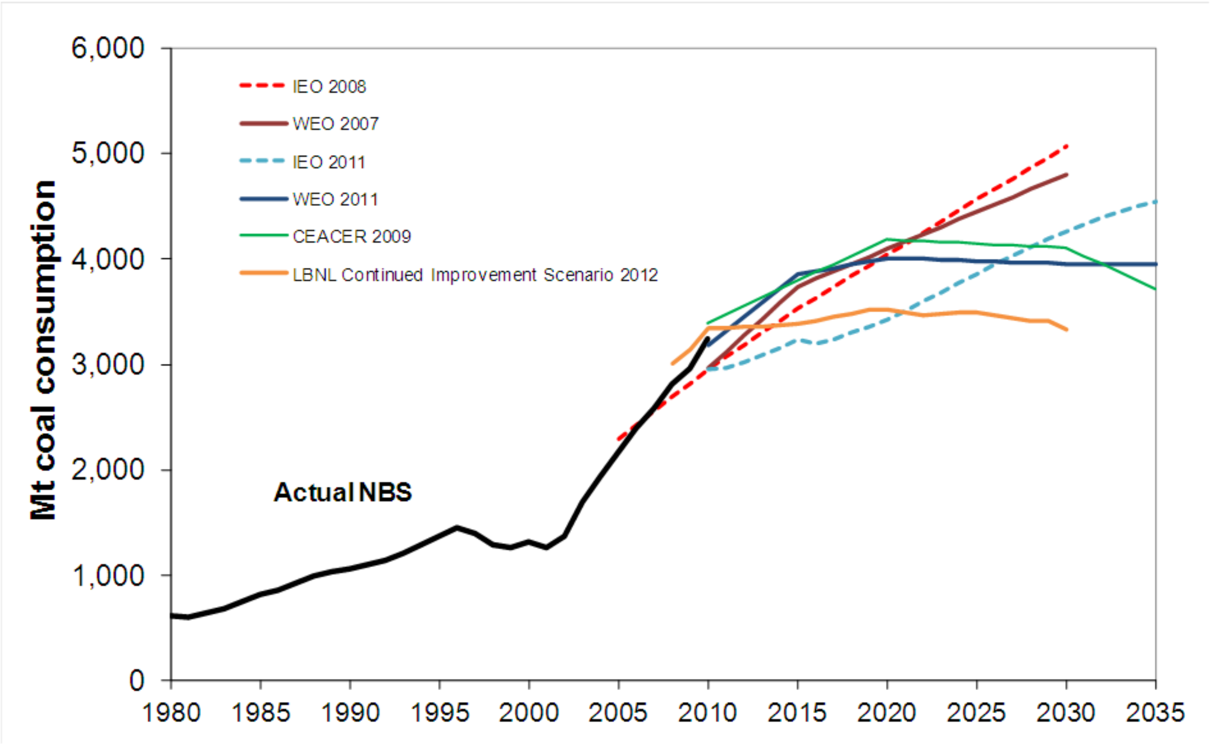


Figure 45. Actual and Forecast Chinese Coal Consumption, 1980 to 2035
Sources: EIA, IEA, NBS, various years. LBNL 2012. CEACER 2009.

A closer look at the LBNL China Energy End-Use model and one possible trajectory of coal consumption by end-use under the continued improvement scenario can help understand how it may be possible to reduce China's future coal consumption. As seen in Table 15, flattened future total coal consumption implies that in addition to decreasing coal input to the power sector, coal demand for all direct end-uses (industry, buildings and other demand sectors) will have to decline as well. While the direct use of coal by buildings will likely continue to decline with urbanization and shifts towards cleaner fuels and electricity, reducing coal demand in industry and the power sector will require efficiency improvements and fuel switching. This is especially true for power generation, which could see its share of total coal consumption fall from current levels of 51% to only 44% by 2030.

Table 15. LBNL Projected Shares of Coal Consumption by End-Use and Growth Rates by End-Use

	2011	2020	2030	2011 - 2030 AAGR
EU1: Industry	16%	13%	11%	-2%
EU2: Buildings	3%	2%	1%	-6%
EU3: Others	1%	1%	1%	-1%
T1: Power Generation	51%	47%	44%	-1%
T2: Coking	20%	22%	24%	1%
T3: Cogeneration, Heat Supply, Mining	10%	14%	19%	3%

Source: LBNL China Energy End-Use Model 2012.

Alongside the expected slowdown in growth of China's coal demand for traditional uses (e.g., industry, power generation), there are also emerging new areas of demand in China's coal industry. For example, China's rapid development of coal seam methane over the last decade and its ambitious 2015 targets for extraction and utilization illustrate that the coal mining industry may soon be providing additional forms of fossil fuels other than coal. Likewise, the government's substantial investment into basic research and development for coal-based polygeneration over the last five years indicate this will become a growing area of coal demand once the technology is fully commercialized. Finally, the coal industry itself is projected to become a larger user of its own output, as greater energy inputs are required per unit of output as production moves into less favorable deposits.

7.2 Coal Production Outlook

In order to elucidate China's potential future coal production pathways, a deeper understanding and evaluation of the economic and technical status of the coal production industry is needed.

From a financial perspective, the average cost of coal mining capacity has increased after over twenty-five years of decline as seen in Figure 46. After reaching the lowest deflated average unit cost of around 400 RMB (2000 constant prices) per ton of capacity in 2003, the average unit cost of new coal capacity has reverted to an upward increasing trend. By 2010, the average unit cost had reached over 700 RMB per ton of new coal capacity. These rising capacity costs will underpin rising coal production costs.

