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China's Carbon Challenge: Insights from the Electric Power Sector

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This report is part of a series of research studies into alternative energy pathways for the global economy. In addition to disseminating original research findings, these studies are intended to contribute to policy dialogue and public awareness about environment-economy linkages and sustainable growth. All opinions expressed here are those of the authors and should not be attributed to their affiliated institutions.

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EXECUTIVE SUMMARY

Rapid growth of China's carbon emissions poses an unprecedented challenge to policymakers, both in China and around the world. If unchecked, China's current patterns of energy use will lead to environmental degradation and escalating energy costs that threaten the country's prosperity. At a global level, trend emissions from China and other Carbon Emergent Economies (CEEs) far exceed medium-term reduction commitments by Carbon Legacy Economies (CLEs). Rapid growth in CEE carbon emissions may render it impossible to achieve stabilization of atmospheric greenhouse gases below thresholds that pose catastrophic consequences for humanity.

This report uses official Chinese data and policy targets to elucidate energy pathways within the Chinese economy, focusing on the electricity sector. As China transits through industrialization to a more service-oriented economy, electric power and transport services will emerge to dominate energy use and carbon emissions. This transition presents challenges and opportunities for China and the international community to forge a new basis for cooperation on climate change mitigation.

Failure to do so may have grave implications. China is the world's second largest source of greenhouse gas (GHG) emissions and its principal source of growth in GHG emissions. China accounted for 44 percent of the growth in global CO_2 emissions from 1990-2004, and, as its economy continues to rapidly expand, China will be the world's main source of emissions growth from 2005-2020. China's official economic growth objective, to quadruple 2000 GDP by 2020, implies relatively moderate annual growth (about 6.5 percent). Recent trends in energy demand growth and resource use far exceed this pace, e.g. China's electricity demand over 2002-2005 grew at an annual rate of 14.5 percent. Steel production in 2005 exceeded official 2020 targets by 67 percent; coal production in 2005 was 10 percent above its 2020 target. As a whole, the Chinese economy's energy use and intensity in 2005 were 40 and 17 percent higher, respectively, than official targets.

To meet rising electricity demand, China will have to install as much as 860 GW of additional generation capacity by 2020, an amount exceeding the EU's total 2004 installed capacity. More than 60 percent of this new capacity will comprise coal-fired power plants, fossil fuel infrastructure with an operating lifetime of 40-50 years. Given the scale of China's electricity infrastructure that remains to be built, about two-thirds of the coal-fired power plants built in China by 2020 will still be operational in 2050. These plants alone represent a commitment of roughly 2-3 billion tons of annual CO_2 emissions until 2050.

Even if China's ambitious goals for alternative generation and power plant efficiency are met, if electricity demand grows as fast as GDP from 2005-2020, CO_2 emissions from electricity generation in China will rise by more than 2 billion tons. This amount significantly exceeds the reductions required for OECD countries to reach 1990 emissions from their 2004 levels. Alternatively, a shift toward more service-intensive GDP and improvements in energy efficiency could significantly moderate growth in electricity demand as a source of China's CO_2 emissions.

Well aware of the challenges posed by a recent rise in the energy intensity of its economy, China has instituted ambitious programs to support energy efficiency and increased market penetration of alternatives to coal-fired generation. However, institutional and financial issues present major constraints to scaling up these programs to levels that are meaningful for reaching GHG stabilization targets. CLE countries can make important contributions to this process, and ambitious investment in energy efficiency and alternative technologies in China may represent a more cost effective means of reducing global emissions and climate risk than analogous efforts at home.

More generally, an inclusive multilateral approach that builds on existing incentive structures is needed to advance GHG stabilization objectives. CLE countries have a clear stake in China's sustained growth and transition from an export-driven to a consumer-oriented economy. China has obvious incentives for reducing its energy intensity to relieve pressures on energy and resource supplies, prices, and its environment. This common ground offers a basis for multilateral discussions to secure lasting progress on climate action.

China's Carbon Challenge:

Insights from the Electric Power Sector

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1. Introduction and Overview

As the world's most vibrant economy, China inspires both admiration and apprehension. China has given the world a new model of economic dynamism and efficient international division of labor, lifting millions of households out of poverty while contributing to innovation and greater purchasing power for consumers around the world. At the same time, China's economy is testing conventional thinking about patterns of resource use. Absorption from the Chinese economy has emerged as a primary driver of Asian economic growth and animated global commodity markets.[2] While the former trend is welcomed by exporters worldwide, escalating resource use in China portends important challenges for sustainable growth. In this way, China's emergence reminds us of both the promise and the necessity of resource efficiency. China has proven that more efficient use of traditional factors of production (labor and capital) can yield remarkable prosperity, yet resource scarcity and environmental degradation now threaten the same objective in the future. If market failures in important resource categories can be corrected, we believe that China's growth experience can outlive even the most optimistic projections.

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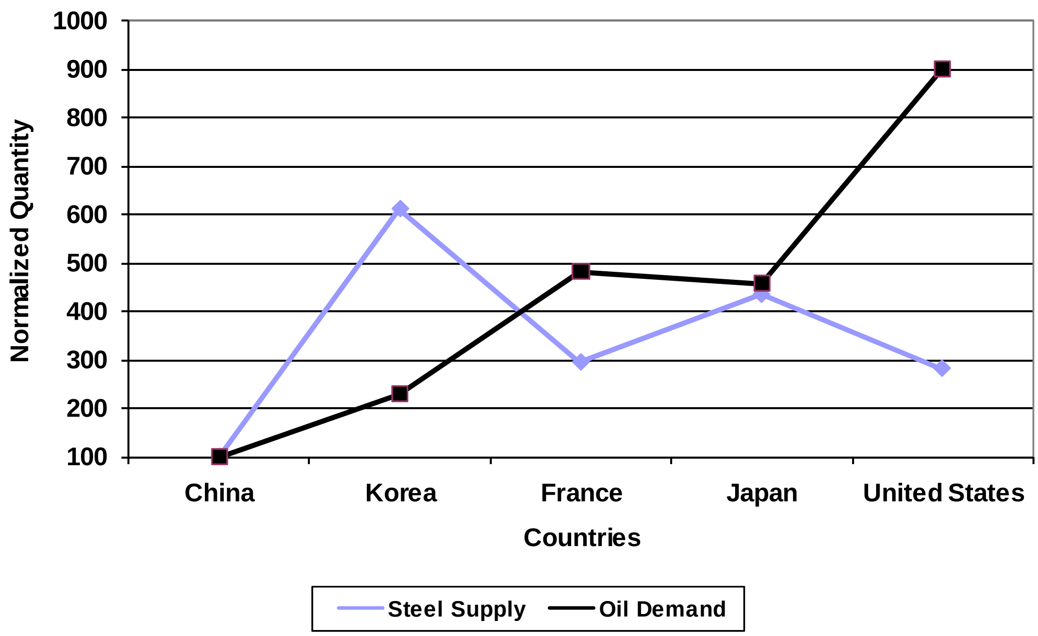
[2] Roland-Holst, 2002.

While China has its own reasons to promote innovation, productivity growth, and greater resource efficiency, it is important to understand its accomplishments and challenges in a global context. Approximately 70 percent of today's GHG stocks were released between 1850 and 2000 by Carbon Legacy Economies (CLEs), mainly the United States and Europe, yet Carbon Emergent Economies (CEEs) are rapidly assuming a major share of global emissions. Among the latter, China is today the world's second largest emitter, and emissions are growing there at more than twice the average rate for the CLEs. Unequal accountability for past, present, and future emissions is further complicated by the prospect of unequal climate change damages. If significant global warming does occur, relative (per capita and as a percent of GDP) damages will generally be higher for lower income countries, despite their relatively small contributions to this global externality. China offers opportunities for dramatic innovation and precedence to a new generation of policy where globalism and sustainability are axiomatic. In the same spirit, China cannot and should not be expected to establish these precedents alone. As a primary contributor to the global commons of climate stabilization, China can expect tangible recognition of its efforts to mitigate domestic greenhouse gas (GHG) emissions.

