Why China Matters

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Chapter Outline

1. INTRODUCTION[1]

There is hardly any field where the impact of China and its rapid development is not felt, and energy and climate change are no exception. In a formidable feat the world's most populous country has followed smaller Asian neighbors in a high-speed developmental trajectory, lifting millions out of poverty in the process. Already it has become hard to recall to memory that as the second half of the twentieth century started, China was an almost completely agrarian country. Since the reforms and "opening up" policy introduced by Deng Xiaoping in the late 1970s, China's gross domestic product (GDP) has increased more than tenfold as it maintained annual growth rates of around 10% on average. The introduction of market principles combined with an abundant supply of cheap labor triggered a growing influx of foreign investment and unleashed an enormous economic activity domestically. As the first decade of the twenty-first century has come to a close, the Chinese economy still shows little signs of slowing down.

The success of China's development, however, comes with consequences not only for China itself but for the world at large. China's economic growth up to

1. This chapter is based on the Clingendael Energy Paper, *China, Copenhagen and Beyond*, Clingendael International Energy Programme, September 2009. Available online at: *www.clingendael.nl/publications/2009/20090900_ciep_report_buijs_china_copenhagen_beyond.pdf*.

Energy, Sustainability and the Environment.

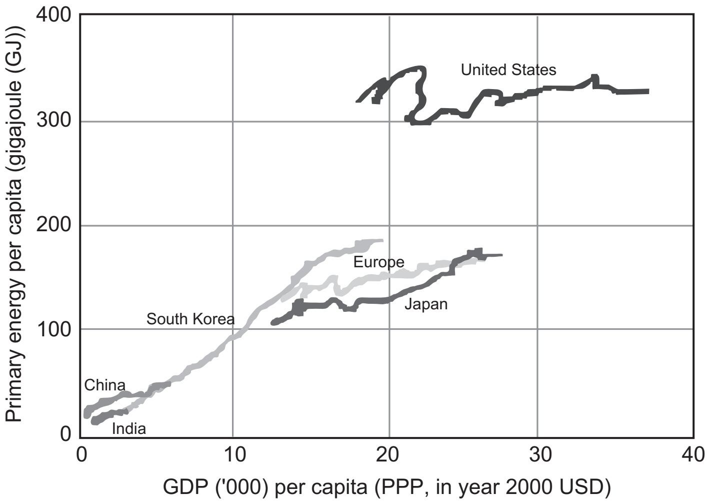


FIGURE 1 Developmental Trajectories (per capita primary energy vs. per capita GDP). *Source: World Energy Council, World Energy and Climate Policy: 2009 Assessment, 2009, p. 60. Adapted from Shell Energy Scenarios to 2050. Available online at: http://www.worldenergy.org/documents/report_final_3.pdf.*

now has followed a traditional developmental pattern: Rapid industrialization has been driving economic growth and the energy system underlying this growth is fueled predominantly by fossil energy resources, especially coal. Yet if we compare the growth patterns that are characteristic of the development path that was followed by other Asian countries such as Japan and South Korea, the implications of China's path will be enormous in terms of energy use and greenhouse gas (GHG) emissions (Figure 1). Simple calculations show that energy consumption in China at OECD levels is hardly imaginable: With per capita oil consumption levels similar to the United States, China would require all of today's global oil production of roughly 85 million barrels per day. In terms of electricity, its current per capita usage of 2.4 MWh per year stands at less than one-third of the OECD average (IEA, 2009a, p. 51). Even if China manages to improve the environmental performance of its carbon-intensive power sector, it will remain extremely difficult to offset the consequences of electricity demand growth on emissions. To illustrate the point: If China were to achieve the same per capita electricity consumption level as Germany *with the same level of carbon dioxide (CO_2) emissions per kWh as Germany,* its total emissions from power and heat generation would nearly double compared to current levels.[2]

2. This would imply almost halving China's current emissions level per kWh which stand at 777 gCO_2/kWh compared to 412 gCO_2/kWh in Germany. IEA. (2009). *CO_2 emissions from fuel combustion highlights (2009 Edition)*, pp. 101. Available online at: *www.iea.org/co2highlights/CO_2highlights.pdf.*

In this sense, China is the key protagonist illustrating the fundamental energy sustainability dilemma: If the whole world would have the same energy consumption patterns as the richest few, neither fossil energy production nor the climate would be able to bear the consequences. China with its population of 1.3 billion—almost one-fifth of the current global population—is probably the first country that faces this challenge directly with respect to its own development. The acknowledgment of this reality by the Chinese government is in fact driving much of the progressive policy that has been implemented in the recent past. China's leadership recognizes that China will need to find a different developmental model that will allow continued growth without becoming restrained by scarcity of energy resources or energy-related environmental issues[3] (Jiang, 2008; CAS, 2007).

To address energy security concerns and the long-term challenge of securing sufficient energy resources for development, China's energy policy includes a strong focus on energy efficiency, energy conservation, and the promotion of renewable energy sources. Although China's rising energy consumption has an increasing impact on the global availability of energy resources, the first and foremost consequences will be felt in the attempts to address the challenge of climate change. According to proposed stabilization schemes to limit the global temperature increase to 2°C, global emissions should peak no later than 2020. As the world's largest emitter of GHGs, China's contribution to attain such a target will be critical. However, as this chapter will show, China's developmental path will need to drastically change course if the required reductions in both energy consumption and emissions are to be achieved.

It is important to point out that China is not only important for climate change because it has become the world's largest emitter, but also because it holds some of the world's largest potential for climate change mitigation. Since China is still in the midst of its development, very significant opportunities to change future energy consumption and emissions levels exist. This holds especially true for sectors that are going through rapid expansion at the moment, such as power generation, housing, and transportation. The deployment of low-carbon and energy-efficient technologies in these sectors could have a significant impact on the future levels of energy demand and emissions. Yet to avoid the lock-in of carbon-intensive technologies, the speed of

3. Jiang Zemin [president of the People's Republic of China from 1993 to 2003]. (2008). 对中国能源问题的思考 [Reflections on energy issues in China], *Journal of Shanghai Jiaotong University*, *42*(3), 257−8, 263−4: "To meet the ever increasing energy demand by one billion plus people in the course of building a moderately prosperous and modern society in an all-round way, China will build the world's largest energy supply and consumption system in the coming 10 to 20 years. Therefore, the urgent task before us is to blaze a new path in energy development with Chinese characteristics, in order to achieve the nation's strategic goal of modernization with a minimal cost of energy resources and impact on the environment." Also see (CAS, 2007).

implementation is crucial: Delaying strong action for a few years or more will mean the largest abatement potential will have been lost. There are also large gains to be had in terms of improving energy efficiency and energy conservation. In many sectors including industry, power generation, and housing, the difference with developed country standards and "best available technologies" is still considerable and closing this gap would contribute significantly to reining in China's demand for energy and related emissions. In some cases technological leapfrogging can actually be cost-effective, as the deployment of state-of-the-art power plants and advanced industrial production techniques in China's economy demonstrates. Yet for the implementation of energy-efficient and low-carbon technologies that are still under development and not economically competitive, overcoming cost barriers in China is as much of a challenge as it is in the developed world.

The crux of the matter regarding a true transition to a more sustainable energy system in China is the relative abundance of coal. When considering the projected levels of energy consumption—even under relatively energy-efficient scenarios—an enormous expansion of energy supply will be necessary. Since China has some of the world's largest coal reserves and it remains one of the cheapest sources of energy, coal will likely maintain a central position in its energy system. Although constraints on the supply of coal domestically might mean that it will have to look out for another staple fuel in the long run, the reserves are so vast that China can remain self-sufficient for a long time still. Unlike with other fossil fuels like oil and gas, energy security concerns will run counter to a big shift away from coal. The large-scale implementation of carbon capture and storage (CCS) technologies, that might allow the continued use of coal while reducing the carbon emissions, is fraught with difficulties and will most likely carry significant economic cost. This means that it will be very hard to turn away from coal and achieve the transformation to a low-carbon energy system in China on the short term, which is required by the stabilization scenarios.

This chapter will discuss the challenges outlined above. The following two sections aim to provide a fundamental understanding of China's developmental stage, its energy system, and its policy measures on energy and climate change. The fourth section will focus on China's growth patterns and opportunities for emissions mitigation in several key areas including industrial energy demand, the power sector, energy efficiency of buildings and the transportation sector. Several quantitative scenarios on China's future development are examined in Section 5, followed by conclusions.

2. DEMAND AND SUPPLY OF ENERGY IN CHINA

This section provides an overview of China's energy use, first discussing its energy consumption in the context of overall development followed by a discussion of the supply side of the energy system.

2.1. China's Development and Energy Consumption

Although in some aspects China already appears to be a fully developed country, it is important to realize that China as a whole is still a country in transition with an uneven level of development.

Average per capita income levels, although having increased significantly in the course of the past few decades, still stand at US$6,600 per year when measured at purchasing power parity terms compared to US$46,400 in the United States. As of 2009, more than half of China's population still lives in rural areas and almost 40% is employed in the agricultural sector, even though that sector only contributes little more than one-tenth to the GDP (see Box 1; and CIA, 2010).