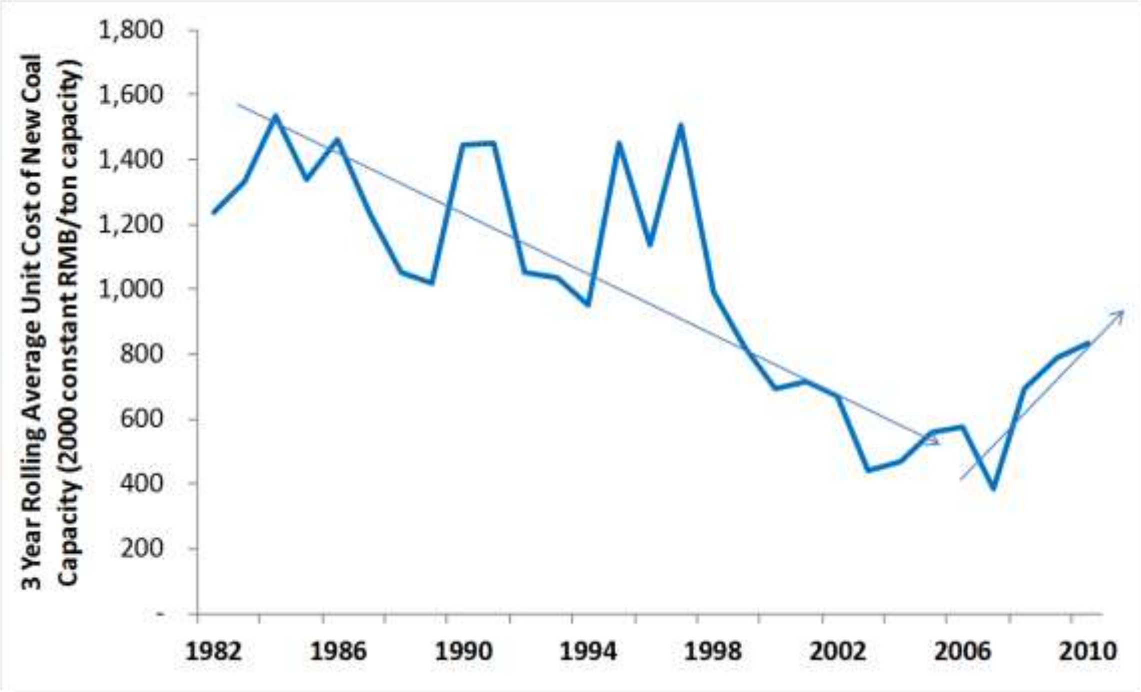


Figure 46. Average Unit Cost of New Coal Capacity, 1982 to 2010

Source: NBS, various years.

In parallel to the trend of rising cost of new coal capacity, Figure 47 shows that the average production cost of state-owned mines responsible for the bulk of domestic coal production have also risen steadily since 2003. Average sales price per ton of coal have also risen over the last decade, but the fast growth in production costs means that production costs has quickly caught up to increases in sales price. By 2009, coal production costs had already exceeded the 2007 price of coal.

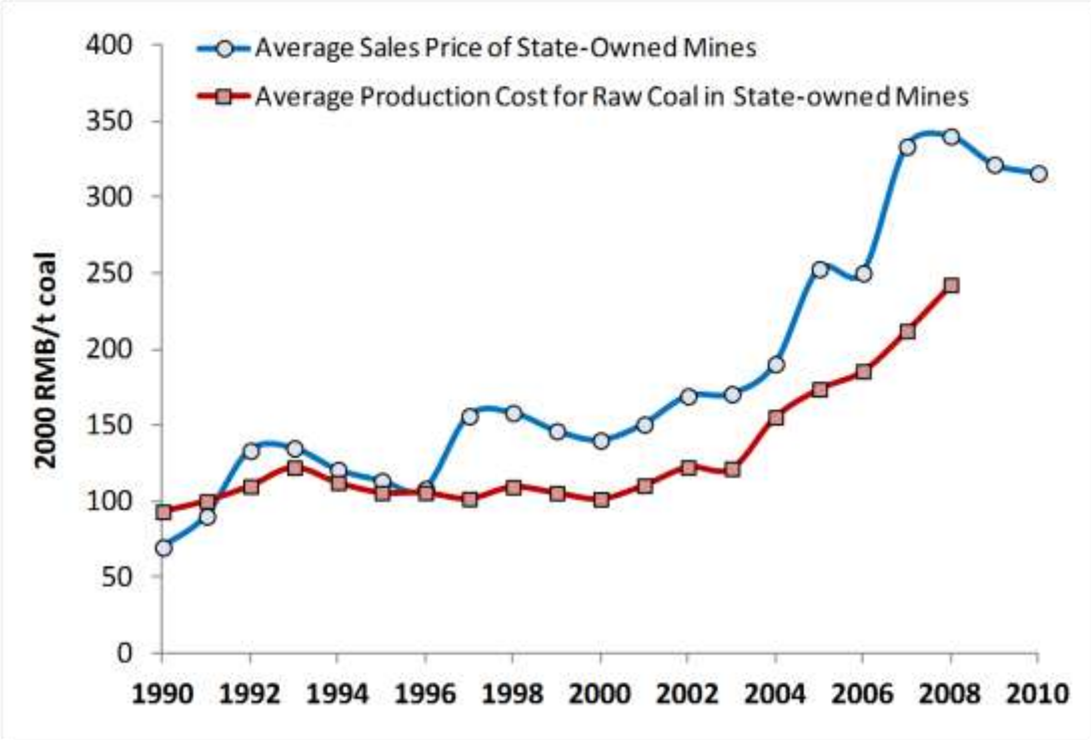


Figure 47. Average Sales Price and Production Cost of State-Owned Mines, 1990 – 2010

The increase in average coal capacity cost as well as production costs of state-owned mines can be traced back to two recent technical trends in the coal mining industry: leveling off of coal mining mechanization improvements and declining productivity growth. Figure 48 shows two phases of improvements in the rate of coal mining mechanization in state-owned mines: an initial period of rapid improvement from 1980 to 1993 and a second period of slower but continuous improvement from 1993 to present. After 2000, in particular, improved mechanization has significantly boosted China's coal production outputs. Actual national average mechanization of all coal mines have improved as well, but nevertheless remained lower at 65% compared to the higher mechanization of 91% for state-owned mines in 2010. By 2015, the mechanization of state-owned mines will be near the maximum upper bound of 100% if the 95% target is reached. This suggests that gains from coal mining mechanization will likely level off in the coming years as maximum mechanization in state-owned mines is achieved, but further gains are possible in the non-state mines, though these mines account for less than 40% of total output.