In this paper, we examine these issues from a specific empirical perspective, China's electric power sector. Although industrialization gave birth to the carbon-intensive economic growth experience, it is now widely recognized that electricity use and transportation will have a more enduring legacy. As the Figure 1 indicates, industrialization (proxied here by steel production per capita) is a transitory experience for emerging economies. Carbon energy dependence (proxied by oil consumption per capita), however, appears to be more monotonic in income. Likewise, while the environmental implications of China's industrial development are the focus of most contemporary analysis, residential electricity and transport services are likely to dominate carbon's contribution to Chinese GDP in the longer term.

Our review of recent evidence indicates that China's carbon dioxide emissions from electricity generation, powered largely by coal, rose much more rapidly from 2002-2005 than projections had generally assumed. This growth in emissions poses a serious long-term challenge to China and, through its contribution to climate change, to both CLE and CEE countries. We also argue, however, that there are many opportunities for domestic and external policy reform that can significantly offset to environmental burden of future growth in China and other CEEs. In this way, China can again assert its leadership as a global innovator, this time with a new generation of policies that reconcile environment and growth policies for sustainable prosperity.

Figure 1. Per Capita Steel Production and Energy Consumption (Chinese levels = 100)

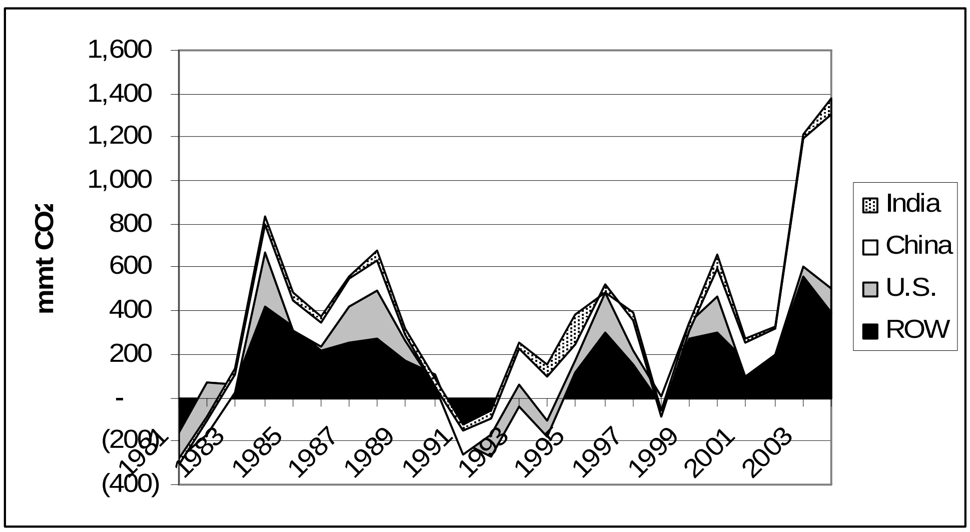


Sources: IISI, Bloomberg.

2. An Overview of CO2 Emissions, Electricity, and Coal in China

As the world's second largest emitter of greenhouse gases (17 percent in 2004), China is also the world's fastest growing energy consumer and largest source of growth in CO_2 emissions.[3] Primary energy demand in China grew by an average of 8.4 percent per year over the period 1990-2004,[4] and China accounted for 44 percent of the growth in global CO_2 emissions over the same period (Figure 2).[5] Recent analysis suggests that China could surpass the U.S. to become the world's largest source of in CO_2 emissions by 2009, rather than 2020 as previously forecast.[6]

Figure 2. Growth in CO_2 Emissions, India, China, U.S., and Rest of World, 1980-2004



Source: Based on EIA (2006).

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[3] EIA, 2006.

[4] This timeframe is maintained for consistency, but here it is slightly misleading. From 1990-1999 primary energy consumption in China grew by an annual average of 3.2 percent; from 2000-2004 it grew by 10.3 percent.

[5] Together, China, the U.S., and India accounted for 69 percent of the growth in global CO_2 emissions from 1990-2004 (EIA, 2006).

[6] IEA, forthcoming.

Electricity generation accounted for 43 percent of China's CO_2 emissions in 2003 and coal-fired generation accounted for 97 percent of these emissions.[7] Using coal consumption as a proxy, it is apparent that electricity generation is also the fastest growing source of CO_2 emissions in China. Electricity's share of China's total coal consumption increased from 26 percent in 1990 to 48 percent in 2003.[8]

That a significant portion of the world's greenhouse gas emissions in the next two decades will come from coal-fired power plants in China poses a special challenge for climate change policy. Coal-fired power plants are unique among fossil fuel infrastructure because they are intergenerational — the typical lifespan of a coal-fired power plant is 40-50 years.[9] As a source of greenhouse gas emissions, coal-fired power plants bridge the divide between short-term and longer-term emissions pathways. Because of this, their inflexibility weighs heavily on the economics of appropriate timing for emission reduction policies.

An influential example of this issue arises in the arguments of Wigley et al. (1996), who give three reasons why a later transition away from fossil fuels would be more efficient economically: fewer resources will be needed to address climate change in the future because of the positive marginal productivity growth in most of the world's economies; existing capital stocks should be fully utilized; and the option value embedded in technological progress should be realized. Wigley et al.'s scenarios are based, however, on continuous transition to a less carbon-intensive future capital stock. In China, this transition could be substantially retarded by the longevity of an emergent coal-fired electric power capital stock. Without a significant shift in the technologies that power and consume electricity in China, the world's future energy infrastructure could be net carbon positive.

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[7] China's *Electricity Statistical Yearbook* (EBCEPY, 2004) classifies electricity generation as "thermal," "hydro," "nuclear," or "other"; fossil fuel-based generation is not disaggregated. Electricity's share of total CO_2 emissions, and coal-fired generations share of these emissions, were calculated by using energy input/output tables and heating values in the *Energy Statistical Yearbook* (NBS, 2004), a 23.012 GJ/ton heating value for thermal coal used throughout this analysis, and carbon conversion factors in IES (2005). Total CO_2 emissions data for China are from EIA (2006).

[8] NBS, 1996-2005

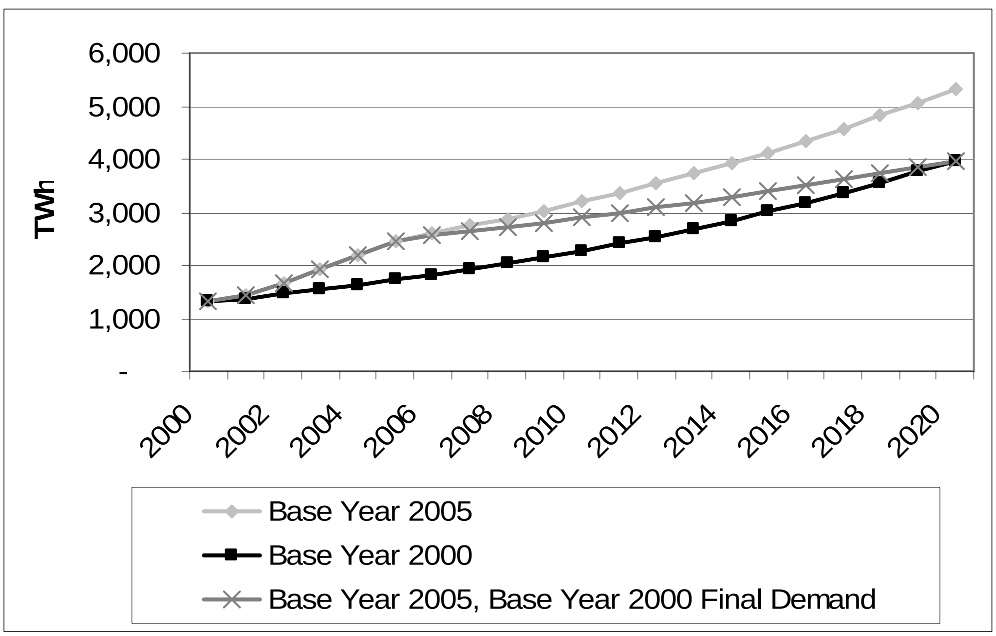
[9] Pouris, 1987.