Indicative of China's uneven developmental stage is the fact that energy consumption is dominated by industry, which accounts for almost 60% of the final energy consumption and 75% of electricity demand. The industrial sector, which accounts for about half of China's GDP, has a large share of energy-intensive sectors such as iron and steel, cement, chemicals, aluminum, other nonferrous metals, and pulp and paper. The main driver for these industries is

BOX 1 People's Republic of China – Key Statistics Including Global Rankings

Population: 1,330,141,295	(1)	Primary energy consumption: 2177 mtoe	(2)
Area: 9,596,961 sq km	(4)	Coal production: 3050 million tonnes	(1)
Arable land: 14.86%		Electricity production: 3.451 trillion kWh	(2)
Urban population: 43% of total		Installed capacity (end 2009): 784 GW	(2)
Literacy rate: 90.9%		Oil consumption: 8.6 million barrels per day	(2)
GDP (PPP): US$8.789 trillion	(2)	Oil imports: 5.1 million barrels per day	(2)
GDP (PPP) per capita: US$6,600	(127)	Natural gas consumption: 88.7 bcm	(6)

Mtoe: million tonnes of oil equivalent. General statistics are 2008/2009 estimates taken from (CIA, 2010). Energy-related statistics over 2009 are taken from (BP, 2010), except electricity production (CIA, 2010) and installed capacity (Xinhua, 2010).

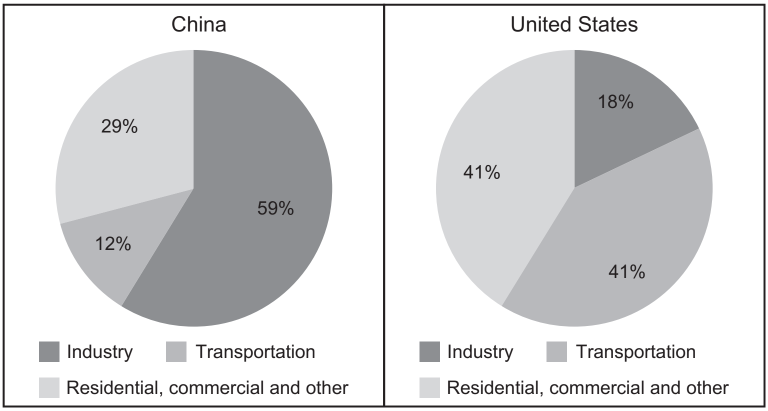


FIGURE 2 Final energy demand by sector in China and the United States. *Source: APERC,* APEC Energy Overview 2008, *March 2009.*

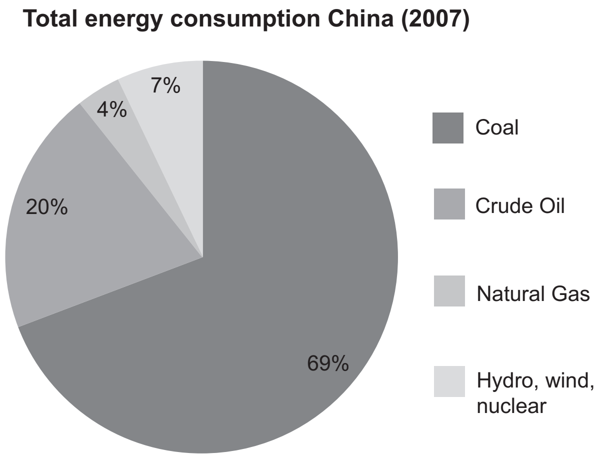
the enormous infrastructure development taking place in China, increasing demand for cement and construction materials, and demand from both light and heavy manufacturing industries for copper, aluminum, and steel (USGS, 2004). Complicating the argument that China should be held responsible for the pollution and emissions caused by its industry is the fact that much of its economy is geared toward exports. According to research by the British Tyndall Centre, roughly one-third of China's total emissions can be attributed to the manufacturing of goods that are exported, or about one-quarter if one adjusts for emissions embodied in imports (Wang and Watson, 2007; IEA, 2008, p. 387).

Per capita primary energy supply and electricity consumption levels stand at one-third of OECD levels, even though China has successfully pursued an electrification program with roughly 99% of its population having access to electricity. Yet, in comparison with more developed countries, energy consumption by transportation and the residential and commercial sectors are still small, indicating the potential for growth. Figure 2 shows the comparison of final energy consumption by sector between China and the United States (IEA, 2009a; ADB, 2009, p. 150).

2.2. Resources Base and Energy System

To accommodate its rising demand for energy, China has expeditiously developed its energy supplies and has remained largely self-sufficient. China accounts for about one-fifth of the world's energy consumption and reportedly overtook the United States as the largest energy consumer in 2009.

Figure 3 shows the structure of China's primary energy consumption and illustrates the dominant position of coal. Coal has fueled China's industrialization as the most abundant and the most easily exploitable fuel available.



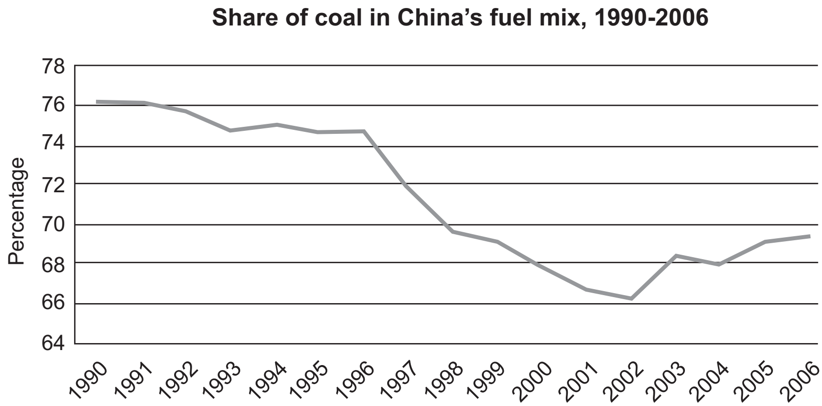


FIGURE 3 China's fuel mix structure and the share of coal 1990-2006. *Source: China Statistical Yearbook (2009).*

China holds the world's third-largest coal reserves, behind the United States and Russia, and the reserves amount to 13.9% of the world's total (BP, 2010). China has emerged as both the world's largest consumer as well as producer of coal. It accounts for about 45% of global coal demand and production and produces more than twice as much as the United States, which ranks second. Moreover, production is increasing at an astonishing rate, doubling between 2001 and 2008 and growing faster than primary energy demand growth in recent years. Although energy policy has aimed to limit the use of coal due to the negative environmental impact, this has had only limited effect up to the present. Figure 3 shows how in past decades the share of coal steadily declined until around 2002, after which it increased again to just under 70%, due to a sudden boom in industrial energy demand.

The second most important fuel in China's energy mix is oil. Even though it is the world's fourth largest country in terms of land area, China's proven reserves amount to only 1.1% of the world's total. Nonetheless, China is the world's fifth largest producer of oil, behind Russia, Saudi Arabia, the United States and Iran, producing about 4 million barrels per day. In spite of this prolific production, it is already reliant on imports for almost 60% of its domestic oil consumption (BP, 2010). This share might reach 80% or more by 2030, as domestic production is expected to flatten while consumption is projected to increase.

Natural gas occupies only a minor share in China's energy system. Gas consumption and production levels stood at 88.7 billion cubic meters (bcm) and 85.2 bcm, respectively, in 2009, but have been increasing at a rapid rate (BP, 2010). It is expected that domestic production will run into constraints however, as proven gas reserves are limited, amounting to 1.3% of the world's total. Demand for gas has been growing at around 10% annually since 2000 (BP, 2010). Gas is used mainly by the petrochemical industry, for fertilizer production, and for enhanced oil recovery. Residential use for heating and for gas-fired power generation are currently small but increasing. Gas import dependency, currently around 5%, is expected to rise quickly in future, adding to China's energy security concerns. It might reach about 50% by 2030 (IEA, 2009b). Exploitation of unconventional gas resources in China has been touted by some analysts as a potential option to counterbalance this rising import dependency. Current production capacity is however still in its infancy (Wang et al., 2009).

China is the world's second largest electricity producer and consumer, behind the United States. In 2008, it consumed 3451 billion kWh of electricity: more than the electricity generation of Africa, Central and South America, the Middle East, and India combined (Box 1; EIA, 2009).[4] Figure 4 shows that about four-fifths of electricity in China is generated by coal-fired power plants. Hydropower is the only other significant source of power generation, contributing 15%, while nuclear power, oil- and gas-fired power plants occupy only minor shares. The large role for hydropower reflects that China holds the world's largest hydropower resources and has emerged as the world's largest producer of hydroelectricity. As hydroelectricity still is by far the world's most important source of renewable energy—accounting for four-fifths of all "renewable" electricity at a global level—this makes China the world's largest producer of renewable energy as well (REN21, 2010). However, the

4. The recent estimate of Chinese electricity consumption (of 3451 billion kWh in 2008) is taken from *CIA World Factbook*, 2010. The international comparison however is based on (preliminary) figures for 2006 from U.S. Energy Information Administration (EIA), Annual Energy Review 2008, June 2009: *www.eia.doe.gov/aer/pdf/aer.pdf*, p. 337. Net electricity generation (in billion kWh) of China is 2717.5, Africa 546.8, the Middle East 641.4, Central and South America 951.0 and India 703.3.

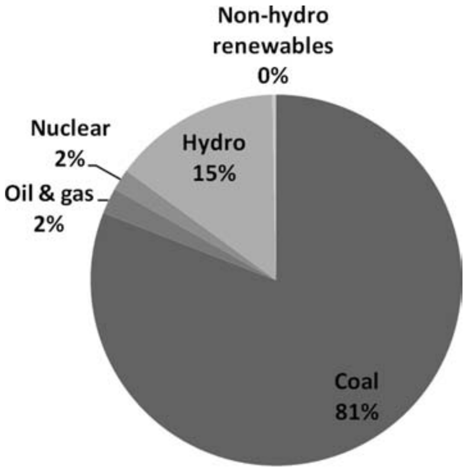


FIGURE 4 China's power generation fuel mix. *Source: IEA, WEO2009 (2007 data).*

contribution of nonhydro renewable energy sources in China, such as wind, biomass, and solar, is still rather marginal and accounts for less than 1% of the electricity supply (IEA, 2009b).