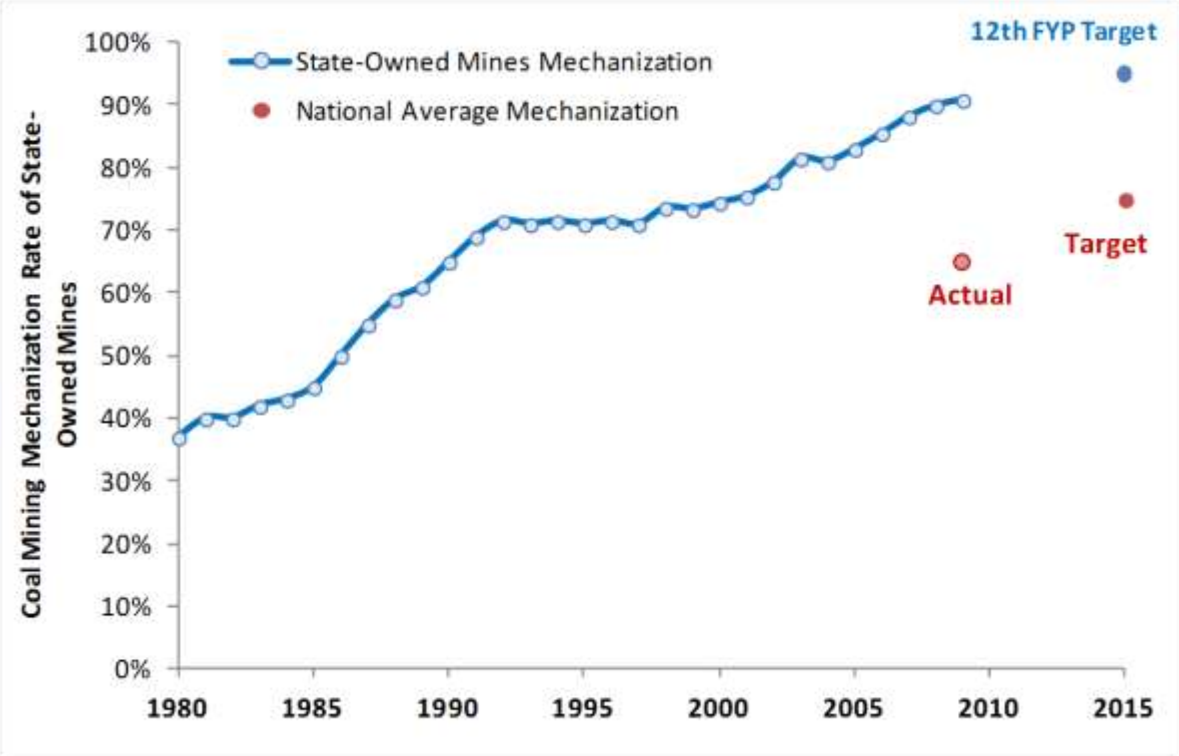


Figure 48. State-Owned Mines' Coal Mining Mechanization Rates, 1980 to 2010

Source: China CIRI, various years. NDRC 2012.

In terms of coal mining productivity, rising mechanization has allowed state-owned mines to maintain steady increases in the tons of coal mined per person-hour since the 1980s with year-on-year productivity growth rates mostly in the 5% to 12% range (Figure 49). After 2003, however, year-on-year productivity growth began to slow and has exhibited a downward trend with a low of only 3% growth in 2010. This mirrors the trend of slowdown in mechanization improvements and also implies that coal production gains from productivity growth are also beginning to level off. This is particularly important given that the average underground mine depth in China is deeper at around 500 meters when compared to only 90 meters in the U.S, and the vast majority of China’s coal is mined in underground mines.

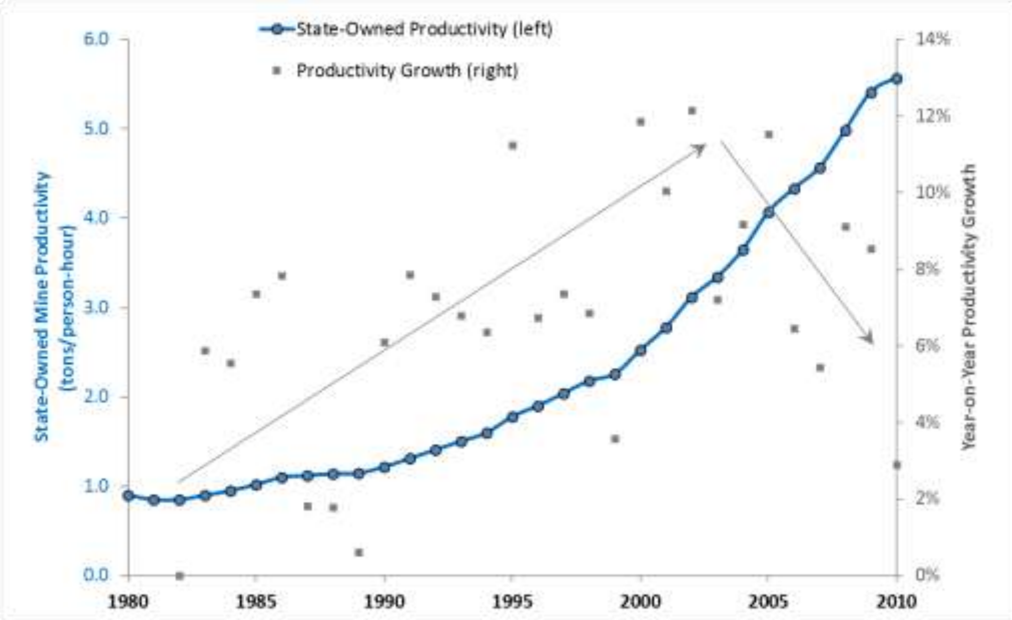


Figure 49. State-Owned Coal Mines Productivity and Productivity Growth, 1980 to 2010