China's Electricity Demand to 2020

China's electricity generation and capacity have more than doubled every decade since 1980. Over the period 1990-2004, electricity generation grew by an annual average of 9.7 percent, while installed capacity increased more than three-fold, from 138 to 442 GW (EIA, 2005). Put a different way, 69 percent of China's entire generation capacity in 2004 had been installed since 1990.

In 2002, China's leaders outlined a goal of quadrupling the country's 2000 GDP by 2020, while only doubling energy consumption and reducing pollution.[10] Because of its political significance, the economic component of this goal represents a widely used baseline for economic and energy analyses in China. Thus it offers a convenient metric with which to gauge China's future electricity and energy consumption.

Figure 3. Electricity Demand to 2020, 2000 versus 2005 as a Base Year



[10] 16th National Congress of the Communist Party of China, 8 November 2002.

Note: Base year 2000 projections are based on a GDP growth rate equivalent to a quadrupling of 2000 GDP by 2020, or 7.2 percent, and an electricity elasticity of 0.8. Base year 2005 projections are based on an implied 2005-2020 GDP growth rate of 6.6 percent, and an electricity elasticity of 0.8.
Sources: 2000-2004 electricity consumption data are from EBCEPY (2001-2005); 2005 electricity consumption data is from NDRC (2006).

Partly because of higher-than-anticipated economic growth from 2002-2005, China's annual electricity demand growth averaged 14.6 percent from 2002-2005 (EBCEPY, 2003-2005). As a result, China's electricity demand trajectory shifted upward by 747 TWh over what it would have been in a similar base year 2000 projection (Figure 3), throwing off earlier demand projections (Table 1). The lowest projection in Table 1 was surpassed in 2005.

Table 1. Projections for China's 2020 Electricity Demand

Organization	Date	Projected Demand 2020 (TWh)
International Energy Agency (IEA)	2000	2,254
2005 Actual	—	2,469
Tsinghua University	2003	2,478
Asia Pacific Energy Research Council (APERC)	2002	2,987
Energy Research Institute (ERI)	2003	Scenario A: 3,437
Energy Information Agency (EIA)	2006	4,256
State Grid Corporation of China (SGCC)	no date	4,400
Development Research Center (DRC)	2004	5,226
China Development Bank (CDB)	2005	5,280-5,780

Sources: 2005 Actual data are from NDRC (2006). IEA, Tsinghua University, APERC, and ERI projections are from APERC (2004); EIA projections are from EIA (2006), and are based on 2003 data; SGCC estimates are from Hu et al. (2005); DRC projections are from Li et al. (2004); CDB projections are from Wu (2005).

The projections in Figure 2 and Table 1 make different assumptions about the relationship between electricity demand growth and GDP growth, or the electricity elasticity of GDP (electricity elasticity below). For instance, the State Grid Corporation of China (SGCC) estimate in Table 1 assumes an annual average growth in electricity demand of 6.1 percent. Measured against the implied 7.2 percent per annum growth rate necessary to quadruple 2000 GDP by 2020 from a base year of 2000, the electricity elasticity is 0.85.

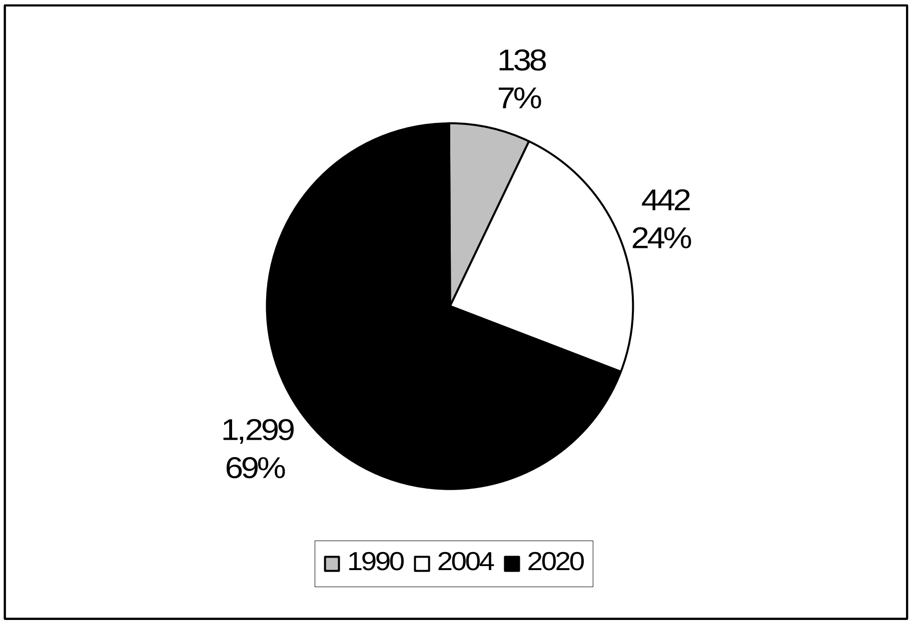
Questions about the appropriate base year for calibration of the electricity demand-GDP relationship, as well as the extent to which electricity elasticity should be a longer or shorter run average, are complicated by periods of high growth like the one in Figure 2. Maintaining the base year 2000 growth trajectory in Figure 2 projected from a 2005 demand would require an electricity elasticity of 0.56 from 2005-2020. For reasons discussed below, however, a band of 0.8-1, projected from 2005 electricity demand, is used here.

From a base year of 2005, quadrupling 2000 GDP by 2020 would require that China's economy grow by an (historically moderate) annual average of 6.6 percent from 2005-2020.[11] If electricity elasticity lies between 0.8 and 1 from 2005-2020, 2020 electricity demand would be between 5,337 and 6,432 TWh and China would need to add roughly 635-860 GW of new capacity from 2004-2020, a figure comparable to Europe's entire installed capacity in 2003 (781 GW).[12] Phrased differently, under these assumptions, 59-66 percent of China's 2020 generating capacity remains to be built (Figure 4).

Figure 4. Share of China's Installed Capacity Built by 1990, 2004, and to be Built by 2020, Assuming Electricity Demand Grows as Fast as GDP

[11] More precisely, to quadruple 2000 GDP (4.86 trillion yuan, 1990 prices) by 2020 (19.48 trillion yuan), China would need maintain an annual average growth rate of 6.59 percent from 2006-2020, projected from a 2005 GDP of 7.46 trillion yuan (1990 prices). 2000-2004 GDP data are from NBS (2005); 2005 GDP estimate is from NBS website, www.stats.gov.cn.

[12] The conversion from energy (kWh) to power (kW) assumes an average capacity factor of 0.63 (5,500 hours), a commonly used benchmark in China, and a conservative 0.9 estimate for load factor (see, for example, Hu et al., 2005). This calculation assumes that the share of generation from power plants that will be retired from 2005-2020 is small, an assumption that depends to a significant extent on policy. Total installed capacity data are from EIA (2006).



Note: Percentages are shares of estimated 2020 capacity; for example, 24 percent of an estimated 1,299 GW of capacity was built by 2004.

