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Global Carbon Emissions in the Coming Decades: The Case of China

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CONTENTS

Key Words

Carbon emissions forecasts, carbon intensity, energy policy, emissions reductions

Abstract

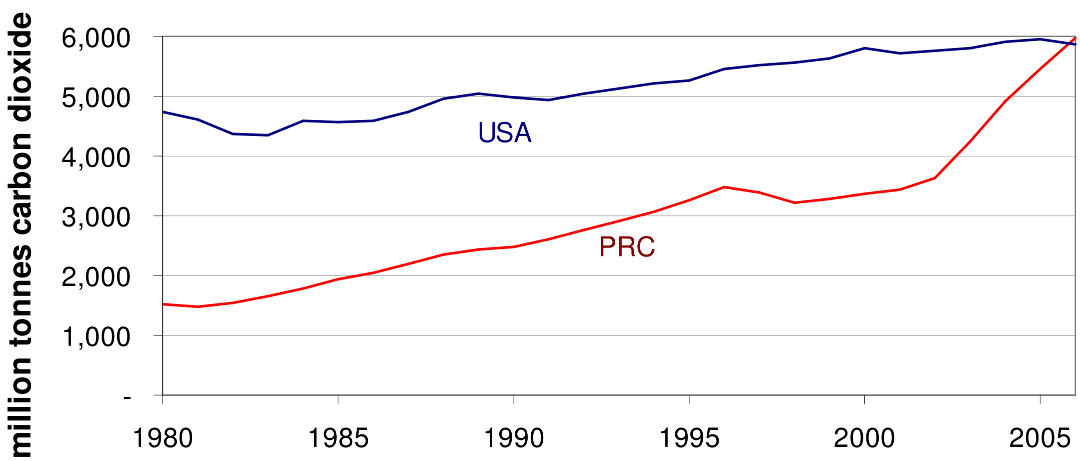
China's annual energy-related carbon emissions surpassed those of the United States in 2006, years ahead of published international and Chinese forecasts. Why were forecasts so greatly in error and what drove the rapid growth of China's energy-related carbon emissions after 2001? The divergence between actual and forecasted carbon emissions underscores the rapid changes that have taken place in China's energy system since 2001. In order to build a more robust understanding of China's energy-related carbon emissions, this article reviews the role of economic restructuring, urbanization, coal dependence, international trade, and central government policies in driving emissions growth.

1. INTRODUCTION

In the year 2000, leading teams of Chinese, American, and international forecasters all projected that China's energy-related carbon emissions would not surpass the United States' until 2019 or later. As late as 2004, the expected year that China would surpass the United States in energy-related carbon dioxide emissions had moved even further in the future, to after 2025 or 2030.

It did not happen that way. Instead, China surpassed the United States in energy-related carbon dioxide emissions in 2006 (1). Figure 1 shows the growth of energy-related carbon dioxide emissions from 1980 to 2006. It is clear that a profound change in the growth rate Chinese emissions occurred around 2002.

Figure 1: Annual energy-related carbon dioxide emissions, 1980-2006



Source: US annual emissions amounts reported by US EIA in the 2006 Annual Energy Review and 2007 Flash Estimate; China emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients by LBNL.

Table 1 provides information on the two leading international forecasts of energy-related carbon dioxide as a function of the year of forecast. (It should be noted that the data used in a forecast year are generally from several years prior to that year; thus there is a lag in the models catching up with actual results. This explains why the 2007 forecasts do not pick up the fact that China had overtaken the United States before that year.)

Table 1: International Forecasts of China Surpassing American Energy-Related Carbon Emissions (1, 2)

Year of Forecast	Forecast Organization	
	IEA (WEO)	EIA (IEO)
1998	(after 2020)	2016
1999	-	2019
2000	(after 2020)	2019
2001	-	(after 2020)
2002	(after 2030)	(after 2020)
2003	-	(after 2025)
2004	2030	(after 2025)
2005	-	2022
2006	2010	2014
2007	2008	2009

We are left with two relevant questions:

- Why were the forecasts so greatly in error?
- What drove the very rapid increase in China's energy-related carbon dioxide emissions in the period after 2001?