3. ENERGY AND CLIMATE CHANGE POLICY

Chinese energy policy has been driven mainly by energy security concerns that favored the development of domestic energy resources. Although energy security remains of paramount importance, concerns about the environmental impact of excessive coal use and perceived economic opportunities in new energy technologies have become important factors as well, as further described in this book's Chapter 2 by Felder et al. This section discusses various aspects of Chinese energy policy and the implications for its policy on climate change.

3.1. Energy Policy

Traditionally, there has been a strong emphasis on energy efficiency and energy conservation in Chinese energy policy, which has led to the remarkable growth pattern observed in the two decades from 1980 to 2000. During this period GDP quadrupled while energy consumption merely doubled, which signifies quite an impressive feat for an industrializing country.

China has reiterated the goal of quadrupling GDP while only doubling energy consumption for the period 2000 to 2020, but with a surge in energy demand in the first decade of the new millennium, reaching this objective has become practically impossible (Figure 5). Nonetheless, China is continuing to strongly promote energy efficiency and set a 20% reduction target in energy

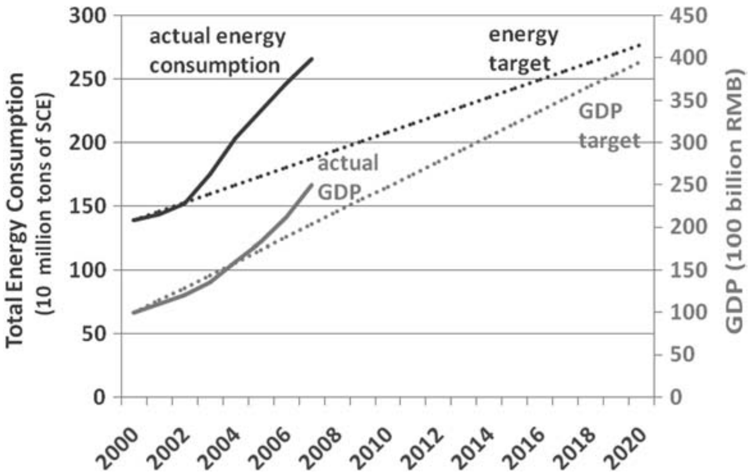


FIGURE 5 Chinese energy demand and GDP growth compared to 2020 targets. *Source:* China Statistical Yearbook 2009*, SCE denotes (Chinese) standard coal equivalent. Based upon: Mark D. Levine, Nan Zhou, Lynn Price, 'The Greening of the Middle Kingdom: The Story of Energy Efficiency in China', Lawrence Berkeley National Laboratory, May 2009, p.22.*

intensity, i.e., energy consumption per unit of GDP, into its 11th Five-Year Plan covering 2005 to 2010. It has been estimated that the emissions savings resulting from this policy are around 1.5 billion tons of CO_2, almost five times as much as the absolute amount set by Europe (EU-15) under its Kyoto Protocol commitment (LBNL, 2007).

To implement its energy efficiency policy China has initiated quite effective programs such as the *Top-1000 Enterprises Program*, which targets the one thousand largest industrial energy consumers that together account for almost half of China's energy demand and two-thirds of its industrial energy demand. Through semivoluntary targets and energy audits at these companies, large improvements in energy efficiency are sought and implemented (Price et al., 2008; and this book's Chapter 12 by Brown et al.). Fuel efficiency standards for cars have been raised following European requirements, and are already stricter than in the United States. In terms of raising efficiency in power plants and industry, China is pursuing a policy to close down small inefficient units and factories. According to government estimates, 55.5 GW of capacity has been closed down in the period 2006–2010 (Reuters, 2009). Energy efficiency labeling has been made mandatory for many consumer products and appliances. Furthermore, a new building code standard has been introduced to achieve a 50% saving standard from previous requirements (WRI, 2009; APERC, 2008, p. 109).

Chinese policy aimed at the power sector has several aspects. Concerning coal-fired power plants, which make up the bulk of power generation capacity, energy policy is directed at modernization of the fleet. Overall energy conversion efficiency of Chinese power plants is estimated be about 33.8% on average, about 6%–7% lower than coal-fired power plants in developed countries. It can be as high as 45%–47% for new state-of-the-art ultra-supercritical power plants, and China is introducing such plants at a significant scale (CIEP, 2009, p. 68).

A second objective is to limit coal-fired power generation due to environmental concerns over air pollution and acid rain. To this end, China is strongly promoting the use of renewable energy and nuclear power. A goal has been set to increase the share of nonfossil energy sources from 7.5% to 15% of primary energy consumption by 2020. An additional incentive is the aim of establishing a strong domestic industry in wind, solar, and nuclear energy (CIEP, 2009, pp. 75–77).

The expansion of hydropower is still the mainstay of renewable energy development and government policies have strongly encouraged the development of both large-scale hydropower projects, such as the 22.5 GW Three Gorges Dam, and small-scale hydropower in rural areas. More recently, nonhydro renewables are stimulated by various policies including *feed-in tariffs* and a *renewable energy portfolio standard* (RPS) for grid and power companies (Martinot and Li, 2007). For wind energy this has resulted in a spectacular growth with total installed capacity doubling four years in a row. China emerged as the largest growth market for wind turbines in 2009.[5] Similarly, China's solar energy industry has been growing rapidly. In contrast to the Chinese wind industry, it has been almost completely directed at the export market. In very little time Chinese solar cell and panel manufacturers have gained significant global market shares. In its *Renewable Energy Medium and Long Term Development Plan* the government announced targets for 2010 and 2020 (Table 1), but some of these have already been exceeded. The 30 GW target for wind by 2020, set in 2007, has already been surpassed. It is likely to be revised upward to 100 GW or even 150 GW. For solar power, the target has been set at 1.8 GW for 2020, although some officials have signaled this could be put much higher at 10–20 GW. This would be quite an ambitious goal considering that there was not even 1 GW of grid-connected solar power installed in China in 2009 and about 21 GW of solar-power installed worldwide as of 2009 (REN21, 2010). The deployment of solar hot water has been more widespread: China holds 70% of all global solar hot water capacity and continued growth is strongly supported by the government (REN21, 2010, p. 12).

The Chinese definition of nonfossil energy also includes nuclear power, which currently plays only a minor role in electricity supply (Figure 4). At present, 13 reactors are in operation with a combined capacity of about 10 GW.

5. Installed capacity of wind power doubled four years in a row: from 1.3 GW in 2005 to 2.7 GW in 2006, 5.9 GW in 2007, 12.2 GW in 2008, and 25.1 GW in 2009 (GWEC, 2009, p. 27).

TABLE 1 China's Renewable Energy Targets for 2020

RE source	Total potential	2005	Target 2010	Target 2020
Hydropower	400 GW (540)	117 GW	190 GW	300 GW
Biomass biomass power biomass pellets biogas bio-ethanol bio-diesel	-	-	– 5.5 GW – 1m tonnes – 19bn m^3 – 2m tonnes – 0.2m tonnes	– 30 GW – 50m tonnes – 44bn m^3 – 10m tonnes – 2m tonnes
Wind power	300 GW onshore, 700 GW offshore	1.26 GW	5 GW onshore, 200 MW offshore	29 GW onshore, 1 GW offshore *(under revision)*
Solar power PV		70 MW	0.3 GW	1.8 GW
Solar thermal		80m m^2	150m m^2 (30 Mtce)	300 m^2 (60 Mtce)
Geothermal power			4 Mtce	12 Mtce
Tidal power			-	100 MW

Source: National Development and Research Commission, *Medium and Long Term Development Plan for Renewable Energy in China* (draft), September 2007.

However, the contribution of nuclear power is set to increase fast, as more than one-third of all nuclear power plants under construction worldwide are being built in China. Official targets aim to expand the nuclear power capacity to 40 GW by 2020, but this target is quite likely to be revised upwards to 60 GW or even 70 GW. Policy documents indicate that China aims to build up a domestic nuclear industry and strong technology transfer conditions were included in contracts awarded to foreign suppliers of nuclear technology (CIEP, 2009; World Nuclear Association, 2010).

3.2. Policy on Climate Change

China unveiled an explicit comprehensive policy on climate change with the launch of its *National Climate Change Programme* in 2007 (NDRC, 2007a). Measures that were included in the document can largely be interpreted as cobenefits arising from China's energy policy (Table 2). Yet even if these policies are partly driven by energy security, and environmental and economic considerations, they already yield significant benefits for climate change stabilization objectives.

TABLE 2 Chinese Estimates of Avoided Emissions, due to Mitigation Measures in *China's National Climate Change Programme*

Emissions avoided by 2010 (Mt of CO_2e)	Measure
550	Implement various energy conservation programmes
500	Continue to expand hydropower for electricity generation
200	Develop coal-bed methane (CBM) and coal-mine methane (CMM)
110	Upgrade thermal power generation: develop (ultra)-supercritical units, combined-cycle units, heat/power cogeneration, heat/power/coal gas multiple supply units
60	Utilize wind, solar, geothermal, and tidal energy
50	Increase forest rate to 20% and enhance carbon sinks
50	Continue to promote nuclear energy
30	Promote bio-energy for power generation and fuels
1550	**TOTAL**

Source: National Development and Reform Commission, *China's National Climate Change Programme*, June 2007.