Source: China CIRI, various years.

Figure 51 shows a continual increase in coal production profitability per ton of coal produced after a decade of loss and zero profitability in the early 1990s prior to price reforms. This upward trend in coal production profitability after 2000 and double digits annual growth reflects the coal production gains that have resulted from improved mechanization and high productivity growth over the last decade that so far have outpaced the rise in costs.

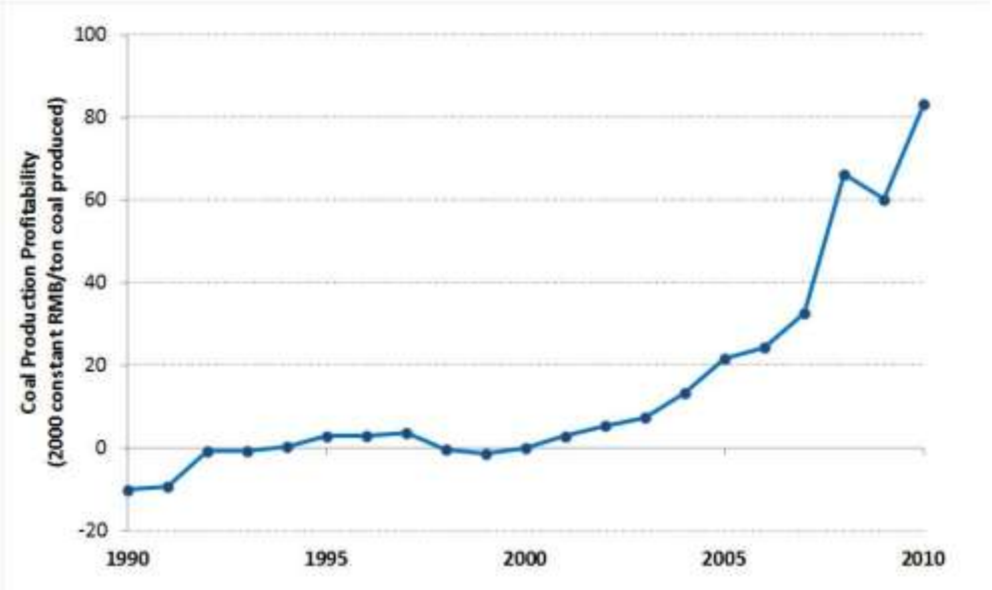


Figure 50. Coal Production Profitability, 1990 – 2010

Source: NBS, various years.

Figure 51 shows that Large- and medium-scale coal producing enterprises have benefited the most with the highest net profits, followed closely by state-owned enterprises while the profitability of foreign-funded enterprises, of which there are few, has remained essentially flat.

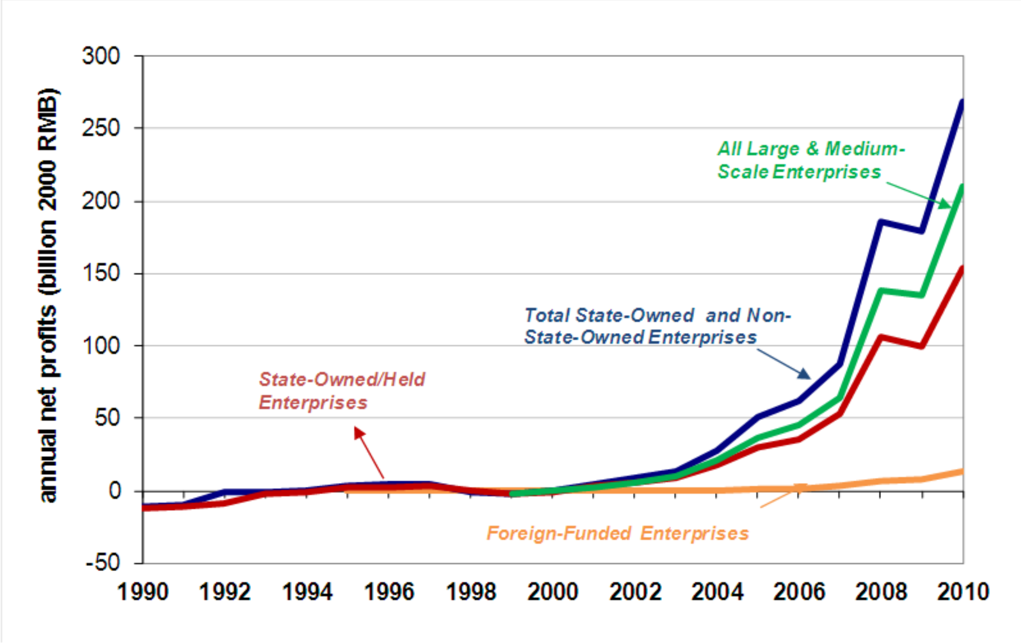


Figure 51. Coal Production Profitability by Type of Enterprise, 1990 - 2010

Source: NBS, various years.