This review will seek to answer these questions in four sections. The next section describes the data on China's energy-related carbon emissions within a global context. The third section evaluates China carbon-emissions forecasts from leading international and Chinese organizations. The fourth section looks at recent China carbon emissions drivers to understand the roots of forecast errors. Section five examines current and historical emissions reduction policies, and the conclusion will discuss implications from this review.

2. CHINA'S CARBON EMISSIONS IN A GLOBAL CONTEXT

2.1. Global Carbon Emissions Trends

Atmospheric carbon dioxide (CO_2) is the largest human contributor to human-induced climate change. Global average atmospheric CO_2 concentrations have risen from 280 ppm at the start of the industrial revolution in the 1700s to 381 ppm in 2006. This increase can be traced to fossil fuel combustion, land use change, cement production, and declining efficiency among CO_2 sinks (4). In order to have a clearly-defined basis of comparison and analysis, this article focuses on carbon dioxide emissions from commercial fossil fuel combustion—i.e., emissions from biomass combustion are not included.

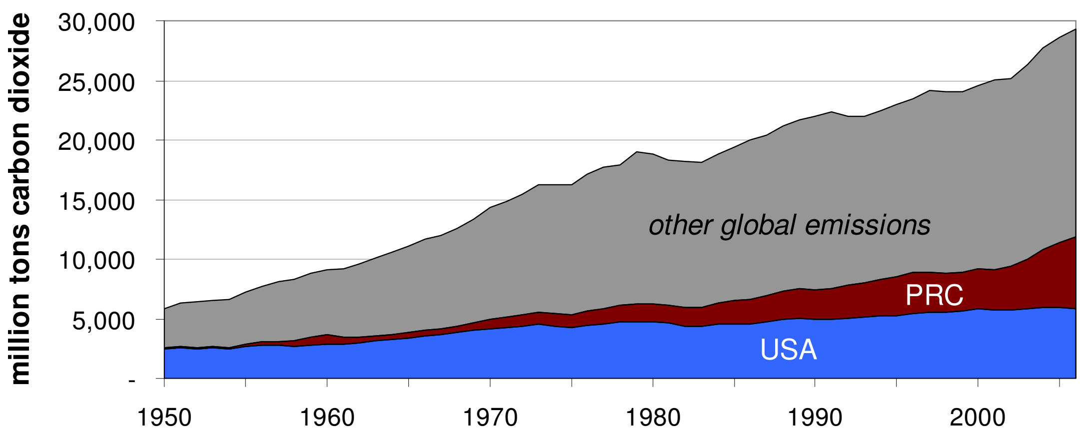
Between 2000 and 2006 global carbon emissions have grown more quickly than expected due to increasing energy intensity of GDP and carbon intensity of energy. In fact, carbon emissions growth rates since 2000 have exceeded the most fossil-fuel intensive Intergovernmental Panel on Climate Change emissions scenario developed in the late 1990s (5). As shown in Figure 2 below, 55% of the growth of global emissions between 2000 and 2006 was a result of increased emissions in China.

The International Energy Agency in its recent World Energy Outlook 2007 projects that under current policies the world's energy needs will be 50 percent higher in 2030. The IEA also forecasts that, for its reference case, 42 percent of incremental global energy-related CO_2 emissions from 2005 to 2030 will be from China. For the high growth and alternative policy (low growth) scenarios, IEA shows incremental emissions from China to be 49 and 52 percent respectively of total global emissions. A goal of this paper is to gain a sense of the likelihood of these numbers.

2.2. Review of China annual, cumulative, and per-capita emissions data

China's share of global annual CO_2 emissions surged from 1% in 1950 to 20% (6 billion tonnes of carbon dioxide emissions) in 2006 (6).