Electricity Demand Growth and CO2 Emissions

China is an Annex II party to the Kyoto Protocol, and as such is not required to set targets for CO_2 emission reductions. In light of the enormous demand growth uncertainty illustrated in Table 1, setting rigid overall targets might confer intolerable risks on both Chinese policy makers and a multilateral emissions convention. For instance, an emissions target for the electricity sector set in 2000 for 2010 might have been eclipsed by 2005, plunging the Chinese government into arrears halfway through the agreement or rendering the system untenable.

It should be emphasized, however, that difficulties in establishing targets do not obviate the need for common, quantitative boundaries. Without common boundaries, it is impossible to ascertain the difference between realistic levels of emissions reductions for China and what should be considered part of a new global CO_2 emissions baseline. A bounded approach, against which change can be measured even during periods of high growth, offers a middle way between hard targets and the status quo. This would be an essential foundation for dialogue between CLE/OECD countries and China on climate change mitigation.

While China's CO_2 pathway may be difficult to trace precisely, it is not without signposts. Coal-fired generation will comprise the bulk of CO_2 emissions from China's electricity sector, and coal-fired generation can be bounded by three parameters: electricity intensity, thermal efficiency, and the penetration of alternative fuels and technologies for electricity generation.[13] A basic projection of upper and lower bounds for these emissions requires three key fixed and three key variable assumptions, described in Table 2.

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[13] Transmission and distribution losses and plant use are two other metrics that bound CO2 emissions from coal-fired generation, but in both cases China is not substantially below international norms. Transmission and distribution losses in China were 7.55 percent in 2004 (EBCEPY, 2005), which is similar to 8-9 percent line losses from centralized generation in the U.S. (EIA, 2005). Plant "in-house" use of electricity for thermal generation and hydropower was 6.85 percent and 0.47 percent, respectively, in 2004 (EBCEPY, 2005), which is comparable with the U.S. rule of thumb of 7 percent (EIA, 2005).

Table 2. Key Assumptions for Projecting CO_2 Emissions from Coal-fired Power Plants in China

Fixed Assumptions	
GDP growth	Annual average growth is assumed at 6.6 percent.
Coal heating value	5,500 kCal/kg, or 23.012 GJ/ton*
Carbon content of coal	57.1 percent**

Variable Assumptions: Upper Bounds	
Power plant efficiency	Thermal efficiency of coal-fired power plants in China reaches 2005 average OECD levels by 2020
Electricity intensity	Electricity intensity of GDP does not change from 2005-2020; average electricity elasticity of GDP is 1
Alternatives to coal	Coal still makes up 78 percent of generation by energy in 2020 (from 97 percent in 2003)

* Coal for electricity use in China tends to be between 5,000-5,500 kCal/kg. Five thousand kCal/kg is often used as a technical parameter in designing thermal equipment (Sinton and Fridley, 2000), but the higher number is chosen here to reflect the increasing tendency of grids to require their power plants to use higher heating value coal.

** Carbon content of coal is based on an IES (2005) value of 24.81 kg-C/GJ for coal.

The upper bound assumptions for efficiency, intensity, and alternatives in Table 2 result in 5,045 TWh of coal-fired generation in China in 2020. New coal-fired electricity generation of this magnitude would imply annual CO_2 emissions of 4.6 billion tons (1.3 GtC) from coal-fired power plants by 2020, or new emissions of 2.9 billion tons (0.8 GtC). The latter is equivalent to 11 percent of 2004 global CO_2 emissions and is nearly 50 percent higher than the total CO_2 reductions required to bring OECD countries back to 1990 emissions levels from their 2004 levels.[14] The former is equivalent to more than one-seventh of the roughly 7 billion ton per year, 50-year CO_2 emission limit required to stabilize greenhouse gas concentrations at 500 ppm_v (Pacala and Socolow, 2005), and is used as an upper bound in the remainder of this analysis (upper bound below).

[14] The 30 OECD countries had total CO_2 emissions of 13.5 billion tons (3.7 GtC) in 2004. Returning to 1990 CO_2 emissions levels of 11.4 billion tons would require a reduction of 2.0 billion tons (0.6 GtC) (EIA, 2006).

3. China's Contribution to Greenhouse Gas Stabilization

China has an historic opportunity to sustain its path to prosperity while at the same time contributing to the global commons of greenhouse gas (GHG) stabilization. As we are reminded by many voices in the scientific and economic communities, a new global agenda is needed to avert potentially devastating local adjustments and substantial degradation of the world's growth potential.[15] China can take leadership in this area, and there are several strategic dimensions where effective domestic sustainability policies can make important contributions to global welfare, directly and by example. We discuss the scope and limits of four of these below and argue that more extensive research and policy innovation in each of these areas should be a high priority.

Electricity Intensity

As the integral of electricity elasticity, electricity intensity — the amount of electricity consumed per unit GDP — will determine whether China's demand for electricity grows faster or slower than GDP. China's electricity intensity, in turn, will be determined by the evolution of domestic economic structure and the efficiency of its buildings and appliances. If China's average electricity elasticity from 2005-2020 falls to 0.8, CO_2 emissions from coal-fired power plants in 2020 would be roughly 780 million tons lower than the upper bound.

As part of China's transition from an export-oriented industrial economy to a consumer-oriented services economy, residential and commercial buildings will gradually replace heavy industry as the main driver behind growth in electricity use.[16] Presently, heavy industry is the primary driver of electricity demand growth in China. Discounting electricity

[15] The recent Stern Review (2006) provides a comprehensive overview of these issues.

[16] For instance, the buildings sector accounted for nearly 60 percent of electricity consumption in OECD countries in 2003 (EIA, 2006). Based on residential and commercial use from EBCEPY (2005), in China it accounted for less than 30 percent in 2004.

used by the power sector itself, 41 percent of the 460 TWh increase in China's electricity consumption from 2002-2004[17] was accounted for by four sectors: industrial chemicals (9 percent), ferrous metals processing (16 percent), non-ferrous metals processing (9 percent), and building materials manufacture (7 percent) (EBCEPY, 2005). Overall, heavy industry accounted for 56 percent of China's electricity consumption in 2004 (EBCEPY, 2005).

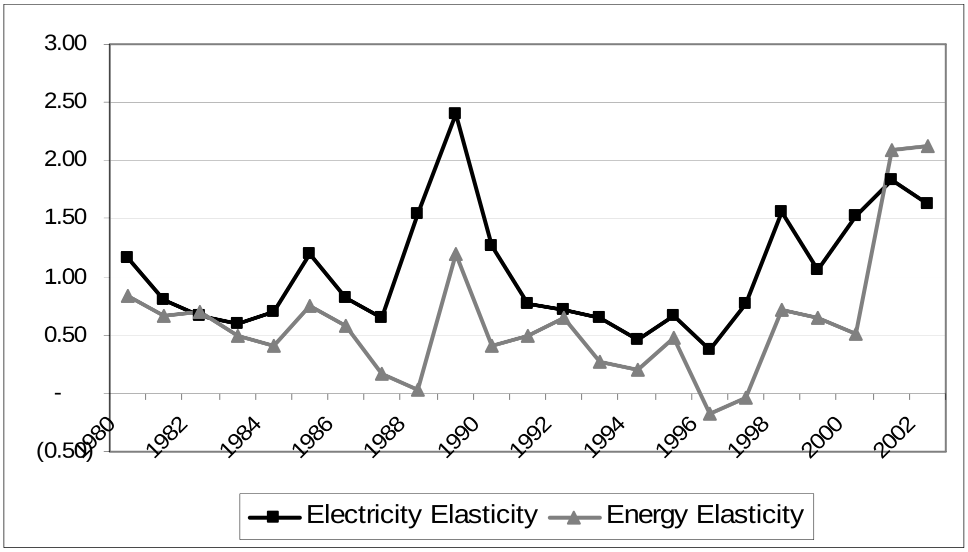
The perceived need to reduce industry's share in the Chinese economy was a major consideration behind the State Council's goal, enunciated in the 11th Five-Year Plan, of reducing energy intensity 20 percent by 2010. Assuming this goal could be met without compromising economic objectives, China's electricity elasticity could theoretically decline as growth in the less electricity-intensive services outpace industrial growth.[18]

In practice, there are four primary ways to reduce electricity intensity: restrict output from small-scale, energy inefficient industrial firms; improve the efficiency of larger firms through equipment upgrades, process improvements, and reduced materials use; increase growth in less electricity-intensive service sectors; and improve building and appliance efficiency. Significant opportunities exist for all four in China, but reductions in electricity intensity are almost certain to be less than those in overall energy intensity. Historically, electricity has been more elastic than energy to changes in GDP (Figure 5), and electricity and energy intensity may become inversely correlated during some periods as state-owned firms upgrade to electric and electronic equipment.