However, the profitability trends only represent one side of the story as Figure 52 shows that both the number of coal producing enterprises with losses and the total amount of loss has started to follow a steep upward trend within the last decade. By 2010, over 1,000 of China's coal producers faced net losses with deflated losses totaling nearly 4 billion RMB (2000 constant prices).

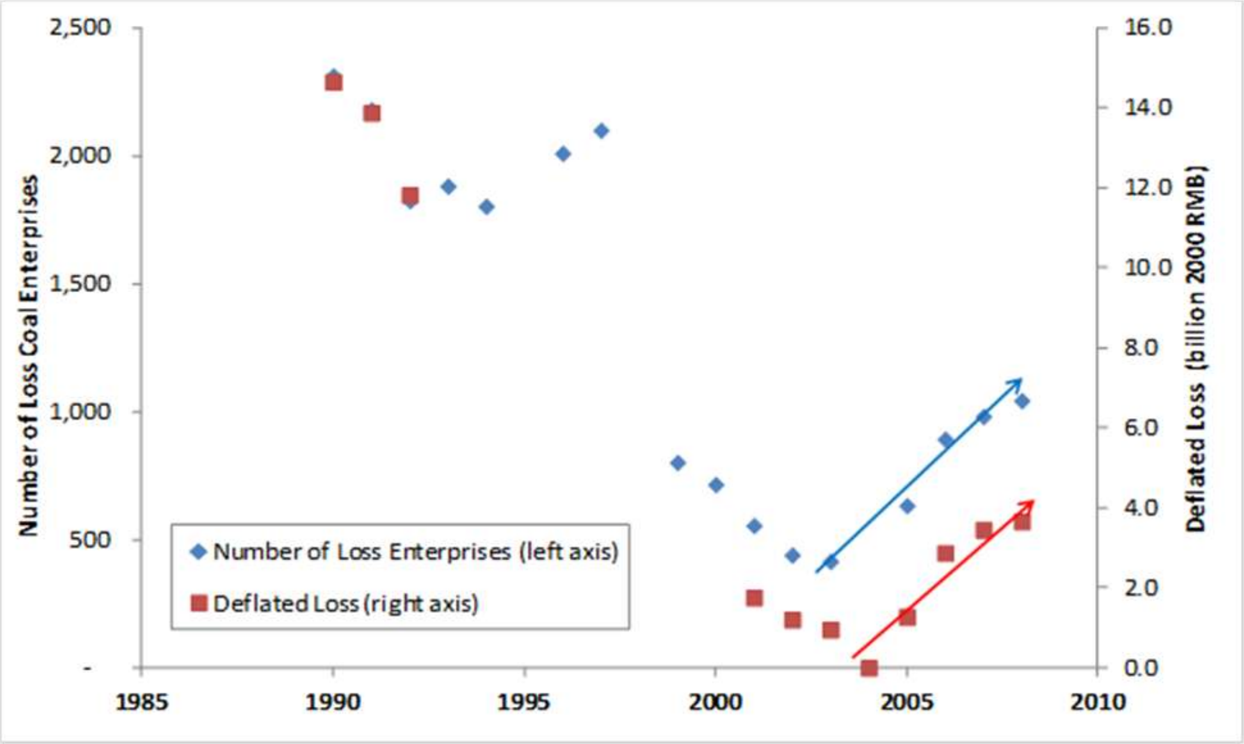


Figure 52. Number of Coal Enterprises with Losses and Total Losses, 1990 - 2010

Source: NBS, various years. China Industry Economy Yearbook, various years.

All of these various trends in mechanization, productivity growth, and costs reflect a broader underlying trend of increasing energy inputs into the coal sector as easy-to-mine and cheap reserves are depleted and the industry moves into more challenging deposits and locations. As seen in Figure 53, the energy return on direct energy invested (ERODEI) illustrates the ratio between the energy value of the raw coal produced compared to the energy input into the mining process. As mechanization and productivity rose in the 1990s and 2000s, more coal could be produced for the same amount of energy input, resulting in a rising trend in ERODEI. Around 2006, when the ratio reached a high of 21.9, however, the trend reversed, indicating that a ton of raw coal production is now requiring rising amounts of energy inputs to extract. To the extent that this trend continues, even greater volumes of coal will need to be produced to supply to the economy to offset that portion of the industry's output that goes back into production of coal (either directly or indirectly in electricity).

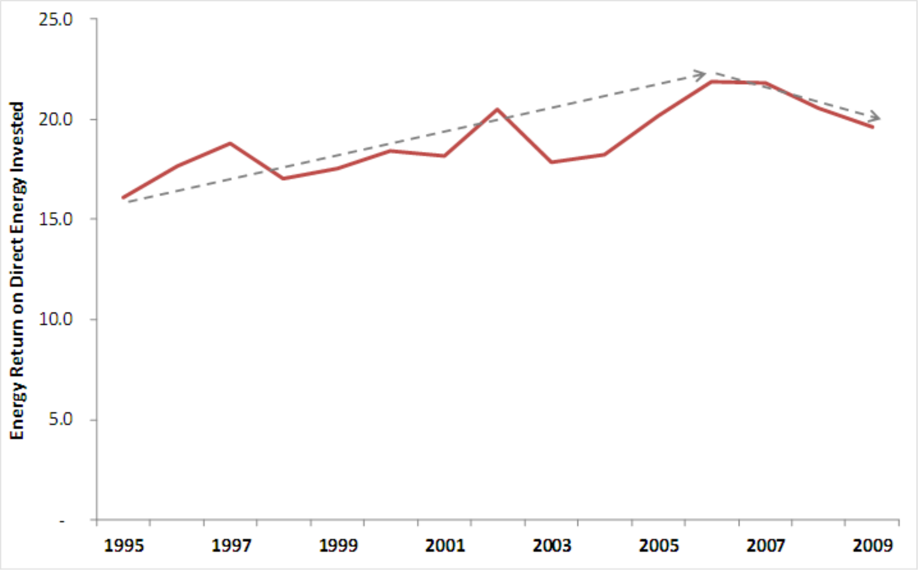


Figure 53. Energy Return on Direct Energy Invested for Coal, 1995 to 2009

Source: China Energy Statistical Yearbook, various years.