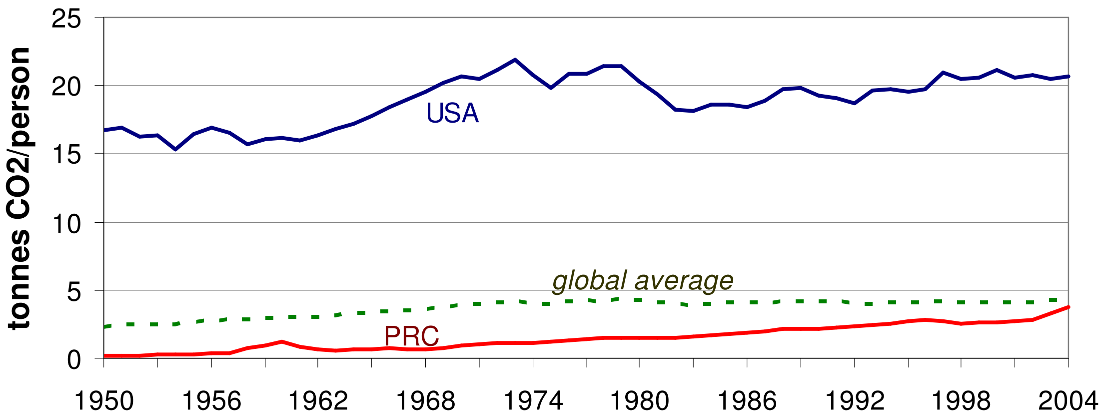
Figure 2: Annual energy-related carbon emissions, 1950-2006



Source: Historical 1950-2003 US and global emissions data from Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center; 2004-2006 US data from BP via Global Carbon Project. China 1950-2006 emissions data are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon coefficients by LBNL.

China's annual energy-related carbon dioxide emissions doubled between 1993 and 2006. The average annual rate of emissions growth doubled from 5% between 1980 and 1995 to 10% between 2000 and 2006.

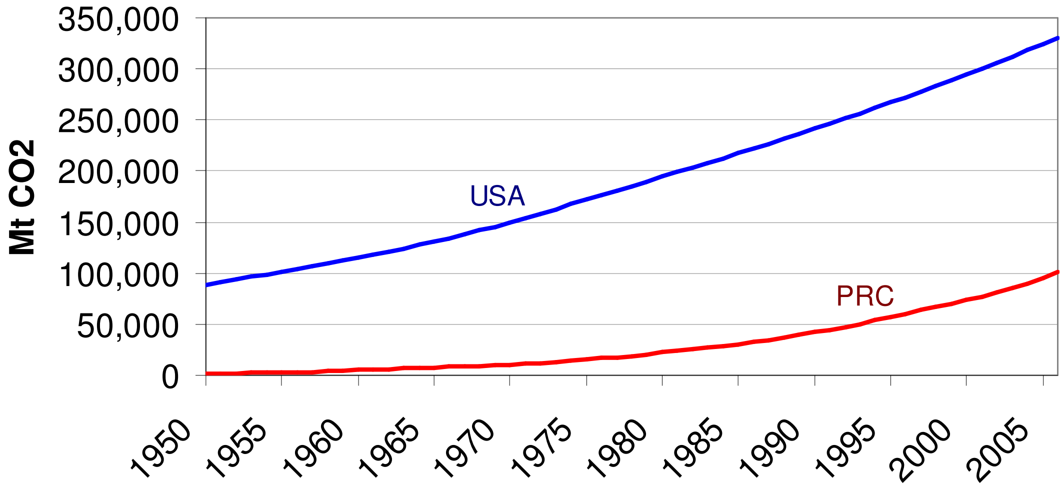
Figure 3: Global, Chinese, and American Per-capita Energy-Related CO_2 Emissions, 1950-2004



Source: China emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients by LBNL; China population data from NBS and US Census (for 1950-51); global and American emissions data from Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center; global and American population data from US Census.

Figure 3 shows that China's annual per-capita emissions from commercial fossil fuel combustion grew from 0.15 tonnes per person in 1950 to 4.17 tonnes CO_2 in 2004. However, Chinese per-capita carbon dioxide emissions remained below average global emissions (4.35 tonnes in 2004), and less than 20% of American emissions in 2004 (20.65 tonnes per person).

Figure 4: Cumulative Energy-Related CO_2 Emissions, 1950-2006



Source: Historical 1800-1980 US emissions data from Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center; 1980-2006 US data from US EIA 2006 AER. China 1902-1949 emissions data from Oak Ridge National Laboratory, Carbon Dioxide Information Analysis Center; 1950-2006 emissions data are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon coefficients by LBNL. Pre-1902 China emissions data unavailable, but generally considered to be negligible.