However, this does not hold for all measures. Gas-fired power plants, for instance, which emit approximately half the amount of CO_2 per kWh, are also set to increase to 70 GW but are not overly promoted due to concerns over the forecasted rise in gas imports (CIEP, 2009, p. 67). China's system of energy pricing is another aspect that is hampering a drive for energy-efficiency and demand reduction. The price of electricity in particular is tightly controlled and kept relatively low. As a consequence, there is little economic incentive for energy-efficiency improvements. Additionally, China is developing coal liquefaction technologies with energy security as the main driver. However, due to the polluting production process, the carbon footprint of coal-based petroleum is much higher than conventional petroleum.

To truly implement policies and measures that will meet climate change objectives on the longer term, it will be necessary to take a step beyond energy security driven policies. The most crucial aspect of that will be to turn away from coal as a main fuel in China's fuel mix or to ensure the widespread deployment of CCS technologies. The former would run counter to energy security and economic concerns, while the latter carries significant costs. China is pursuing advanced coal technologies, including integrated gasification combined cycle (IGCC) power plants and CCS, as demonstrated by the

"GreenGen" project near Tianjin. However, some kind of carbon price or international financial assistance program would be necessary to incentivize the implementation of CCS as long as a direct economic rationale is lacking (Morse et al., 2009).

The adoption of carbon intensity targets in the run-up to the COP-15 summit in Copenhagen in December 2009 should be seen in this light. China announced the goal of lowering the carbon intensity of its economy by 40%–45% by 2020 compared to 2005 levels as a voluntary initiative. This should be regarded as a significant step, as it will also turn the focus to improving emissions monitoring and achieving emissions reductions within China's energy system, on top of improving energy efficiency. However, as illustrated in Section 5, the target aligns with improvements already following from recent energy policy measures and in itself it will not be sufficient to drastically change China's developmental path.

4. GROWTH PATTERNS AND MITIGATION OPPORTUNITIES

This section discusses several areas that can be considered of special importance given their impact on energy and emissions and the potential for mitigation measures.

China's demand for energy is driven mainly by its growing economy and increasing levels of prosperity. Population growth is less of a factor as the growth rate has slowed considerably due to China's one-child policy and now stands at 0.655% annually. This is less than half of India, which is expected to overtake China as the world's most populous country by 2025 (UN, 2008).[6]

The sectors that are the most important in China's current energy consumption system are industry and the power generation sector. They also play a vital role in China's GHG emissions: combined, the two sectors account for practically all coal consumption within China, and coal combustion causes about 75% of China's total CO_2 emissions. These emissions in turn account for about four-fifths of China's total GHG emissions.

Addressing these two sectors will be crucial to curtail rising emissions in China. Both reducing the energy intensity and carbon intensity of further growth will be necessary to make China's energy future more sustainable. While for the power sector there are technological options available to decarbonize the supply of energy, for industry this will remain a significant challenge as described in this book's Chapter 12 by Brown et al. For both sectors there are also significant gains to be had from energy-efficiency and demand reduction. However, other sectors that still contribute less to energy demand and emissions will also be important for pre-empting future growth.

6. According to these same "median variant" UN projections, China's population might already peak in 2030 at almost 1.5 billion and fall to 1.4 billion by 2050. In its high growth rate variant, however, China's population would increase further to 1.6 billion people by 2050.

4.1. Economic Growth and Industrial Energy Demand

Economic growth forecasts for China remain quite robust and the expansion of economic activity will be the main driving factor for an increasing demand for energy. When considering the ratio between the primary energy supply and GDP, China's economy is still more than four times as energy-intensive as the OECD average. The main reason for this is the predominance of energy-intensive industries in China's economy, mentioned in Section 2.1. China is a major global producer in many heavy industries: it accounts for 33% of the world's production of aluminum, 49% of cement, 51% of pig iron, and 38% of raw steel (USGS, 2010). A second contributing factor is the fact that the energy efficiency of the production processes in these industries are still significantly below the standard of best available technologies. This holds especially true for energy-intensive heavy industries such as steel, copper, aluminum, ammonia, plate glass, and cement, where energy intensity levels are still 25%–60% higher than the advanced international levels (APERC, 2008)[7]. As a consequence, improving energy efficiency in these sectors can contribute significantly to reducing energy consumption levels. However, in general these energy-efficiency and energy-conservation gains cannot be expected to offset significantly higher demand caused by expanding production in these sectors (IEA, 2009c). In the end, industrial restructuring and moving toward a more service-oriented economy will be essential for lowering China's future energy demand (Wang and Watson, 2008 and 2009).

4.2. The Power Sector and Electricity Demand

At a global level, the existing power generation sector already determines much of our future carbon emissions. Three-quarters of all generated electricity in 2020—and more than half in 2030—is estimated to come from power plants in operation today, according to the IEA (IEA, 2008, p. 12). In that sense, China and the massive expansion of its power sector offers a unique opportunity to influence the future energy system and level of emissions.

The power sector in China has been going through a phase of frenzied growth as consumption of electricity has been soaring. Demand has been increasing with growth rates between 9% and 15% in the past decade and installed capacity more than doubled in size since 2000. To illustrate the scale of this expansion, for every year in the three-year period 2005–2008, the equivalent of the whole power sector of the United Kingdom has been added in

7. APERC, *APERC Energy Overview 2007*, 2008, p. 46. APERC, *Understanding Energy in China*, 2008, pp. 101–103. Potential energy efficiency gains in energy resource consumption per unit of output for various industries: coal-fired power (17%), steel (18%), copper smelting (56%), aluminium (38%), ammonia (25%), cement (14%), plate glass (44%), and paper and paper products (120%).

China. Although the economic and financial crisis caused a drop in electricity consumption in the beginning of 2009, the total yearly electricity consumption in 2009 grew 6% and installed capacity reached 784 GW (MIT, 2008; CBS, 2009; Xinhua, 2010).

The previous section on Chinese energy policy indicated that China is striving to limit the role of coal in its power system. However, despite increasing investment in nuclear power and renewable energy sources, the majority of the growth in electricity supply is still coal-fired (Figure 6). China has been building the equivalent of several 500 MW coal-fired power plants per week (MIT, 2008). Considering that one 500 MW coal-fired power plant emits about 3 million tonnes of CO_2 per year, large amounts of CO_2 emissions are being locked-in (MIT, 2007, p. ix). Apart from the impediments to CCS that were already discussed, offsetting the coal-related emissions would require a tremendous upscaling of the technology; today's largest CCS activities at Sleipner (Norway) In Salah (Algeria) and Weyburn (U.S./Canada) store less than 5 million tons of CO_2 per year in total.

Table 3 shows that coal would still account for 58% of all installed capacity if China would meet all its ambitious targets by 2020 and electricity demand would follow the relatively conservative projection of the IEA. Given the fact that the renewable energy sources do not generate electricity according to their full capacity due to intermittency, the share of coal in terms of total generated electricity would even be higher.

In the medium term, the development of renewables in China will also face several impediments. One very significant challenge is that the development of hydropower in China will run into natural constraints. According to China's *Medium and Long Term Development Plan for Renewable Energy* (NDRC, 2007b), the total economically feasible potential for hydropower is estimated to be 400 GW, with a technically feasible upper limit of 540 GW. This means that

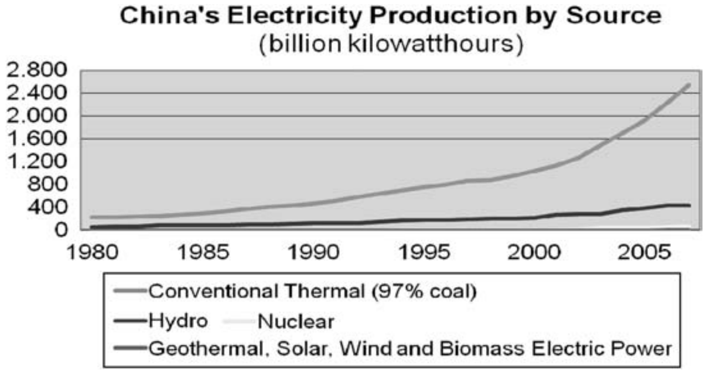


FIGURE 6 Development of Chinese electricity production by source 1980-2007. *Source: Energy Information Administration (EIA), U.S. Department of Energy,* International Energy Data, *Net Electric Power Generation. Most Recent Annual Estimates (2008).*

TABLE 3 Overview of Chinese Power Generation Capacity by 2020, Under the Assumption that Suggested Policy Objectives will be Achieved, in Gigawatt

Energy type	Capacity (2006)^x	Shares	Capacity (2020)	Shares
Hydro	132	21%	300	21%
Wind	3	0%	100	7%
Gas	14	2%	70	5%
Nuclear	7	1%	70	5%
Biomass	2	0%	30	2%
Oil	16	3%	20^x	1.4%
Solar	0	0%	10	0.7%
Total non-coal	*174*	*28%*	*600*	*42%*
Coal	449	72%	818	58%
Total capacity	623	100%	1418^x	100%

Source: CIEP, 2009, p. 63. Based upon various government targets, additional projections (marked by ^{x}) taken from the Reference Scenario in International Energy Agency, *World Energy Outlook 2008*, p. 531.

already nearly half of the total potential economically viable hydropower reserves have been utilized, and this will grow to three-quarters if China achieves its target of establishing 300 GW of hydropower by 2020 (Table 3).