[17] 2005 data was not available at the time of writing.

[18] This is an example of the so-called 'composition effect.' Macro emission patterns in an economy arise from three component sources: aggregate growth, changing sectoral composition, and technological change.

Figure 5. China's Electricity Elasticity and Energy Elasticity, 1980-2003



Sources: Electricity elasticity here is based on EIA (2006) data, which reflects net rather than gross consumption (gross consumption minus losses and exports). GDP growth rates are based on constant prices from IMF Econstats, online at www.econstats.com. Energy consumption data are from EIA (2006).

China's electricity intensity from 2005-2020 will depend on the extent to which industry's declining share of electricity consumption is offset by the increasing share of residential and commercial demand, and the feedbacks among these. Government targets for urbanization portend a reversal of China's 2000 rural-urban distribution by 2020, with 300-400 million people moving into cities from 2000 to 2020. This demographic transition has important implications both for residential and commercial electricity demand and for heavy industry via civil infrastructure requirements.[19]

To forecast electricity demand beyond orders of magnitude amidst such uncertainties is a tenuous exercise. The lower bound of 0.8 used here is itself arbitrary, albeit commonly used,[20] and based on an assumption that electricity intensity may at least temporarily decline as China passes its industrial peak. Additionally, it should be noted that

[19] Actual projections of China's total urban population in 2020 vary but most estimates have settled within a range of 50 to 70 percent urban by 2020. See Wang (2004) for a discussion of the parameters germane to urbanization-related policy discourse in China.
[20] See, for instance, Li et al. (2004), Wu (2005), and Zhou et al. (2000). See Bo (2003) for an econometric analysis of historical electricity elasticity in China.

the mid- to late 1990s, coinciding with the Asian Financial Crisis and China's preparation for World Trade Organization (WTO) entry, was characterized by an anomalous decline in energy intensity.[21]

Power Plant Efficiency

At 33 percent in 2004, the average thermal efficiency[22] of coal-fired power plants in China was 3 percentage points lower than the comparable average in OECD countries in 2004.[23] Adding large-scale, high efficiency units to China's stock of coal-fired power plants would have a visible effect on average efficiency because of the magnitude of generating capacity that remains to be built from 2005-2020. Assuming the National Development and Reform Commission's (NDRC's) targets for power plant efficiency over 2005-2020 are met, CO_2 emissions from coal-fired power plants in 2020 would be 288 million tons lower than the upper bound.

Whereas the majority of generating units built in China during the late 1980s and early 1990s were between 100 and 300 MW, newer units tend to be between 300 and 600 MW. For conventional pulverized coal, a new 600 MW unit is roughly 10 percent more efficient than a new 100 MW unit, and 15 percent more efficient than a 100 MW unit built

[21] Fridley et al., 2003.
[22] Thermal efficiency for coal-fired power plants in China is typically reported in grams per kilowatt-hour (g/kWh) and termed 'coal consumption for electricity provision' (供电煤耗 | *gongdian meihao*). This value can be converted to a percent using a "standard coal equivalent" (SCE) of 7,000 kCal/kg (29.288 gigajoules/ton, lower heating value). However, the accuracy of this conversion is uncertain. In particular, it is unclear how the g/kWh efficiency data reported by EBCEPY (2005) are collected and verified; if the conversion from g/kWh takes place at an aggregate level, much of the regional and plant-specific variation in coal heating values would be lost, and it is further uncertain whether this loss would be more likely to lead to an under or overestimate of efficiency. See Sinton and Fridley (2002) for a further discussion of issues in converting between coal consumption and percent efficiency values.
[23] China efficiency data are from EBCEPY (2005). OECD efficiency data are from IEA (2003).

in 1990.[24] New coal technologies are likely to raise efficiencies to around 45 percent in the medium term.[25]

The NDRC's *Medium and Long-term Plan for Energy Efficiency*[26] outlines a goal of increasing the average efficiency of coal-fired power plants to 34 percent by 2010 and 38 percent by 2020. Increasing average efficiency to these levels, given the efficiency of existing units, would imply that after 2010 all new units would be more than 40 percent efficient. Stated differently, by 2010 new coal-fired power plants in China would be predominantly supercritical or integrated gasification combined cycle (IGCC) plants.[27] By the same reasoning, 38 percent is likely to be an upper limit for the average efficiency of China's coal-fired power plant fleet in 2020, without decommissioning significant numbers of existing generating units before they become technically obsolete, either for age or size reasons.

In four provinces surveyed as part of this study,[28] less than 2 percent of 2004 total dispatchable generation from coal-fired power plants came from units built during the 1960s; 6 percent came from units built during the 1970s. Assuming that 10 percent of China's total coal-fired generation is produced by units built before 1980, retiring and replacing their generation with generation from 45 percent efficient units would raise average efficiency by just over half of one percentage point.[29]

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[24] Efficiency estimates are drawn from Jie (2005) and a three percent increase in efficiency per decade, and based on various online reports of power plants' efficiencies. See, for instance, Datang International Power Generation Corp. website, online at www.dtpower.com/en/operation/operation_data.jsp

[25] IEA, 2003.

[26] NDRC, 2005.

[27] For an overview of these technologies, see IEA Clean Coal Center website, online at www.iea-coal.org.uk.

[28] Included in this survey were individual generating units on the North China Power Grid (NCPG), which comprises Beijing, Tianjin, Shanxi, Hebei, western Inner Mongolia, and, more recently, Shandong. The 'four provinces' refers to the former four. Aggregated power plant data were drawn from SGCC (2005), and disaggregated into individual generating units using a variety of print and online sources.

[29] This calculation assumes that the average efficiency of pre-1980 power plants is 400 g/kWh, or 30.7 percent. Replacing 10 percent of 2004 coal-fired generation (est. 1,707 TWh) with generation from 45 percent efficient units would raise 2020 average efficiency from 38.41 to 38.96 percent.

Similarly, retiring small, coal-fired power plants provides relatively limited scope for improving average efficiency. Although coal-fired plants under 100 MW account for roughly 65 percent of total coal-fired generating units in the four provinces surveyed, they accounted for only 15 percent of total electricity generation in 2004. Assuming this number is representative of national conditions, replacing 15 percent of generation nationwide with generation from 45 percent efficient units would lead to an average efficiency increase of nine-tenths of one percentage point.[30]

Raising the average efficiency of power plants substantially beyond 38 percent by 2020 would require replacing generation from relatively newer 100-300 MW plants that make up the bulk of generation and CO_2 emissions from China's existing coal-fired power plants. This step could only be taken at substantial economic cost and would require policy commitment that is unprecedented in China or, for that matter, in any other economy.

Alternative Technologies

Eager to diversify away from its heavy reliance on coal, the Chinese government is actively promoting alternative fuels and technologies in the electricity sector. Most of these alternatives are still in the initial stages of market development. The NDRC has set targets of adding 471.8 GW of power from fuel sources other than coal and petroleum distillates by 2020 (Table 3). Meeting these targets would imply a reduction of approximately 550 million tons of CO_2 against the upper bound.