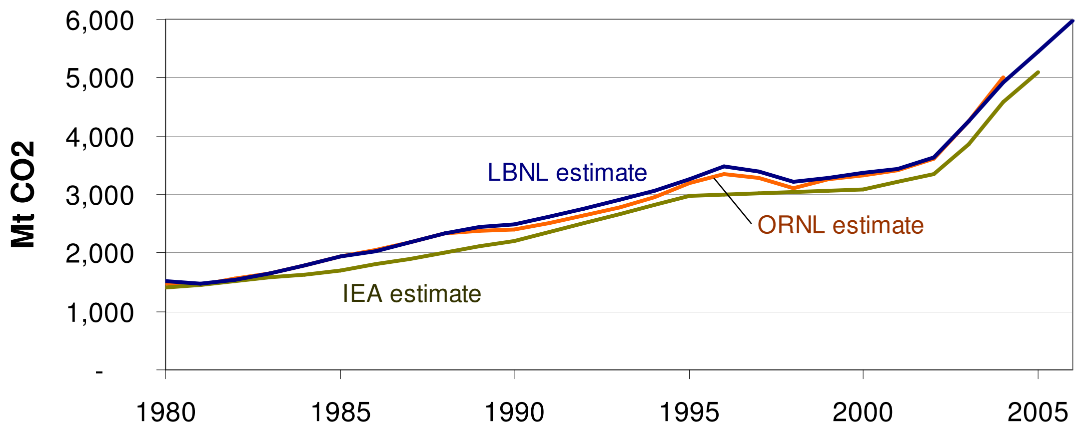
Figure 4 shows cumulative energy-related carbon dioxide emissions for the United States and China. China's cumulative energy-related carbon emissions reached 101 billion tonnes of carbon dioxide in 2006, a level reached by the United States in 1955. While China's population is more than four times larger than the United States, it is responsible for less than one third the cumulative carbon emissions.

2.3. Estimates of China's historical carbon emissions

China's National Bureau of Statistics (NBS) publishes extensive historical data on economic, demographic, physical, and social indicators dating back to the founding of the current republic in 1949. However, the NBS does not publish data on China's carbon emissions, per se. On the basis of NBS energy data, the International Energy Agency

(IEA), the Oak Ridge National Laboratory (ORNL) and the Lawrence Berkeley National Laboratory (LBNL) have published varying estimates of China's historical energy-related carbon emissions. Figure 5 shows estimates of China's annual energy-related carbon emissions from LBNL, IEA, and ORNL.

Figure 5: China Historical Carbon Dioxide Emissions Estimates, 1980-2006



Sources: IEA, Carbon Emissions from Fossil Fuel Combustion 2007 (post-1997 estimates include Hong Kong); ORNL, Carbon Dioxide Information Analysis Center; LBNL, emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients.

ORNL and LBNL estimates of carbon dioxide emissions are very close to one another and higher than those of the IEA. One possible explanation for the variance is that LBNL and ORNL use NBS data which were retrospectively revised in the 2005 China Energy Statistical Yearbook. Indigenous coal production in 2000, for example, was upwardly revised by 30% in subsequent NBS publications. The LBNL series also includes declining emissions for 1997 and 1998, in spite of continued GDP growth during that period. Subsequent NBS revisions have shown that this decline was of a shorter duration than reported in the initial data. The anomalous dip in energy use was primarily due to government-mandated reductions of coal consumption among the least efficient heavy industrial enterprises (7).

3. EMISSIONS FORECAST ASSESSMENTS

For this analysis we use World Energy Outlook (International Energy Agency), the International Energy Outlook (U.S. Department of Energy) and three highly respected sources in China.

3.1. International Forecasts

Table 2 shows the WEO forecasts (by IEA) released in 1994 to 2007 and the IEO forecasts (by the Energy Information Administration of the U.S. Department of Energy) issued in 1995 to 2007. The degree of variation in the forecasts over a short period of time is noteworthy. For example, the WEO shows 2010 forecasts declining from 5322 Mt CO_2 (WEO 1998) to 4155 Mt CO_2 (WEO 2002), or a 22% decrease 12 and 8 years out. The 2010 forecast increased from 4386 Mt CO_2 (WEO 2004) to 6867 Mt CO_2 (WEO 2007), or a 56% increase in a three year period for a forecast 3 to 6 years out!