Regarding the development of wind and solar energy, China has a large potential but significant challenges exist as well. The resource potential for wind power is estimated at 1000 GW, of which about 300 GW is onshore and 700 GW offshore (Table 1; NDRC, 2007b). The best onshore resources are located in northern and western provinces (Figure 7). A consequence is that considerable transmission capacity is needed to transport the wind energy to urban demand centers. Problems with connecting far-off wind farms to the grid and the intermittency of the electricity supply are impeding China's wind energy expansion already. It is estimated that one-third of all wind farms in China are not connected to the grid. For developing solar energy resources, similar problems can be expected, as China's western provinces such as Tibet, Xinjiang, and Qinghai are the most promising but located far away from consumption centers (Figure 8). Offshore wind resources have the advantage that they are located close to the densely populated coastal regions, but investment costs are still relatively high. The deployment of offshore wind in

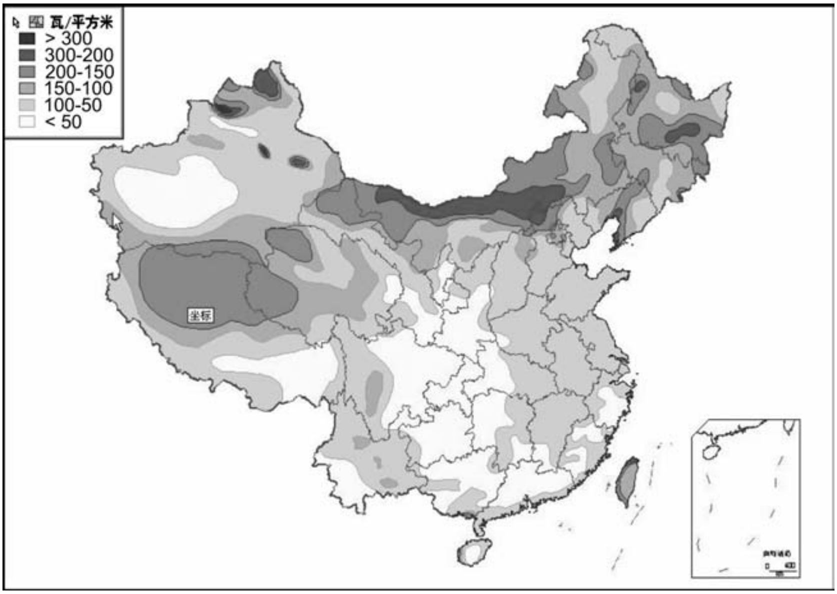


FIGURE 7 Map indicating regional spread of wind energy resources in China. *Source: Asia Pacific Energy Research Centre (APERC) (2004).* New and Renewable Energy Overview in the APEC Region.

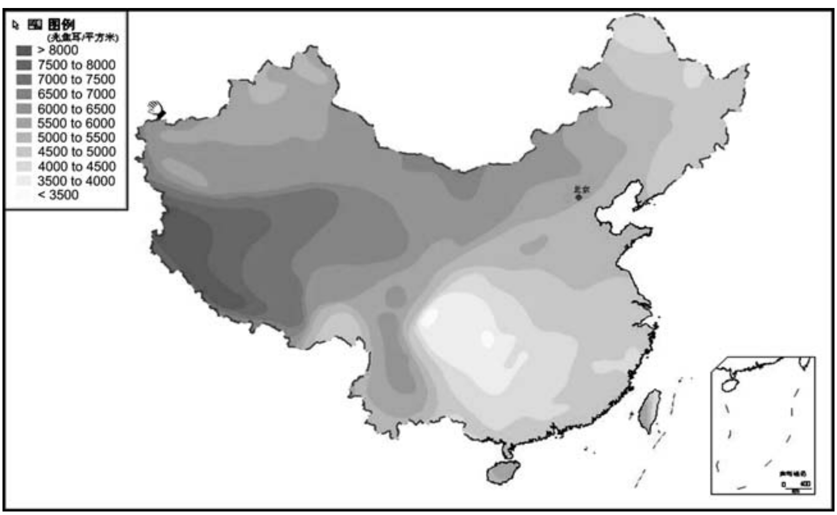


FIGURE 8 Map indicating regional spread of solar energy resources in China. *Source: Asia Pacific Energy Research Centre (APERC), 2004. New and Renewable Energy Overview in the APEC Region.*

China just started with a 100 MW wind farm off the coast near Shanghai, but a rapid growth of offshore wind farms is expected.

As far as biomass power is concerned, there is a potential for using large volumes of agricultural waste products, but developing and improving energy grasses and second-generation energy crops will be required to greatly expand biomass as a source of electricity. Currently biomass-fueled power capacity stands at only 2 GW and growth will need to accelerate rapidly to meet the 2020 target of 30 GW (Table 3).

Nuclear energy has the advantage that uranium and other reactor fuels are relatively abundant globally and it can play a serious role in reducing carbon emissions from China's power sector. The cost-effectiveness and high load-factor once in operation make it a viable option that could have a large impact. The main impediments are capacity constraints concerning the construction of nuclear power plants at a massive scale and potential environmental concerns over safety and nuclear waste.

4.3. Urbanization and the Energy Efficiency of Buildings

Urbanization is playing a key role in the growth of energy demand in several ways. First, urban per capita energy consumption levels are much higher than in rural areas. Second, the construction of housing and infrastructure is driving much of the demand for products of China's energy-intensive industries such as cement, steel, and other building materials. Lastly, the residential and commercial buildings constructed now will lay the foundation for future energy consumption levels to a great extent (LBNL, 2008a and 2008b).

The fundamentals underlying China's urbanization imply the trend is by no means exhausted. More than half of China's population still lives in rural areas and China's urban population is steadily increasing at the rate of 15–20 million annually. From 2000 to 2006, China's urban population expanded by 26% from 459 to 577 million and it is expected to surpass the 1 billion mark between 2025 and 2030. This means China could have almost 110 cities with over 1 million people by 2015, growing to more than 220 cities by 2025 (McKinsey, 2009b).

China is currently engaged in an unprecedented housing boom to accommodate the growing urban population. It accounts for about half of all building construction taking place worldwide, with about 2 billion square meters of floor-space added every single year.

While the construction sector contributes to current industrial energy use by creating demand for China's energy-intensive industries, it can be considered even more important for mitigation purposes in the long run. In developed countries, buildings on average account for 30%–40% of the total energy consumption via heating, cooling, lighting, and other appliances. New building techniques, passive design concepts, and smart metering technologies can however significantly lower this energy demand, as discussed in this book's Chapter 9 by Gray and Zarnikau, Chapter 10 by Ehrhardt-Martinez et al., and Chapter 14 by Bauermann and Weber.

Implementation of such features in China could have a lasting major effect on future levels of energy consumption and emissions.

4.4. Transportation

Private car ownership in China is still low by international standards as only 3 people out of 100 own a car, compared to developed countries where the figure stands at roughly 50 per 100 people in European countries and exceeds 76 per 100 in the United States. As a consequence, transportation energy demand has been relatively small, up to now. Figure 2 showed that transportation in China accounts for only 12% of the total final energy use, compared to 41% in the United States.

This, however, is set to change rapidly as sales volumes of cars in China have been skyrocketing, taking over the United States as the largest automobile market in 2009. A growing number of middle-class citizens can now afford to own cars with significant implications for energy use and carbon emissions. Analysts expect car ownership to surge fivefold by 2020 to reach about 15 cars per 100 residents. Aviation is also experiencing rapid growth, with Beijing-Shanghai already ranking as the world's sixth busiest route, with slightly more than 4 million passengers per year (China Daily, 2009; UNEP, 2008).

On a global level, emissions from transportation amount to almost one-quarter of energy-related CO_2 emissions and are projected to continue to rise swiftly. The sector remains one of the hardest to address in moving toward a more sustainable system in terms of energy and emissions.[8] This also holds for China, but as a sector still in expansion there is still scope for influencing the development.

Several options are being pursued. First, the growth in private car ownership is being discouraged with restrictions being in place in China's most populous cities. Second, large investments are being made in public transport, both within cities as well as in-between cities. Metro line construction is progressing at an enormous pace and a high-speed railway network is being developed between the largest cities (MIT, 2010). There are also experiments with other concepts such as a bus rapid transit system that will be introduced in Guangzhou.

The most commonly identified alternatives to petroleum-based transportation are biofuels, electric and/or hybrid vehicles, or hydrogen-based vehicles. Since China has limited arable land suited for agriculture (Box 1), expanding biofuels at a large-scale does not seem to be a promising option, at least not until suitable second-generation biofuels become available. The development of hydrogen-based vehicles might be an option, depending on breakthroughs in technology and costs.

8. For this reason, the IEA projects that the most incremental investment for achieving their 450 Scenario will be needed in the transport sector: about three times as much as for buildings (ranking second) and more than three times as much as for the power generation sector (ranking third). Mentioned is estimated cumulative investment for the period 2010–2020. IEA, *World Energy Outlook* 2009, p. 263, Fig. 7.2.

Electric cars can be considered as the most promising alternative for China, as this would align well with the objectives of reducing its oil import dependency and building up an internationally competitive car industry. There are several factors which make China well-positioned to take a lead in the development of electric cars: China's domestic car industry has focused largely on small efficient cars and China also has a strong base in battery manufacturing industry. The Chinese firm BYD, originally a battery manufacturer that moved into the electric car sector, is one prime example that caught quite a lot of attention and might be an indication of future developments. The ability of the Chinese government to issue strong centralized policy could be a major advantage in enforcing necessary standardization and infrastructure adjustments for electric vehicles. The potential impact of government measures is illustrated by the ban on gasoline scooters that has been issued as an air pollution reduction measure in major cities such as Shanghai and Beijing, which led to a rapid and near-complete shift toward electric bicycles and scooters.

However, for electric cars to really take off in China, or anywhere else, large improvements in cost and convenience will need to be made. The government has been running several promotion schemes that give consumers subsidies for buying an electric car, but prices are still relatively high and domestic sales volumes have been negligible up to now. Furthermore, although the introduction of electric cars would have an immediate effect in reducing oil demand, it would have little impact on emissions if the electricity used for transportation would still be generated by a highly carbon-intensive power sector.