[30] Using the same assumptions as in footnote 29, but lowering efficiency of pre-1980 power plants to 425 g/kWh.

Table 3. China's 2020 Targets for Alternative Electricity Sources and Estimated Resource Availability

Targets	**2004 Capacity (GW)**	**2020 Target Capacity (GW)**	**Implied Average Annual Growth**	**Estimated Resources**
Natural gas	0.70	60	32%	2.35 trillion m^3
Wind	0.82	30	25%	Land: 235 GW Offshore: 750 GW
Hydro	105.24	300	6.8%	Total: 541 GW Small: 125 GW
Solar	0.06	1.8	125%	3.96 $kWh/m^2 \cdot day$
Nuclear	6.84	40	11.7%	n/a
Biomass	0	30	n/a	n/a

Sources for Targets: Targets for wind, hydro, solar, nuclear, and biomass are from the NDRC's Medium- to Longer-term Plan for Renewable Resources, cited from the Office of The National Energy Leading Group website, online at: http://www.chinaenergy.gov.cn. The target for natural gas is based on NDRC targets, cited from EF (2006).
Sources for Resource Estimates: Natural gas estimates are from BP (2006); Wind, small hydro, and solar irradiation estimates are from CREDP (2005); total hydropower estimates are from CER (2006).

Coal comprised an estimated 78 percent of China's total electricity generation inputs on a kilowatt-hour basis in 2003.[31] Assuming that government targets for alternative electricity generating sources by 2020 are met, 51-64 percent of China's new electricity demand from 2005-2020 would be met through coal, and coal would account for 63-69 percent of China's total generation in 2020.[32]

Achieving these targets, and moving beyond them,[33] will mean bridging the divide between low cost of coal-fired generation and higher cost of alternatives. At a levelized cost[34] of less than 0.3 yuan/kWh (US$.04/kWh), only older hydropower plants are cost competitive with coal on a per kilowatt-hour basis, despite dramatic increases in coal prices

[31] *Supra* 3.
[32] Assuming capacity factors for natural gas, wind, hydro, solar, nuclear, and biomass of 0.63, 0.30, 0.40, 0.25, 0.80, and 0.85, respectively.
[33] The Global Wind Energy Council (GWEC), for instance, argues that as much as 170 GW of wind power will be built in China by 2020 (GWEC, 2006).
[34] Levelized cost represents the all-inclusive, life-of-project present value average cost per unit of output.

over the past 3 years. Coal prices rose from around 200 yuan/ton in 2005 to 400-600 yuan/ton in 2005.

China's central government has strategic reasons to be interested in fossil fuel alternatives. Natural gas and oil fueled generation are both reliant on imported supplies, and subject to external price shocks. Although China could be self-sufficient in coal, local oligopolies, supply constraints, and transportation bottlenecks have contributed to rising coal prices and a surge in imports from Viet Nam and Australia.[35] Allowing electricity generators to pass these costs on to consumers could propagate inflation. On the other hand, without retail reforms that allow prices to reflect scarcity, capital investment in coal production might be insufficient. Based on the low and high bounds used in this discussion, China would need to increase coal production by 540 million to 1.4 billion tons by 2020 to meet demand for coal for electricity generation. As a reference point, China's total coal production in 2003 was 1.7 billion tons.[36]

In theory, alternatives imply higher costs and higher electricity prices. Part of the impetus for the June 2006 increase in China's national electricity tariffs was to provide a means for electricity producers to absorb preferential feed-in tariffs for renewable energy, as mandated in China's 2005 Renewable Energy Law. In actuality, as China transitions toward a more competitive electricity industry and more efficient consumption, the direction of average energy prices over the next 15 years is unclear.

Electricity Prices and Sector Reform

In 2002, the NDRC abolished its longstanding "guiding price" for coal, allowing coal producers to set and negotiate their own prices. In the same year, the NDRC began a process of deregulation in the electricity sector that unbundled generation and transmission

[35] A rough average of 40-50 percent of the retail price of coal in China derives from transportation costs. For instance, the average mine-mouth price of coal in China's "three wests" region was 172 yuan/ton in 2003, while the cost of transporting it to China's eastern seaboard is 100-150 yuan/ton (Zhang and Lei, 2005).

[36] NBS, 2005.

and distribution, creating five generating corporations and two grid companies. This electricity sector reform was built on three pillars: separation of generation and transmission and distribution (电网分开 | *dianwang fenkai*); separation of government and business (政企分开 | *zhengqi fenkai*), and creating a competitive pricing scheme (上网竞价 | *shangwang jingjia*).

Longer-term wholesale and retail electricity prices in China will be conditioned by this deregulation process in coal and electricity. After adjudicating disputes between coal and electricity producers from 2002-2004, the NDRC has ended its interventions in coal prices. In mid-2005, the agency implemented a temporary system of coal and electricity price "joint movement" (煤电价格联动 | *meidian jiage liandong*). This allows electricity producers to pass on up to 70 percent of their cost increases to consumers, subject to NDRC approval. Prices have been on the rise, with the NDRC approving rate increases in May 2005 and June 2006.

On the other hand, with the corporatization of electricity production, capital costs for electricity generation in China have fallen rapidly. Capital costs for wind generation have decreased from roughly 9,000-12,000 yuan/kW in 1998[37] to as low as 5,500 yuan/kW in 2006. Similarly, capital costs for coal-fired generation fell from 5,000 yuan/kW in 1998 to 3,900 yuan/kW in 2006, and the cost of adding scrubbers fell from 750 yuan/kW in 2000 to 150-250 yuan/kW in 2005.[38] Capital costs for new coal technologies, such as supercritical boiler technologies, have fallen to the point where they are almost competitive with conventional coal.[39]

Future paths for electricity prices in China will be determined by a balance of falling capital costs, rising fuel costs, and new environmental requirements. Higher retail electricity rates would have broader macroeconomic implications, which have not been adequately

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[37] Lin, 1998
[38] Scrubber costs are from Chen (2005). Unless otherwise noted, cost estimates are based on personal communication, State Power Economic Research Institute (SPERI) staff, Beijing, China, August 2006.
[39] Personal communication, World Bank staff, Beijing, China, August 2006.

analyzed. Alternatively, a strong commitment to reducing electricity intensity, both through macroeconomic and energy sector policies, would in principle offset the economy-wide costs of higher retail electricity prices as consumers use less electricity and as coal supply constraints are eased.

Energy Efficiency and China's 10th Fifth Year Plan

The remarkable pace of China's economic expansion during the country's 10th Five Year Plan (2000-2005) was accompanied by double digit growth in both energy and resource use. Central government targets for national steel and coal production for the year 2020, for example, were exceeded by 2005. China's 11th Five Year Plan (2006-2010) enunciates a clear objective of reducing its economy's energy intensity by 20 percent, in no small part a reaction to the supply, price, and environmental pressures caused by the prior surge in energy and resource consumption.

Fang (2006) outlines the scale of growth in energy and resource consumption over the period 2000-2005. Steel production in 2005 exceeded 2020 targets by 67 percent; coal production in 2005 was 10 percent higher than the government's 2020 target for coal. As a whole, the China's aggregate energy use and intensity were 40 and 17 percent higher, respectively, than targets set for 2005 (Table 4).

Table 4. Energy and Resource Consumption, China, 2000 and 2005 Planned and Actual

	2000 Plan	2005 Plan	2005 Actual	2020 Plan
Energy Consumption (EJ)	39.54	46.28	65.02	
Energy Intensity (MJ/yuan)	3.98	3.57	4.19	
Coal (billion tons)	1.30	1.52	2.19	2.00
Electricity (TWh)	1,356	1,730	2,469	
Steel Production (million tons)	129	150	350	210

Sources: 2000 Actual data are from NBS (2005); 2005 Plan and Actual and 2020 Plan data are from Fan (2006).