WEO shows greater changes in forecast results for longer time horizons. Over a period of 3 years, forecasted 2030 emissions grew from 6,718 Mt CO_2 (WEO 2002) to 11,448 Mt CO_2 (WEO 2007), an increase of 70%.

IEO shows similar year to year variability in forecasts, although in some cases less pronounced. In particular, 2030 results do not show large variations because 2030 IEO forecasts were done in only two years, 2006 and 2007.

It is fair to note that some of the differences in the forecasts are due to changes in the baseline energy data, which are not attributable to the model.

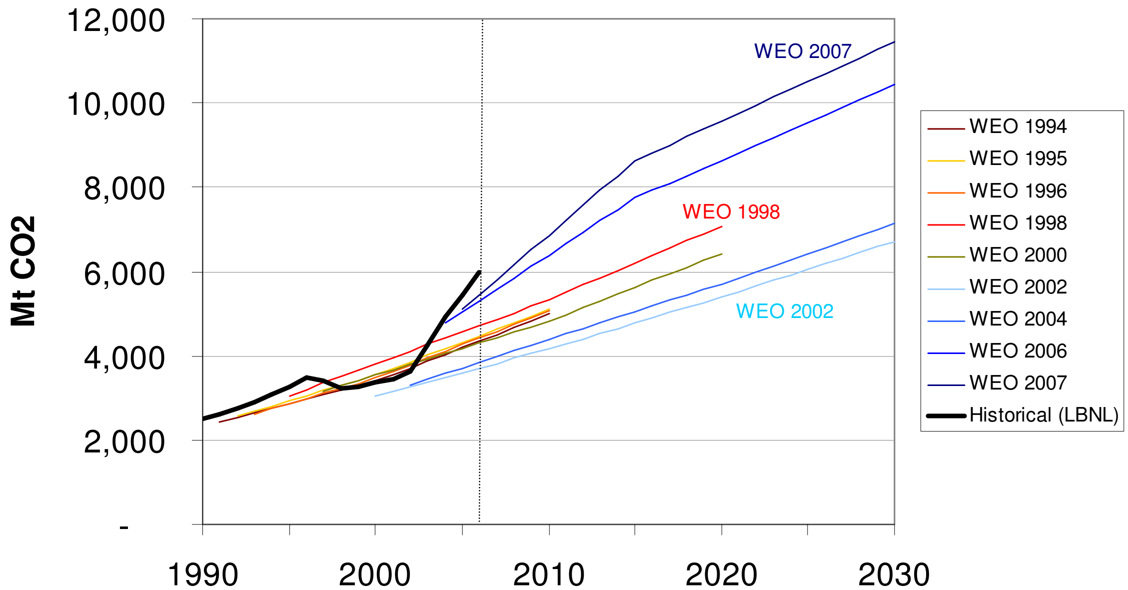
Table 2: China Carbon Emissions Forecasts and Average Annual Growth Rates (Mt CO_2)

	Forecast	2010	2020	2030	2005-2010 AAGR	Total AAGR
IEA	WEO 1994	4,986	----	----	3.5%	3.9%
	WEO 1995	5,101	----	----	3.4%	3.9%
	WEO 1996	5,062	----	----	3.5%	3.9%
	WEO 1998	5,322	7,081	----	3.1%	3.4%
	WEO 2000	4,822	6,426	----	2.9%	3.1%
	WEO 2002	4,155	5,393	6,718	2.9%	2.7%
	WEO 2004	4,386	5,708	7,144	3.4%	2.8%
	WEO 2006	6,392	8,638	10,425	4.9%	3.1%
	WEO 2007	6,867	9,571	11,448	6.1%	3.3%
EIA	IEO 1995	4,536	----	----	2.7%	3.4%
	IEO 1996	5,361	----	----	4.0%	4.1%
	IEO 1997	5,584	----	----	3.9%	4.1%
	IEO 1998	5,430	8,580	----	4.3%	4.4%
	IEO 1999	5,100	7,447	----	4.0%	3.9%
	IEO 2000	5,342	7,667	----	4.2%	4.1%
	IEO 2001	4,147	6,171	----	4.9%	3.6%
	IEO 2002	4,132	6,204	----	5.0%	4.5%
	IEO 2003	4,066	5,771	----	4.5%	3.5%
	IEO 2004	4,063	5,693	----	3.0%	3.3%
	IEO 2005	5,536	7,373	----	5.9%	4.0%
	IEO 2006	5,857	8,159	10,716	6.9%	4.2%
	IEO 2007	6,497	8,795	11,239	5.4%	3.4%

Note: "Total AAGR" shows average annual growth rates for entire forecast period, e.g. average annual growth between 2000 and 2025 for the IEO 2003.