5. FUTURE SCENARIOS

China's GHG emissions have been growing prodigiously, together with its energy consumption. The massive population but low per capita income and energy consumption levels clearly point to the staggering potential growth that might still take place.

Although the overall long term trend is inexorably upward, it has proven to be rather difficult to establish a "business-as-usual" (BAU) scenario for China. Previous projections have seriously underestimated the growth rates for both energy and emissions. In particular the surge in primary energy consumption and emissions which took place in the years following 2002, due to a sudden boom in heavy industry, was unforeseen by most analysts[9] (LBNL, 2008c).

Taking these considerations into account, several scenarios that illustrate BAU and alternative growth trajectories for China will be examined.

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9. The U.S. Energy Information Administration in its *International Energy Outlook 2004,* for instance, projected that it would take China until beyond 2025 to overtake the United States as the largest emitter of CO_2. In fact, this already happened in 2007. As a consequence, emissions trajectories for China have been significantly revised upwards in more recent projections. Estimates for Chinese emissions in 2030 by the IEA, to take another illustrative example, were increased by 70% between its *World Energy Outlook* of 2004 and 2007 (LBNL, 2008c).

5.1. Business-As-Usual Scenarios

According to China's own statistics, total GHG emissions increased from 4.060 million tons of CO_2 equivalent (Mt CO_2e) in 1994 to 6.100 in 2004: an increase of about 50% in one decade (NDRC, 2007a, p. 6). Total Chinese GHG emissions for 2007 have been estimated at 7.6 Gt CO_2e, of which 6.1 Gt are energy-related CO_2 emissions.[10]

Table 4 shows that most BAU scenarios see China's emissions more or less doubling by 2030, taking into account that energy consumption and emissions have shown a significant acceleration since 2002. Energy-related emissions of CO_2 are expected to exceed 11 Gt by 2030, with total GHG emissions reaching 14.5 Gt according to McKinsey. The underlying assumption of economic growth is a very significant factor in making these projections. The McKinsey baseline scenario assumes an overall average GDP growth rate of 7.8% over the projection period.[11] In its *World Energy Outlook 2007*, the IEA also included a High Growth scenario which assumed Chinese average GDP growth over the

TABLE 4 Several Business-As-Usual Emissions Scenarios for China to 2030

Emissions (Gt CO_2e)	Base year emissions	2020	2030	Average growth
IEA, WEO2007, Reference Scenario	5.1 (2005)		11.4	3.3%
IEA, WEO2007, High Growth Scenario	5.1 (2005)		14.1	4.2%
EIA, IEO2009, Reference Scenario	6.0 (2006)	9.4	11.7	2.8%
EIA, IEO2009, High Ec. Growth Scenario	6.0 (2006)	9.9	12.9	3.2%
IEA, WEO2009, Reference Scenario	6.1 (2007)	9.6	11.6	2.8%
McKinsey, *China's Green Revolution* (2009), baseline scenario	7.6 (2007)*		14.5*	2.8%

Average growth denotes average annual growth rate of emissions over the period base year-2030.
(*): McKinsey emissions statistics are based on overall GHG emissions (i.e. all GHG gases), while IEA and EIA emissions statistics only consider energy-related CO_2 emissions. As a global average, energy-related CO_2 emissions represent 64% of total GHG emissions; for China this percentage lies higher at approx. 80%.
Sources: McKinsey, *China's Green Revolution*, 2009, pp. 22; IEA, WEO2007, pp. 389-402 (High Growth Scenario), 596-599 (Alternative Policy and Reference Scenario); EIA, EIO2009, pp. 131, 148; IEA, WEO2009, pp. 199-200, 210, 623, 647.

10. 7.6 Gt overall GHG in 2007 taken from McKinsey, *Green Revolution* (2009a), p. 29. See p. 22 for what is included in this estimate (CO_2, CH_4, N_2O, and carbon sinks). 6.071 Mt of en.rel. CO_2 emissions taken from IEA, *World Energy Outlook* (2009), p. 647.

11. Dropping from 9.9% between 2005 and 2010 to 8.2% between 2010 and 2020, and 6.5% between 2020 and 2030 (McKinsey, 2009a, p. 32).

period 2005–2030 would be 7.5% instead of the 6% annual growth used for the *WEO2007* Reference scenario. This would lead Chinese energy-related CO_2 emissions to exceed 14 Gt by 2030, pushing the total of all GHG emissions even higher (Table 4; IEA, 2007, pp. 389, 401). A few observations are worth noting:

- First, the official goal of quadrupling GDP between 2000 and 2020 while only doubling energy demand in the same period implies an average GDP growth rate of 7.2% and a primary energy demand growth of 3.5% annually up to 2020. If such a trend would continue until 2030, it would mean that China will be more in line with the High Growth scenario rather than the Reference scenario of the *WEO2007*.
- Second, the baseline scenarios already expect a significant decline in emissions growth compared to the past two decades. Annual growth rate of overall GHG emissions stood at 4.7% for the period 1990–2007, whereas most reference projections for 2030 see this slowing down to around 3% for 2005–2030 (Table 4; McKinsey, 2009a, p. 29). This reflects that baseline projections have already been adjusted to incorporate the effects of China's energy strong policy on energy efficiency, renewables, and nuclear power of the past years. The baseline scenario of McKinsey, for instance, projects an average energy intensity reduction of 17% in every five-year period between 2005 and 2030 (McKinsey, 2009a, p. 37). This nearly equals the much-touted 20% energy intensity reduction target that China issued for its 11th Five-Year Plan (2005–2010).
- Third, a similar observation holds with respect to China's carbon intensity target that was mentioned in Section 3. The *World Energy Outlook 2009* reference scenario already assumes a 37% decline in carbon intensity of China's economy, measured in CO_2 emissions per unit of GDP, over the period 2007–2020. This almost equals China's carbon intensity reduction target of 40%–45% by 2020 compared to 2005 levels that was announced in the run-up to the climate treaty negotiations at the Copenhagen COP-15 meeting. Similarly, the reference projections of the U.S. Energy Information Administration (EIA) that were published in May 2009 already projected a drop of 44% in carbon intensity for China's economy between 2006 and 2020 (IEA, 2009, p. 183; EIA, 2009, p. 148).

These observations point out that the BAU scenarios for China might be considered already reasonably "ambitious" and that there is also a risk that they underestimate the growth of Chinese energy consumption and emissions.

5.2. Alternative Scenarios

Several quantitative scenarios have been developed in other studies that indicate how energy consumption and emissions from China would develop if

China were to take a different course from what can be inferred from recent trends. Since many of China's progressive policies of recent years have already been incorporated in the BAU scenarios, this means a significant deviation from what has been implemented up until this point.

TABLE 5 Three 'Alternative' Emissions Scenarios for China to 2030

Emissions (Gt CO_2e)	Base year	2020	2030	Average growth
Alternative Scenario 1: IEA, WEO2009, *450 Scenario for China*	6.0 (2007)	8.4	7.0	0.7%
Extra details: Over the period 2007-2030, - CO_2 intensity of the vehicle fleet drops from 235 gCO_2/km to 90 gCO_2/km. - Power CO_2 intensity drops from 922 gCO_2/kWh to 448 gCO_2/kWh. - Share coal in power generation drops from 81% to 50%. Power sector in 2030 includes the following (approx.): 770 GW coal without CCS; 110 GW nuclear 100 GW of gas without CCS; 120 GW other RES 370 GW hydro; 250 GW wind 40 GW of coal and gas with CCS.				
Alternative Scenario 2: IEA, WEO2007, *Alternative Policy Scenario for China*	5.1 (2005)		8.9	2.3%
Extra details: - Coal supplies 64% of electricity by 2030. - Energy demand increases with 90% in 2030 compared to 2005, but is 15% lower than the reference scenario. Structural changes in the economy account for more than 40% of the total energy savings.				
Alternative Scenario 3: McKinsey, China's Green Revolution (2009), *abatement scenario*	7.6* (2007)		7.8*	0.1%
Extra details: Power sector in 2030 has total capacity of 2122 GW and includes the following: 550 GW coal (25% with CCS); 144 GW gas 317 GW (large) hydropower; 380 GW wind 120 GW (small) hydropower; 380 GW solar 182 GW nuclear; 48 GW other				

Average growth denotes average annual growth rate of emissions over the period base year-2030.
(*): McKinsey emissions statistics are based on overall GHG emissions (i.e. all GHG gases), while IEA and EIA emissions statistics consider energy-related CO_2 emissions. See note at Table 4.
Sources: McKinsey, *China's Green Revolution*, 2009, pp. 22; IEA, WEO2007, pp. 389-402 (High Growth Scenario), 596-599 (Alternative Policy and Reference Scenario); EIA, EIO2009, pp. 131, 148; IEA, WEO2009, pp. 199-200, 210, 623, 647.

We evaluate the findings of three different scenarios. One has been developed by using back-casting (i.e. calculating backwards from a "desired" outcome): the *IEA 450 Scenario* of the *World Energy Outlook 2009*.[12] Two more scenarios assess how special measures or policies might work out and impact on China's energy and emissions characteristics: the *Alternative Policy Scenario* of the IEA's *World Energy Outlook 2007* and the full abatement scenario in McKinsey's *China's Green Revolution* study (2009a).

Table 5 summarizes the emissions trajectories and key statistics of the different scenarios. Some background information of the scenarios is briefly sketched in the three subsections below, after which we will turn to the implications for climate change stabilization goals.