China's energy demand growth during the 10th Five Year Plan (2000-2005) is striking because it reversed a 20-year trend of investment in and commitment to energy efficiency that began in the late 1970s. As a result of determined energy efficiency programs, China's energy demand grew at less than half the rate of annual GDP growth for twenty years to 2000 (NBS, 2005). However, policy commitment and financial support for China's energy efficiency programs began to weaken sharply beginning the mid-1990s (Jiang, 2005). In part because of China's increasingly regionalized and pluralistic polity and economy, renewing and maintaining this focus will likely be more difficult than in the past (RCSD, 2006).

It should be noted that the principal drivers behind the meteoric rise in China's energy demand from 2002-2005 remain uncertain. Some attribute this growth to a shift toward energy-intensive production (Jiang, 2005; He and Zhang, 2006), but these observers do not address root causes. Public infrastructure development and private real estate investment are two likely demand sources that implicate the construction sector, but construction represented approximately 15 percent of energy consumption on a life-cycle basis in 2000.[40] Identifying the drivers behind China's new pattern of energy consumption thus represents an important area of research.

[40] Based on the 2000 energy and economic input-output tables of NBS (2005).

Table 5. Energy Intensity of Steel, Aluminum, Copper, and Cement Production in China, 1990-2020

	1990	2000	2010 (target)	2020 (target)
Steel (kgce/ton)	991	784	685	640
Aluminum (tce/ton)	n/a	9.92	9.47	9.22
Copper (tce/ton)	n/a	4.71	4.26	4.00
Cement (kgce/ton)	201	181	148	129

Note: Units are in kilograms and tons coal equivalent per ton output. One ton coal equivalent is equal to 29.288 gigajoules.
Source: NDRC (2005).

For a number of energy-intensive products in China, the energy intensity of production has decreased measurably since 1990. Table 5 illustrates significant potential for energy efficiency that remains to be realized in China. The NDRC reports that the energy intensity of medium-sized and large steel, copper, cement manufacturers in China are 21, 65, and 45 percent higher, respectively, than “advanced international” levels (NDRC, 2005). Overall, the NDRC’s goal is to reduce energy consumption by nearly 7 exajoules (EJ), or 11 percent of 2005 consumption, through energy efficiency programs (He, 2006). One program in particular, that involves more than 1,000 of China’s largest companies, seeks to reduce energy consumption by nearly 3 EJ, or 4.5 percent of 2005 consumption, by 2010 (Wang, 2006a).

Recent trends inspire concern about China’s efficiency goals, such as reducing energy intensity by 20 percent by 2010. Researchers and policymakers within China privately express skepticism that the 2010 goal can be met. In an influential paper, He and Zhang (2006) argued that the goal could be achieved through complementary approaches to structural change, improvements in energy conversion efficiency, and increases in end use efficiency.

In China, administrative measures continue to be the primary tool for regulating energy use. For instance, since late 2003 the NDRC has attempted to control the production of steel, cement, and aluminum by limiting permits for new plants and bank loans. In addition, forced closures of small, inefficient production facilities extend back to the late 1990s. Given continued high growth in energy-intensive manufacturing, the effectiveness of these measures is uncertain. Provincial and local governments often circumvent central government controls on plant permitting and finance, and many small producers have remained open despite official censure.

The institutional impasse between China's central government and provincial governments is illustrative of a substantial enforcement problem which will be a critical determinant of China's future energy path. An investigation by the Ministry of Construction in 2005, for instance, revealed that only 23 percent of buildings met existing codes from 2000-2004 (RCSD, 2006). The vast majority of steel plants are violating basic regulations, and most have not been subjected to any environmental impact assessment (Fang, 2006).

In the case of electricity, energy efficiency offers significant benefits to the Chinese economy, reducing scarcity and relieving price pressures. Shortages, such as the rolling blackouts that have plagued China since 2003, are a direct constraint on economic growth (Shiu and Lam, 2004). Demand-side management programs, currently in place in several major cities in China, could help trim final demand and relieve the incidence of forced outages (Hu et al., 2005). Similarly, technology upgrades could play a role in scaling back intermediate consumption and relieve pressures on coal prices, passing through to electricity rates. Reducing the energy intensity of steel production to 2020 targets, for example, would allow China's steel industry to increase production by 22.5 percent with the same amount of energy.

When purchasing, replacing, and upgrading equipment, firms face a trade-off between higher upfront costs of and savings from lower electricity bills with more efficient equipment. In many Chinese industries, the payback is currently insufficient to induce such investment in more sustainable growth. Small average plant size remains a problem, but most advanced energy efficiency equipment is imported and electricity savings are not enough to offset the cost differential between domestic and imported technologies (Wang, 2006b).

More effective regulation and financing for energy efficiency improvements will require a sea change in the Chinese policy environment. Improving enforcement capacity so that laws — such as the 1997 Energy Conservation Law (RCSD, 2006) — actually realize their putative intent will require a substantial strengthening of China's legal and administrative systems. Meanwhile, policies to finance energy efficiency must recognize and facilitate private sector participation. The scale of required investment is much larger than the Chinese government alone can support (Jiang, 2005).

Sharing the Costs of CO_2 Emission Reductions

By meeting thermal efficiency goals and expanding alternatives to coal-fired generation, China could reduce its CO_2 emissions from coal-fired power plants by approximately 840 million tons against a baseline where electricity demand grows as fast as GDP targets from 2005-2020. With an estimated 4,435 TWh of coal-fired generation, China's annual CO_2 emissions from coal-fired power plants would reach 3.8 billion tons (1.0 GtC) by 2020, an increase of 2.0 billion tons (0.6 GtC) over 2004.

Whether China's actual CO_2 emissions from coal-fired power plants are lower than 3.8 billion tons in 2020 will depend on the country's electricity intensity from 2005-2020. If targets for coal alternatives and thermal efficiency are met and electricity elasticity falls to an average of 0.8 from 2005-2020, annual CO_2 emissions from coal-fired power plants would reach 2.9 billion tons (0.8 GtC) by 2020, or an increase of 1.1 billion tons (0.3 GtC) (Table 6).

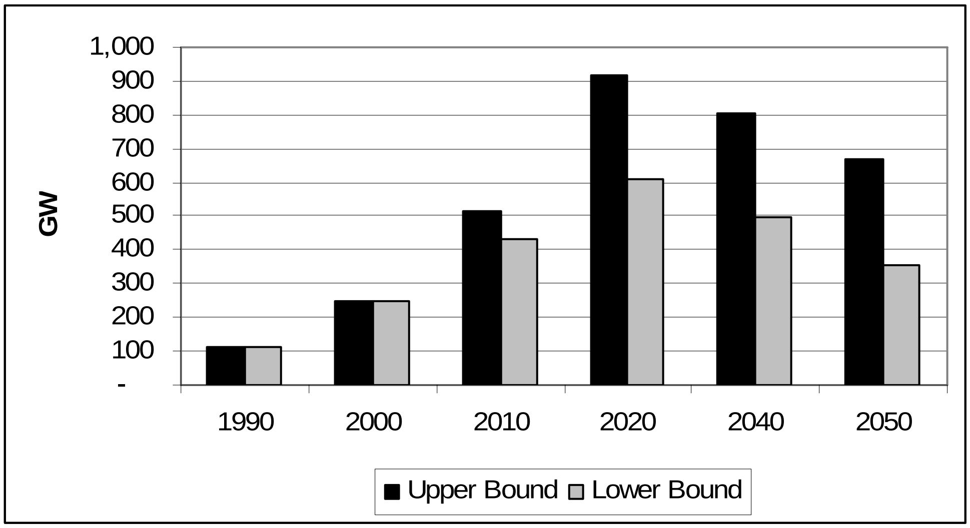
Table 6. CO2 Emissions and Emissions Growth from Coal-fired Power Plants in China

	Annual Emissions 2020 (GtCO2)	**Growth in Annual Emissions from 2004 (GtCO2)**
Upper Bound	4.589	2.880
Thermal Efficiency and Alternative Technologies	3.747	2.037
Thermal Efficiency, Alternative Technologies, 0.8 Electricity Elastiticity	2.847	1.138

Note: Thermal Efficiency and Alternative Technologies assume that central government goals for power plant efficiency and alternative sources of electricity are met, with an electricity elasticity of 1.0. The final scenario assumes that thermal efficiency and alternative technology goals are met, and that the electricity elasticity of GDP is 0.8.