Figure 6 presents the IEA forecasts in graphical form. Forecasts for the two most recent years show the highest forecasts. However, forecasts for the two prior years show the lowest forecasts. The older forecasts fall in the middle.

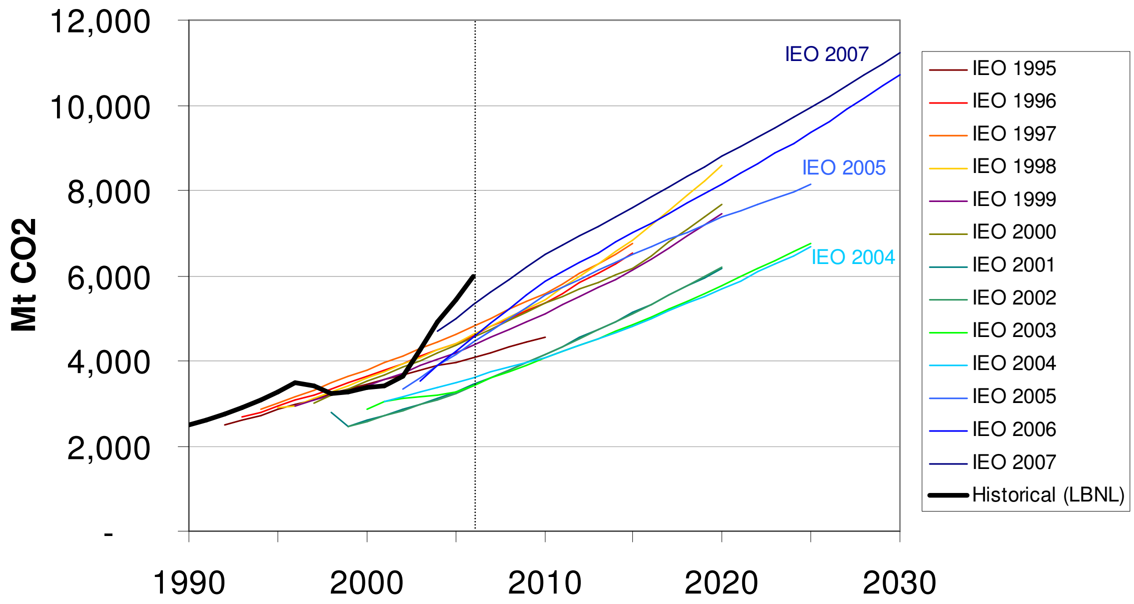
Figure 6: Historical and Forecast China Carbon Emissions (WEO), 1990-2030



Note: forecasts are displayed as linearly continuous on the basis of published periodic data.

Figure 7 presents similar results for the EIA forecasts. Again, the latest forecasts show the highest demand growth. Because China's energy demand grew faster than any of the forecasts – and the EIA forecasts are the highest of the forecasts – EIA tended to obtain results that are closer to actual energy demand in China. However, even for EIA, the estimates are much lower than actual for almost all years. In 2004, the EIA projected a CO_2 emissions level in 2020 that was lower than actual emissions in 2006.