5.2.1. Alternative Scenario 1: IEA 450 Scenario—China (WEO, 2009)

The *450 Scenario* by the IEA envisions a future in which global emissions would be reduced to allow for a stabilization of GHGs in the atmosphere at 450 ppm, equivalent to a 50% chance of limiting the temperature increase to 2°C. China plays an essential role in this scenario as it contributes 37% and 33% to the required global primary energy demand and emissions reductions by 2030, respectively.

At the end of the projection period in 2030, China would occupy almost 27% of global energy-related emissions. Per capita emissions of CO_2 would be 4.8 tonnes of CO_2 per capita by 2030—roughly the same as in 2007—after peaking in 2020 at 5.9 tonnes per capita.

While there is no detailed description of how China would achieve this scenario, both energy demand reduction and decarbonization of the energy consumption are critical. If we focus on the year 2030, energy demand would need to be reduced by almost one-quarter compared to the reference scenario, and the average carbon content of electricity would need to drop with 49% from the expected 922 to 448 gCO_2/kWh. To this end, the share of coal-fired electricity generation in the fuel mix would need to decline from 81% to 50%, while the absolute amount of electricity supplied by nuclear power should increase more than 15-fold (by 2030). Renewables would also need to experience an astonishing growth: Electricity generated by hydro should increase fourfold; wind 70-fold; and other renewable energy sources 230-fold. What this would entail in terms of generating capacity by 2030 can be seen in Table 5. Considering transport, the CO_2 intensity of China's car fleet would need to be reduced by 57% from 235 grams of CO_2 per kilometer (gCO_2/km) to 90 gCO_2/km. To achieve this by 2030, 10% of all vehicles would need to be electric and 8.1% should run on biofuels. In terms of energy security consequences, China's gas imports would drop with 22% compared to the reference scenario, and oil

12. Another excellent back-casting analysis of Chinese emissions has also been made by the Tyndall Centre, that incorporates four different future scenarios (Wang and Watson, 2008; 2009).

imports would be limited to 11 million barrels per day by 2030 (IEA, 2009b, pp. 216–218).

5.2.2. Alternative Scenario 2: IEA Alternative Policy Scenario (WEO, 2007)

In this scenario, the IEA evaluated how several policy measures might work out that have been considered but not fully implemented by the Chinese government. This includes the strong promotion of natural gas over other fossil fuels, reforming the pricing system, the introduction of fuel taxes, and shifting the economy away from energy-intensive industry. Moreover, the scenario differs from the reference scenario (of WEO, 2007) in that it assumes a very effective enforcement of all related policy measures. Energy demand in 2030 would be 15% lower than its reference projection, but would nonetheless increase by 90% compared to 2005. Emissions would decrease by 2.6 Gt, equivalent to 22.5% compared to BAU: More than half of these reductions would be achieved through changes in the power sector, although coal would still supply 64% of all electricity in 2030. Structural changes in the economy would account for more than 40% of the total energy savings and also coal demand would fall with almost one quarter mostly due to less electricity demand. Emissions would stabilize soon after 2020 at 9 Gt CO_2 per year.

5.2.3. Alternative Scenario 3: McKinsey, China's Green Revolution (2009)

According to the McKinsey report, China's overall GHG emissions could almost be cut in half by 2030 compared to the baseline scenario, achieving a reduction of 6.7 Gt of CO_2e. The largest reductions (3.8 Gt) would take place in the power sector, where emissions would drop 70% compared to the baseline trajectory. The share of coal in the electricity generation fuel mix would decline to 34% by 2030, by vigorously promoting renewables, natural gas, and nuclear energy. CCS would need to be implemented to limit emissions from coal-fired power plants. Other important areas for abatement are emission-intensive industries (2.1 Gt), buildings and appliances (1.6 Gt), and road transportation (0.6 Gt).

As the power sector would contribute the most to reducing emissions, it is worthwhile to review the structure of the power generating capacity that would be required by 2030, which is summarized in Table 5, and compare this to our discussions in Section 3 and Section 4.2.

The costs of implementing this scenario are estimated at 150–200 billion euros per year over the period 2010–2030, on top of baseline investment figures. One-third of these investments are estimated to have positive economic returns, one-third will have slight to moderate economic cost, and the final one-third will have substantial costs associated with them.

Technology is critical in McKinsey's abatement scenario, as it requires new technologies that save on energy demand and emissions to be introduced across all sectors. This holds especially for the largest growth sectors identified in the baseline scenario: power generation, road transport, buildings, and appliances. In the coal sector, the most important new technologies to be implemented are *integrated gasification combined cycle* (IGCC) coal plants (implemented at 100 GW in the abatement scenario) and *carbon capture and storage* (to be implemented on one quarter of all coal-fired power plants by 2030), on top of more highly efficient ultra-supercritical plants already incorporated in the reference scenario. In the power sector, there will need to be more nuclear power, more wind (particularly offshore), more solar power, and more cofiring with bioenergy and (bio)power from switch grass and municipal solid waste. Hybrid and electric vehicles play a significant role in transportation apart from advanced fuel efficiency improvements in ordinary internal combustion engines. New technologies should be implemented in industry, especially in energy-intensive sectors such as steel and cement production. In terms of buildings, much can be gained by upgrading building codes and introducing passive design elements that have high energy savings for new buildings.

Finally, one crucial observation from the McKinsey report concerns the importance of the speed of implementation of mitigation measures. Since China's expansion in various energy-consuming sectors is taking place at such a rapid pace, it is estimated that after a five-year delay of starting full-scale of implementation of all options, 30% of the abatement potential would be lost. A ten-year delay would increase this to 60%.

5.3. Implications for Emissions Stabilization Scenarios

Stabilization scenarios have been developed by the Intergovernmental Panel on Climate Change (IPCC) of the United Nations as a suggested course of action to address climate change. Most attention has focused on limiting a global temperature increase to 2°C, which has been confirmed as an important threshold to limit ecological damage arising from climate change.

The objective of limiting a temperature increase to a maximum of 2°C is considered to be equivalent to stabilizing concentration levels of GHGs in the atmosphere at 450 parts per million (ppm), as this would give a 50% chance of keeping the temperature rise below that level. To improve the chances of not surpassing that threshold, even lower stabilization levels would be required.

As the concentration level of GHGs is determined by the cumulative total that is emitted over a certain period of time, various emissions trajectories are possible that would lead to a certain stabilization level. However, postponing emissions reductions will require a faster decline and steeper reductions later on.

According to the *Fourth Assessment Report* of the IPCC, stabilization scenarios in the range of 445 ppm—490 ppm would require global emissions to peak between 2000 and 2015 and decrease between 50% and 85% by 2050 compared to 2000 levels (IPCC, 2007a).

The burden-sharing of such global emissions reductions has been the subject of much discussion, but one of the most prominent suggestions has been for developed countries to reduce emissions by 25% to 40% by 2020 compared to 1990 levels, while asking developing countries to improve on their BAU projections of emissions by 15%−30%. In 2050, developed countries should have reduced emissions by 80%−95% compared to 1990 levels, allowing for more "carbon space" for developed countries as long as global emissions are reduced by 50% (IPCC, 2007a).

On the basis of the modeling results by the IPCC, the IEA has developed its own *450 Scenario* that sees global GHG emissions peaking in 2020 at 44 Gt of CO_2e and declining to 21 Gt in 2050. In terms of energy-related emissions this would mean a peak before 2020 at 30.9 Gt and a decline to 26.4 Gt in 2030 and 15 Gt in 2050. In this scenario, global energy related CO_2 emissions would have to decrease by about 1.5% per year in the period 2020−2050. Other suggested scenarios are even more strict: The trajectory suggested by the United Nations Environment Programme includes a global emissions target of 44 billion tonnes of CO_2e for 2020 and 16 billion tonnes of CO_2e by 2050 (UNEP, 2010).

The reference scenario projections for China, which were presented earlier, render such stabilization scenarios impossible or, at best, extremely unlikely. If China's energy-related CO_2 emissions were to continue to grow along the BAU trajectories indicated by the IEA and EIA (Table 4), they would already take up more than 40% of the annual global budget required for limiting a temperature increase to 2°C by 2030. The McKinsey baseline scenario, which also takes non-energy related GHGs into account, shows that Chinese emissions might reach 14.5 Gt by 2030 while still being on the increase. This would be rather hard to integrate with the UNEP target for global emissions in 2050 standing at 16 Gt (UNEP, 2010).

Of the three "alternative" quantitative scenarios that we examined, some still allow China's emissions to be incorporated into a 2°C stabilization goal. Of course, this is self-explanatory in the case of the *450 Scenario* by the IEA for China, which has been designed exactly to meet this objective. In this scenario, Chinese energy-related emissions would reach 7.0 Gt by 2030. The McKinsey abatement scenario projects *total* GHG emissions to be 7.8 Gt by 2030, which would still be in the range of what is required in the IEA's *450 Scenario*. However, a comparison between the required power sector structure for 2030 by McKinsey (Table 5) and the evaluation presented in Sections 3 and 4.2 indicate the enormous challenge that this scenario represents and questions the feasibility of such a transformation. The IEA *Alternative Policy* scenario shows that even with more stringent policy Chinese emissions might very well be above the required level for stabilization, projecting 2030 energy-related emissions at 8.9 Gt.

CONCLUSIONS

As a country still in the midst of its development, there are significant opportunities for China to develop along a more sustainable pathway than many countries that industrialized before it. China has a chance to put strong policy in place that can impact the energy system and energy-consuming infrastructure that is being laid out and that will determine future energy consumption and emissions levels up to a large extent. This holds especially true for several sectors that are undergoing a rapid phase of expansion, such as power generation, housing, and transportation. There are also large potential gains to be had by increasing the level of energy efficiency throughout China's economy and society.