All the above scenarios represent growth in emissions that would have to be neutralized by reductions from either other sectors in China's economy or other countries to reach a given global GHG stabilization target. Moreover, these are long-term carbon commitments. Assuming a lifetime of 50 years for coal-fired power plants, 60-70 percent of China's 2010 coal-fired installed capacity will still be operational in 2050 (Figure 6). Based on the assumptions used here, this represents fixed commitments of 2-3 billion tons (0.5-0.8 GtC) in annual CO_2 emissions until 2050.

Figure 6. Coal-fired Installed Capacity in China, 1990-2050, Assuming No New Coal-fired Capacity is Added after 2020



Finally, China runs the risk of being associated with "carbon deficits," where even aggressive reduction policies by OECD countries are insufficient to neutralize growth in global CO_2 emissions. As an example, upper bound CO_2 emissions here represent a net emissions growth that is 1.1 billion tons greater than the 1.8 billion tons of CO_2 emission reductions required by OECD countries to reach the IPCC's 1990 target reference point.

Although growth in China's CO_2 emissions over the next two decades is subject to significant uncertainty, even with generous allowances for variance there are obvious differences between growth trajectories for emissions from coal-fired generation required to meet electricity demand in China. In the breach between global GHG intentions and the economic fundamentals of China's growth imperative, substantial opportunities exist for multilateral economic and technical cooperation. Because of the zero sum nature of stabilization targets, the distance between upper and lower bounds in Table 4 translates into higher marginal CO_2 emission reduction requirements for CLE countries. Providing incentives for China to maintain high economic growth rates and reduce CO_2 emissions through substantial energy efficiency improvements would similarly reduce marginal CO_2 emission reduction requirements, and their associated costs, for CLE countries.

Carbon capture and sequestration (CCS), which has not figured into the discussion thus far, may be a medium-term option for reducing China's contribution to greenhouse gas concentrations.[41] At present, the costs and feasibility of large-scale geological sequestration in China are uncertain, and national and multilateral incentives are presently too weak to support more extensive, detailed research. In the absence of clearer signals from CLE/OECD countries, and incentives to support these, decisions are already being made that will have legacy implications. For example, a substantial portion of China's new generation capacity is currently being added at existing sites, with no consideration for carbon capture or sequestration costs.

4. Conclusions: Engagement and Research

China's remarkable economic progress challenges its leadership to sustain and extend prosperity across a vast and diverse nation and future generations. At the same time, its emergence in the global economy brings new opportunities for international leadership and partnership, particularly in the same context of sustainability. China's present carbon emission trajectories guarantee it prominence in the global dialogue over pathways for stabilizing atmospheric greenhouse gas concentrations. How China contributes to this will depend on its own priorities and multilateral initiative. We believe that the domestic agenda for sustainability will lead China to a path of innovation and ever-greater resource efficiency, but the international community should facilitate this with more determined and constructive engagement. As the United States gradually moves toward more substantive climate change mitigation policies, CLE/OECD countries' constructive engagement with China on climate change is a logical next step.

Our research into official data on the electricity indicates that these issues are becoming more urgent. China is the world's second largest source of greenhouse gas (GHG)

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[41] See Williams for a discussion of options for carbon sequestration in China. Zhang et al. (2005) estimate that China's CO_2 geological sequestration capacity is 1.4548 trillion tons, which would be more than sufficient to store its annual CO_2 emissions for at least hundreds of years.

emissions and its principal source of growth in GHG emissions. China accounted for 44 percent of the growth in global CO_2 emissions from 1990-2004, and, as its economy continues to rapidly expand, China will be the world's main source of emissions growth from 2005-2020. China's official economic growth objective, to quadruple 2000 GDP by 2020, implies relatively moderate annual growth (about 6.5 percent). Recent trends in energy demand growth and resource use far exceed this pace, e.g. China's electricity demand over 2002-2005 grew at an annual rate of 14.5 percent. Steel production in 2005 exceeded official 2020 targets by 67 percent; coal production in 2005 was 10 percent above its 2020 target. As a whole, the Chinese economy's energy use and intensity in 2005 were 40 and 17 percent higher, respectively, than official targets.

To meet rising electricity demand, China will have to install as much as 860 GW of additional generation capacity by 2020, an amount exceeding the EU's total 2004 installed capacity. More than 60 percent of this new capacity will comprise coal-fired power plants, fossil fuel infrastructure with an operating lifetime of 40-50 years. Given the scale of China's electricity infrastructure that remains to be built, about two-thirds of the coal-fired power plants built in China by 2020 will still be operational in 2050. These plants alone represent a commitment of roughly 2-3 billion tons of annual CO_2 emissions until 2050.

Even if China's ambitious goals for alternative generation and power plant efficiency are met, if electricity demand grows as fast as GDP from 2005-2020, CO_2 emissions from electricity generation in China will rise by more than 2 billion tons. This amount exceeds the reductions required for OECD countries to reach 1990 emissions from their 2004 levels. Alternatively, decoupling economic growth and electricity demand growth in China through a shift toward more service sector-intensive growth and improvements in energy efficiency could significantly reduce growth in China's electricity base CO_2 emissions.

While it may be counterproductive to expect China to establish short term targets for emission reduction, longer term boundary objectives could be an important and innovative form of policy guidance. Establishing common boundaries, even as basic as the ones presented here, can frame progress against shared objectives and provide a middle way between definite targets and a very uncertain status quo.

The Chinese government has its own incentives to reduce greenhouse gas emissions. Improving overall energy and power plant efficiency would reduce pressures on the price of coal, mitigate local and regional air quality damage, and moderate electricity prices. Increasing penetration of renewable energy in the electricity portfolio would similarly ease coal constraints, improve air quality, and support China's emergence as a leader in renewable energy technologies. Ambitious goals for increasing energy intensity, thermal efficiency, and alternative energy currently exist, but their economywide application is hindered by institutional and financial constraints.

While this study has identified challenges and proposed a few areas for policy initiative and reform, much more research is needed at the scientific, economic, and institutional levels. In the context of carbon energy, climate change, and economic sustainability, all the world's policy makers face considerable uncertainty. With such risks, however, come opportunities for innovation and leadership. Both in China and abroad, there is limited understanding of the interaction among energy efficiency, energy prices, energy demand, energy-related pollution, fiscal policy, and broader institutional reforms. Without a better understanding of the costs of energy efficiency programs, for example, it is difficult to identify "no regrets" opportunities — where benefits exceed costs, or to measure the cost-effectiveness of energy efficiency programs. Most studies of energy-economy dynamics have also focused at the national level, and little is known about provincial conditions, where incentives are often different from those applying to national institutions and monitoring and enforcement mechanisms may be weak.

If CLE/OECD countries want a viable option for globally coordinated efforts to stabilize greenhouse gas concentrations, the time to engage with China is now. Cost sharing mechanisms require time and consensus to formulate, implement, and sustain. As is apparent from the evidence presented here, waiting raises the costs and the difficulty of reaching such a consensus.

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