8. Conclusions

China's low carbon development programs began in 2007 and have taken off in the last two years with the launch of several national programs, including the National Development and Reform Commission (NDRC)'s pilot low carbon development program for 5 provinces and 8 cities. The above evaluation of the existing systems of low carbon indicators and low carbon plans for the 8 NDRC pilot cities reveal challenges that have resulted from the formation of several parallel low carbon development programs in a very short period of time. The absence of explicit definitions for low carbon city and multitude of parallel programs have created complexity, confusion, and overlaps in the development of low carbon cities. Some cities belong to several pilot programs, and while it might be beneficial to receive technical and financial support through different programs, the overlap of programs has resulted in unclear focus, repetitive planning processes, and ineffective implementation of low carbon development planning.

This study also finds that there is a significant need to provide explicit definitions, guidelines and methodologies for municipal low carbon plans from the national level. Large divergence was observed among the low carbon plans in terms of targets, scope, content and planning and implementation procedures. Clear definitions, guidelines and methodologies would help provide a much needed comprehensive framework with clear targets and focused scope for low carbon development planning for municipal governments, particularly those that are relatively new to the energy and carbon field.

In terms of target-setting, carbon emission targets have largely overshadowed the need for energy consumption targets in existing low carbon plans. Going forward, the overall targets of the low carbon city plan should include both carbon emission and energy consumption targets, which correspond to China's 12th FYP and 2020 targets. The roadmap of the low carbon city plans also need to be formulated and sector-based targets should be decomposed from the overall targets to enable better implementation, performance evaluation and policy adjustment. A series of supportive policies such as industry or sector-specific 12th FYPs also needs to be developed under the direction of the low carbon city plan. The sector targets in the low carbon city plan can serve as the overall target for each special plan, while projects and measures proposed in the special plan can help ensure effective implementation of low carbon city plan.

Existing regulations and policies are insufficient for implementing low carbon city plans and more relevant regulations and policies on energy conservation, efficiency, energy audit and monitoring need to be established. In particular, more market-based, rather than administrative, instruments need to be introduced in order to facilitate greater participation and coordinated implementation of the low carbon city plan. Third-party surveillance and evaluation of low carbon city plan implementation at the different levels of governments are also needed. Public disclosure and information dissemination should be more consistent and comprehensive, allowing the public to participate and oversee implementation of the low carbon city plan.

After years of continuous growth, coal production appears to be reaching a turning point as highlighted by analysis conducted in this study. Since 2000, coal output has more than doubled, supported largely by policy-driven development of new coal production regions in Western China, modernization of mining techniques, and consolidation of the industry into larger-scale mining companies. Geographical concentration of coal production is expected to continue moving westward, while consumption centers will remain in the highly developed eastern coastal regions. The transportation needs for moving all this coal is a challenge and transport bottlenecks, particularly in the railway system, will remain. In recognition of rising transport demand for all freight commodities and not only coal, the government has taken steps to expand China's rail network but investment and capacity additions have been insufficient in keeping pace with coal transport demands. For the first time, water has now replaced rail as the major mode of long-distance transport for coal. At the same time, truck transport will undoubtedly remain important in intra-provincial and short-distance transfers of coal, contributing further to China's strong growth in diesel demand. An emerging area in coal production is the development of coal seam methane extraction and utilization. China's coal reserves are now seen as a potentially large source for coal seam methane, if technological and policy challenges can be overcome.

On the demand side, the power sector will remain the main driver of coal demand, but acceleration of alternative energy including renewables, hydro and nuclear, and to a lesser extent, natural gas, may slow the growth in coal generation. The coal-power conflict that exists in China needs to be resolved to reduce distortions in the market. The resolution is likely necessary from the power price side, as pressure for reform is mounting with larger amount of renewable energy generation and coal seam methane power generation. Formation of coal-power bases is one way to defer reform by bringing coal production and power generation within a company, where internal financial settlements of pricing differentials can avoid the more public disputes evident at the annual Coal Conferences.

Coal demand in other sectors is likely to plateau soon as growth in iron and steel, cement and other heavy industry moderates and energy demand from the buildings sector are met with higher quality fuels such as electricity and natural gas/LPG. Power sector decarbonization is therefore the key to reducing growth in China's coal demand. In addition to the power sector, there are also potential new sources of coal demand from government-supported, coal-based polygeneration development. Taking recent trends into consideration, the overall coal demand outlook through 2020 ranges from a high of 4 Bt coal in the IEA outlook to 3.5 Bt coal in the LBNL model.

In the international arena, China has quickly become one of the largest coal importers in the world and already impacts prices in the Asia-Pacific region. China's appetite for imports from the world market have increased as coal imports often have lowered costs compared to northern coal for (primarily southern) coastal importers. Coal imports also serve as a swing source for some coastal power producers faced with fixed electricity prices but rising domestic coal costs. However, China's ability to continue to increase its coal imports rests on outlook for coal exports from the major suppliers of Indonesia and Australia on the supply side; and competing demand from Japan, Korea, and Taiwan on the demand side.

Looking forward, the NDRC has proposed a 3.9 billion production cap for coal by 2015. Overtly, this is part of the government's policy to achieve emissions reductions by 2015, but may also be in recognition that recent industry trends have indicated increasing coal production in coming years will be more challenging than in the past decade. These tell-tale technical, economic and physical trends include: a declining rate of mechanization growth, a declining rate of worker productivity growth, increased transportation costs and logistical problems, rising investment costs, rising production costs, and declining energy return on direct energy investment. These all point to greater difficulties and challenges in increasing China's coal production over the next five to ten years when domestic coal demand is expected to continue rising.