China's current progressive policies are already having significant positive effects in reducing energy demand and energy-related emissions, as they stimulate energy efficiency and conservation, renewable energy sources, and nuclear power. The goal of establishing strong domestic industries in the field of advanced coal utilization, wind energy, solar energy, nuclear energy, and electric cars greatly contributes to a transition to a more sustainable energy system. China's role as a major global manufacturing center combined with these progressive industrial policies make China well-positioned to develop and deploy low-carbon and energy-efficient technologies. However, Chinese energy policy does not have sustainability as its main priority and there are serious impediments to achieving a sustainable energy system that will need to be addressed. As the cheapest, most abundant, and most carbon-intensive fuel available, the future role of coal in China's energy system is the crux of the matter regarding China's drive for sustainability.

Our analysis of several quantitative scenarios of China's future development showed that the demand for energy and especially energy-related emissions show an enormous increase, even if recent progressive policy measures—including China's carbon intensity targets—are taken into account. It can be concluded that BAU trajectories are impossible to reconcile with climate change stabilization scenarios that would limit a global temperature increase to 2°C. In fact, the most critical observation is that even with extreme measures and vigorous implementation, these global stabilization scenarios will be difficult to meet.

While current policies are not sufficient to achieve a sustainable energy system in the short-term span required in order to mitigate climate change, there are significant technical, economic, and political barriers that will hamper a strengthening of current policy measures. The main priority of China is economic development and the increase of welfare for its population. This means there are limits to implementing measures such as raising energy prices, limiting industrial energy demand, supporting renewable energy to expand even beyond current high growth rates, and developing and deploying CSS techniques to reduce emissions.

The necessity of a sustainable energy future for China should not be just a concern for China itself, however, as it will impact on the energy and climate future of the world at large. Given the global repercussions, the world will need to think about how to encourage an energy transition in China. Technologies, learning experiences, and best practices suggested in the other chapters of this book can hopefully provide inspiration and a contribution to this challenge.

BIBLIOGRAPHY

Asia Pacific Energy Research Centre (APERC). (2004). *New and renewable energy overview in the APEC region*.

Asia Pacific Energy Research Centre (APERC). (2008). *Understanding energy in China*.

Asian Development Bank (ADB). (2009). *Energy outlook of DMCs in East Asia*.

BP. (2010). *Statistical review of world energy.*

China National Bureau of Statistics (CBS). (2009). *China statistical yearbook 2008*. China Statistics Press.

China Daily. (2009). China car boom could last a few years: analysts. 9 July 2009. *www.chinadaily.com.cn/china/2009-07/09/content_8401265.htm*.

Chinese Academy of Sciences (CAS). (2007). Jointly addressing the challenge: Developing a sustainable energy system. 22 October 2007. (Announcing the release of the report: Chinese Academy of Sciences, *Addressing the Challenge: Developing a Sustainable Energy System*, October 2007.) http://english.cas.cn/Ne/CASE/200710/t20071022_18287.shtml.

Cho, J.-M., & Giannini-Spohn, S. (2007). Environmental and health threats from cement production in China. *A China Environmental Health Research Brief*, Wilson Center. *www.wilsoncenter.org/index.cfm?topic_id=1421&*fuseaction=topics.item&news_id=274782.

CIA. (2010). *CIA World Factbook – Country Profile China*. https://www.cia.gov/library/publications/the-world-factbook/geos/ch.html.

Clingendael International Energy Programme (CIEP). (2009). *Bram Buijs. China, Copenhagen and beyond*. Clingendael Energy Paper. *www.clingendael.nl/publications/2009/20090900_ciep_report_buijs_china_copenhagen_beyond.pdf*.

Energy Information Administration (EIA). (2009). *Annual energy review 2008*. U.S. Department of Energy. *www.eia.doe.gov/aer/pdf/aer.pdf*.

Global Wind Energy Council (GWEC). (2009). *Global wind report 2009*. *www.gwec.net/fileadmin/documents/Publications/Global_Wind_2007_report/GWEC_Global_Wind_2009_Report_LOWRES_15th.%20Apr.pdf*.

International Energy Agency (IEA). (2007). *World energy outlook 2007*.

International Energy Agency (IEA). (2008). *World energy outlook 2008*.

International Energy Agency (IEA). (2009a). *Key world energy statistics 2009*.

International Energy Agency (IEA). (2009b). *World energy outlook 2009*.

International Energy Agency (IEA). (2009c). *Energy technology transitions for industry.*

IPCC. (2007a). *Fourth assessment report. Climate change 2007 – synthesis report, summary for policymakers. www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf*.

IPCC. (2007b). *Climate change 2007: Mitigation. contribution of working group III to the fourth assessment report of the IPCC – summary for policymakers*.

Jiang, Z. (2008). Reflections on energy issues in China. *Journal of Shanghai Jiaotong University, 42*(3).

Lawrence Berkeley National Laboratory (LBNL). (2007). *Taking out 1 billion tons of CO_2: The magic of China's 11th Five-Year Plan?* Lawrence Berkeley National Laboratory Report (LBNL-757E). Authors: Lin, J., Zhou, N., Levine, M., & Fridley, D.

Lawrence Berkeley National Laboratory (LBNL). (2008a). *Current status and future scenarios of residential building energy consumption in China*. Lawrence Berkeley National Laboratory Report (LNBL-2416E). Authors: Zhou, N., Nishida, M., & Gao, W.

Lawrence Berkeley National Laboratory (LBNL). (2008b). *Estimating total energy consumption and emissions of China's commercial and office buildings*. Lawrence Berkeley National Laboratory Report (LNBL-248E). Authors: Fridley, D.G., Zheng, N., & Zhou, N.

Lawrence Berkeley National Laboratory (LBNL). (2008c). *Global carbon emissions in the coming decades: The case of China*. Authors: Levine, M.D., & Aden, N. T.

Martinot, E., & Li, J. (2007). Powering China's development: The role of renewable energy. *Worldwatch Special Report*.

McKinsey. (2009a). *China's green revolution*.

McKinsey. (2009b). *Preparing for China's urban billion*. *www.mckinsey.com/mgi/reports/pdfs/China_Urban_Billion/MGI_Preparing_for_Chinas_Urban_Billion.pdf*.

MIT. (2007). *The future of coal*.

MIT. (2008). *Greener plants, greyer skies? A report from the frontline of China's energy sector*. China Energy Group, MIT Industrial Performance Center. Authors: Steinfeld, Lester, & Cunningham.

MIT. (2010). China's high-speed-rail revolution, *MIT Techology Review*. *www.technologyreview.com/energy/24341/page1/*.

Morse, R. K., Rai, V., & Gang, H. (2009). The real drivers of carbon capture and storage in China and implications for climate policy. *Program on Energy and Sustainable Development*. Stanford University. Working Paper no. 88. *http://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID1485003_code1265440.pdf?abstractid=1463572&mirid=3*.

National Development and Reform Commission (NDRC). (2007a). *China's national climate change programme*.

National Development and Reform Commission (NDRC). (2007b). *Medium and long term development plan for renewable energy*.

Price, L., Wang, X., & Jiang, Y. (2008). *China's top-1000 energy-consuming enterprises program: Reducing energy consumption of the 1000 largest industrial enterprises in China*. Lawrence Berkeley National Laboratory Report (LBNL-519E).

REN21. (2010). *Renewables 2010 – global status report*.

Reuters. (2009). *China to shut more small power plants in 2010 – media*. *http://uk.reuters.com/article/idUKTOE5BR06A20091228*.

UN. (2008). *World population prospects: The 2008 revision*. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. *http://esa.un.org/unpp*.

UNEP. (2008). *Most commonly used air routes, in million passengers a year. UNEP/Grid Arendal. Data source: ENAC Air Transport Database*. French Civil Aviation University. *http://maps.grida.no/go/graphic/most-commonly-used-air-routes-in-million-passengers-a-year*.

UNEP. (2010). *Climate pledges*. *www.unep.org/climatepledges/*.

U. S. Geological Survey (USGS). (2004). *China's growing appetite for minerals*. Open-File Report 2004-1374 (presentation). *http://pubs.usgs.gov/of/2004/1374/2004-1374.pdf*.

U. S. Geological Survey (USGS). (2010). *Mineral commodity summaries 2010*. *http://minerals.usgs.gov/minerals/pubs/mcs/2010/mcs2010.pdf*.

Wang, H., Wang, G., Liu, H., Zhao, Q., & Liu, D. (2009). *Development trend of unconventional gas resources in China*. Langfang Branch Institute of the Research Institute of Petroleum

Exploration and Development, International Gas Union (IGU) Working Paper. *www.igu.org/html/wgc2009/papers/docs/wgcFinal00144.pdf*.

Wang, T., & Watson, J. (2007). *Who owns China's carbon emissions?* Tyndall Briefing Note No. 23. Tyndall Centre for Climate Change Research.

Wang, T., & Watson, J. (2008). *Carbon emissions scenarios for China to 2100*. Tyndall Centre for Climate Change Research.

Wang, T., & Watson, J. (2009). *China's energy transition. Pathways for low carbon development*. Tyndall Centre for Climate Change Research.

World Nuclear Association. (2010). *Nuclear power in China*. *www.world-nuclear.org/info/inf63.html*.

World Resource Institute (WRI). (2009). Energy and climate policy action in China. *http://pdf.wri.org/factsheets/factsheet_china_policy_2009-11-03.pdf*.

Xinhua. (2010). *China's power consumption grows 6% in 2009*. *http://news.xinhuanet.com/english/2010-01/06/content_12763227.htm*.