Figure 7: Historical and Forecast China Carbon Emissions (IEO), 1990-2030

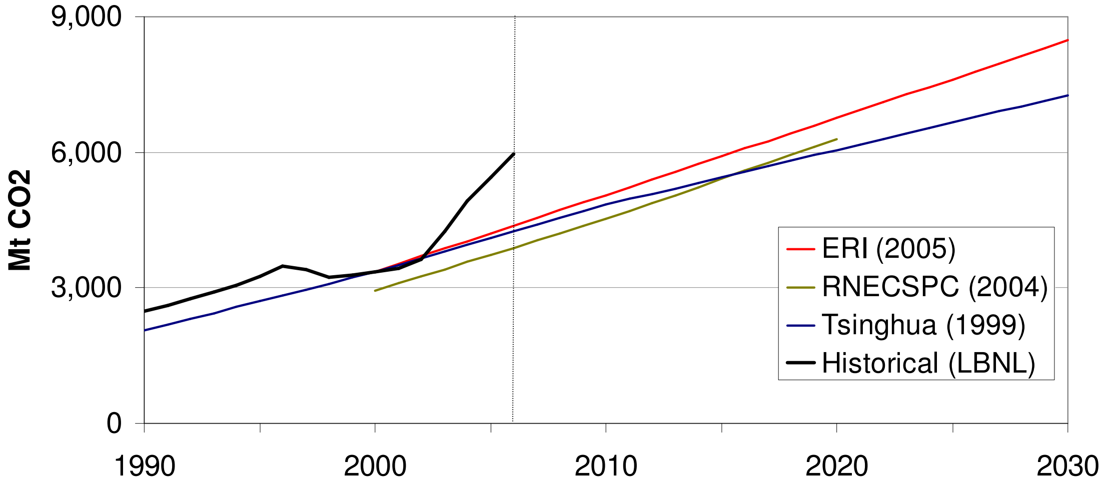


Note: forecasts are displayed as linearly continuous on the basis of published periodic data.

3.2. Chinese Forecasts

The interesting issue arises of whether the Chinese have done a better job at projecting their emissions than foreigners. Figure 8 shows three published forecasts in China at the time they were made. They were performed respectively by a team at Tsinghua University as part of the U.S. Country Studies exercise; at the Energy Research Institute as input into the Chinese national planning exercise; and at the Development Research Center (with technical assistance from the Energy Research Institute) as the underpinnings of national energy strategy for China (abbreviated as RNECSPC) (8, 9, 10).

Figure 8: Historical and Forecast China Carbon Emissions, 1990-2030 (Error! Bookmark not defined.**,** Error! Bookmark not defined.**,** Error! Bookmark not defined.)



Note: forecasts are displayed as linearly continuous on the basis of published periodic or future single-point data.

There is consistency among these results. They show similar average annual growth rates and the 1990 and 2000 baseline CO_2 numbers are close to each other. Unfortunately, all of them miss the dramatic increase in CO_2 emissions from 2002 to 2005 (and thereafter) as did the IEA and EAI forecasts that were done before 2006.

Table 3: China Carbon Emissions Forecasts (Mt CO_2)

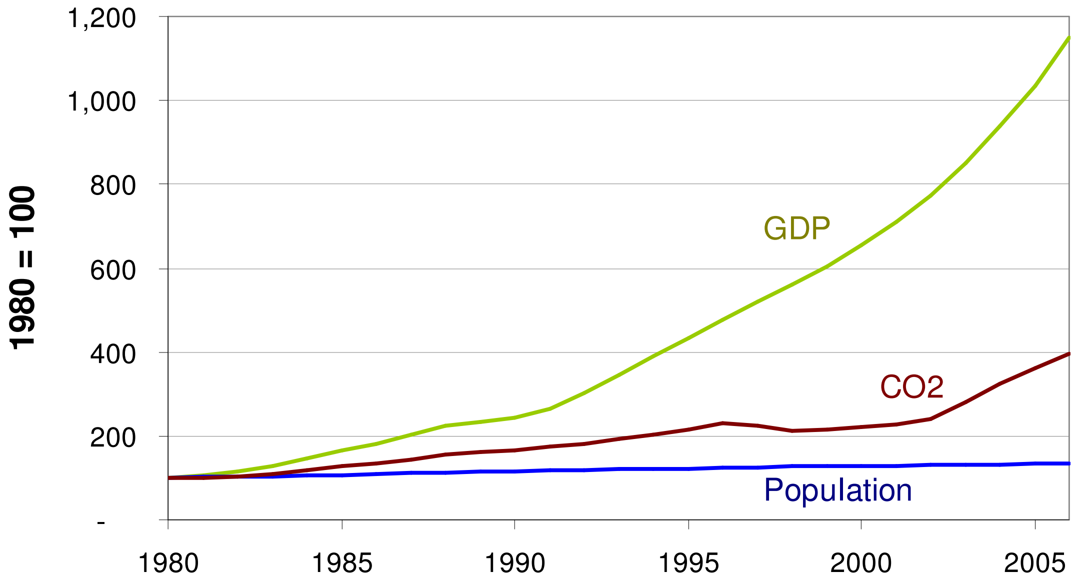
Forecast Organization	2010	2020	2030	2000-2020 AAGR
China Country Study (1999)	4,840	6,051	7,263	3.0%
China Energy Strategy (2004)	4,525	6,292	----	3.9%
ERI (2006)	5,059	6,763	8,467	3.6%