As the largest coal industry in the world, China's coal sector remains precariously balanced between these supply forces and demand trends. As the difficulty in sustaining growth in domestic output grows, China has looked beyond imports to consideration of acquiring resources directly overseas, such as in Mongolia, Indonesia, Australia, Russia, South Africa, and Botswana, but each of these countries presents its own combination of logistics, infrastructure, labor costs, or environmental policy challenges to rapid scalability. Mongolia is the site of the largest untapped reserves of coking coal, but Mongolia's desire to balance China and Russia with other developed economies suggests that the reserves are unlikely to become "captive" to China.

China's coal industry is also among the world's most advanced in terms of ongoing research and development into coal mining technology, particularly for thin-seam coal exploitation. The ability to mine thin seams effectively would extend the life of some coal mining areas and may temper the decline in productivity growth. Mining thin seams, however, is already an indication that the richer and easier-to-access reserves are in decline.

Although it is difficult to see potential breakthroughs that would fundamentally change the trajectory of China's coal supply, it is possible for China to experience rapid and sharp declines in the demand for coal as a result of economic disruption or severe recession. Although this would relieve pressure on the industry to expand output and likely result in falling coal prices, bringing relief to the power sector as well, a long period of low coal prices would, as in the case with the oil industry today, undermine investment in high-cost new supplies, potentially creating further supply strains as the economy rebounds. Nonetheless, despite the current focus on rapid expansion of non-fossil power generation to displace coal, the enormous scale of the industry will leave China dependent on the health of its coal system for many years to come.

References

Anderson B. 2003. “Barriers to the implementation of coal syngas/polygeneration (CSP) in China.” *Energy for Sustainable Development* 7 (4): 25-27.

Baoding Development and Reform Commission. 2008. “Baoding city people’s government views on building low-carbon city.” 24 December, 2008. See also: http://news.bdall.com/epaper/bdrb/page/1/2008-12-24/01/46931230098875390.pdf.

Baoding Municipal Government. 2012. “Baoding China Electricity Valley Development Plan (in Chinese). http://www.docin.com/p-19023455.html

Cai N. 2010. “Development of Coal Gasification & Polygeneration in China.” Presentation at IEA-MOST Workshop on Fossil Fuel Technologies. Beijing, China: 11 June 2010.

China Coal Information Research Institute (CIRI). N.d. *China Coal Industry Yearbook (in Chinese),* various years. Beijing: Coal Information Research Institute.

China Coalbed Methane Clearinghouse (CBMC). 2004. *Investment Guide for China CMM/CBM*. http://www.epa.gov/cmop/docs/guildline3.doc

China Communications Press. N.D. *China Transport Statistical Yearbook (in Chinese),* various years. Beijing: Communications Press.

China Energy and CO_2 Emissions Research Group (CEACER). 2009. *2050 China Energy and CO2 Emissions Report (in Chinese)*. Beijing: Science Press.

China Society for Urban Studies, Ed. 2010. *The Progress Report on China's Low-Cabon Eco-city Development (in Chinese).* Beijing, China Building Industry Press.

The Climate Group. 2010. *Low Carbon Cities -- An International Perspective*. London, The Climate Group.

Duan Q. 2007. “Status of China’s coal transport corridors and study on optimized policies (in Chinese).” *Research and Approach* 29: 27-32.

Energy Information Administration (EIA). 2011. International Energy Outlook 2011. http://www.eia.gov/forecasts/ieo/index.cfm

Equity Research. 2010. “Coalbed Methane in China.” Standards Chartered Bank. http://www.enviro-energy.com.hk/admin/uploads/files/1292913959Coalbed_combined%20%28Standard%20Chartered%29%28Dec%202010%29.pdf

He G. 2012a. *China’s Low Carbon Eco-Cities Development and Indicator Systems.* Report prepared for the China Energy Group. Berkeley, California: Lawrence Berkeley National Laboratory.

He G. 2012b. “China’s Coal and Power Conflict and Its Implications to Global Energy and Climate Policy.” Presentation to China Energy Group. Berkeley, California: 29 February 2012.

International Energy Agency (IEA). 2009. Coal Mine Methane in China: A Budding Asset with the Potential to Bloom. Paris: OECD/IEA.

IEA, 2011. World Energy Outlook 2011. Paris: OECD/IEA. http://www.iea.org/weo/docs/weo2011/homepage/WEO2011_Press_Launch_London.pdf.

Jiang K. 2011. “Potential Secure, Low Carbon Growth Pathways for the Chinese Economy.” Center for Strategic and International Studies (CSIS) Working Paper. Washington, DC: CSIS. http://csis.org/publication/potential-secure-low-carbon-growth-pathways-chinese-economy

KPMG. 2011. China’s 12th Five-Year Plan: Overview. March 2011. See also: http://www.kpmg.com/cn/en/IssuesAndInsights/ArticlesPublications/Documents/China-12th-Five-Year-Plan-Overview-201104.pdf.

Lawrence Berkeley National Laboratory. 2012. China Energy End-Use Model. Berkeley, California: Lawrence Berkeley National Laboratory.

Li Z., W. Ni, H. Zheng and L. Ma. 2003. “Polygeneration energy system based on coal-gasification.” *Energy for Sustainable Development* 7 (4): 57-62.

Lin, H., H. Jin, L. Gao and W. Han. 2011. “Techno-economic evaluation of coal-based polygeneration systems of synthetic fuel and power with CO2 recovery.” Energy Conversion and Management 52 (1): 274-283.

Liu, C. 2012. “China’s power monopoly dilemma.” *China Dialogue*, 23 August 2012. http://www.chinadialogue.net/article/show/single/en/5123

Low-Carbon City China Alliance. 2012. “Baoding, Hebei Province.” http://www.low-carboncity.org/index.php?option=com_flexicontent&view=items&cid=45%3Abaoding&id=205%3Alow-carbon-achievements&Itemid=8&lang=en

Lu’an Group. 2011. http://www.cnluan.com/luan/cpyfu/cyjs/webinfo/2011/04/1298247354487618.htm

Mao Y, H. Sheng, F. Yang 2008. *The True Cost of Coal*. http://www.greenpeace.org/eastasia/PageFiles/301168/the-true-cost-of-coal.pdf

Morse R., V. Rai and G. He. 2009. Real Drivers of Carbon Capture and Storage in China and Implications for Climate Policy. Working Paper #88. Palo Alto: Freeman Spogli Institute for International Studies.

National Bureau of Statistics (NBS). n.d. *China Energy Statistical Yearbook*, various years. Beijing: China Statistics Press.

National Bureau of Statistics (NBS). n.d. *China Statistical Yearbook*, various years. Beijing: China Statistics Press.

National Development and Reform Commission (NDRC). 2012. “The 12th Five-Year Plan for Coal Industry Development.” March 2012. Beijing: NDRC.

National Energy Administration (NEA). 2011. “12th Five-Year Plan for Energy Science and Technology.” 5 December 2011. http://www.nea.gov.cn/2012-02/08/c_131398856.htm

Peng W. 2011. “Coal secto reform and its implications for the power sector in China.” *Resources Policy* 36: 60 – 71.

People's Daily Online. 2011. "Full speed ahead for China's railways in 12th Five-Year Plan." People's Daily, 9 May 2011. http://english.people.com.cn/90001/90778/90862/7374341.html

People's Government of Chongqing City, 2012. "The action plan for Chongqing's low carbon pilot city (in Chinese)." March, 2012. See also: http://www.cq.gov.cn/gw/FaguiQuery/GwShowWithLogo.aspx?gwz=%E6%B8%9D%E5%BA%9C%E5%8F%91&gwnh=2009&gwqh=95.

People's Government of Guiyang City. 2010. "The city of Guiyang's low carbon development action plan framework (2010-2020)." July 2010. See also: http://www.gygov.gov.cn/gygov/1442563657983590400/20100731/252024.html.

People's Government of Hangzhou City. 2009. "The views of the people's government of Hangzhou on building low-carbon city (in Chinese)." 29 December, 2009. See also: http://www.hzls.gov.cn/Html/201005/13/103730.html.

People's Government of Nanchang City. 2011. "Notice on the action plan of Nanchang's national low-carbon pilot city (in Chinese)." 2 November, 2011. See also: http://xxgk.nc.gov.cn/fgwj/qtygwj/201111/t20111116_395269.htm.

People's Government of Shenzhen City. 2012. "Medium and Long-term plan for Shenzhen's low carbon development (2011-2020)." February, 2012. See also: http://city.sz.net.cn/city/2012-02/28/content_2900181.htm.

People's Government of Tianjin City. 2010. "Notice on Tianjin's climate change program (in Chinese)." 19 March, 2010. See also: http://www.tjzb.gov.cn/system/2010/05/05/000243884.shtml.

Robert W. 2001. "Toward zero emissions from coal in China." *Energy for Sustainable Development* 5 (4): 39-65.

Rui H., R. Morse and G. He. 2011. *Remaking the World's Largest Coal Market: the Quest to Develop Large Coal-Power Bases in China.* Working Paper #98. Palo Alto: Freeman Spogli Institute for International Studies.

Tu J. 2011. *Industrial Organization of the Chinese Coal Industry.* Working Paper #103. Palo Alto: Freeman Spogli Institute for International Studies.

Tu J. and S. Johnson-Reiser. 2012. *Understanding China's Rising Coal Imports*. Carnegie Endowment for International Peace Policy Outlook. http://carnegieendowment.org/files/china_coal.pdf

United Nations Statistics Division. 2012. "United Nations Commodity Trade Statistics Database (UN Comtrade)." http://comtrade.un.org/db/

United Nations Department of Economic and Social Affairs (UN DESA). 2012. "World Urbanization Prospects 2012, Country Profile: China." http://esa.un.org/unup/Country-Profiles/country-profiles_1.htm

Wang, Z. 2010. "Coal Bed Methane and Coal Mine Methane Power Generation". http://www.nios.com.cn/common/files/File/14.Caterpilla_EN.pdf

World Bank, 2007. *Cost of pollution in China*. Beijing, China. See also: http://siteresources.worldbank.org/INTEAPREGTOPENVIRONMENT/Resources/China_Cost_of_Pollution.pdf.

Xiamen Municipal Commission of Construction and Administration. 2010. "The overall planning framework for low-carbon city of Xiamen (in Chinese)." January, 2010. See also: http://www.csuaee.com.cn/UpFiles/FckFiles/%E5%8E%A6%E9%97%A8--%E5%8E%A6%E9%97%A8%E5%B8%82%E4%BD%8E%E7%A2%B3%E5%9F%8E%E5%B8%82%E6%80%BB%E4%BD%93%E8%A7%84%E5%88%92%E7%BA%B2%E8%A6%81.pdf.

Zhang J. 2009. "Current and Future China's Railway Development." Presentation in New Delhi, 25 March 2009. http://siteresources.worldbank.org/INTSARREGTOPTRANSPORT/6034746-1243944302638/22213053/3_Mar25_Zhang_Jianping_prsntn.pdf

Zhao G. 2011. "New Development of CMM/CBM Projects and Policies in China." Presentation, 14 October 2011. http://www.globalmethane.org/documents/events_coal_101411_sub_china.pdf