The carbon emissions forecast that has come closest to recent Chinese outcomes was jointly performed by the China Energy Research Institute (ERI) and the Dutch National Institute for Public Health and the Environment (RIVM) in 2003. Rather than creating their own forecast, the ERI-RIVM team used a simulation model to extract Chinese national-level emissions profiles from selected IPCC global SRES scenarios (11). Within van Vuuren et al.'s analysis the A1f SRES scenario of high growth with extended fossil fuel usage came closest, though it was also exceeded by China's unexpectedly high emissions growth.

4. CHINA EMISSIONS DRIVERS: ROOTS OF FORECAST ERROR

Energy-related carbon dioxide emissions do not consistently correlate with aggregate GDP or population growth. Figure 9 illustrates the separate growth trajectories of China's GDP, energy-related carbon emissions, and population relative to 1980 levels. Whereas GDP increased ten-fold and population grew by one third, energy-related carbon emissions quadrupled between 1980 and 2006.

Figure 9: China GDP, CO_2 Emissions, and Population Growth, 1980-2006



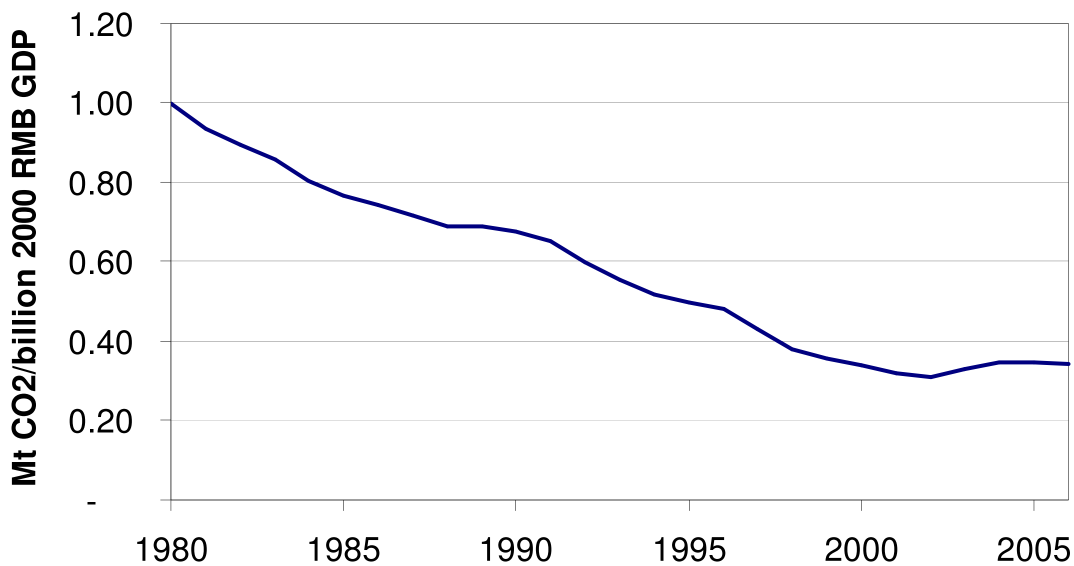
Source: LBNL, emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients; population and GDP data published by NBS (2007).

Between 2000 and 2006 China's unexpectedly high carbon emissions were driven by market reforms, urbanization, coal dependence, and increased international trade. This section examines the role of each of these four variables in explaining China's carbon emissions growth.

4.1. Economic Reform and Carbon Intensity of GDP

Market reforms have altered China's economic structure, energy use, and carbon emissions. The gradual elimination of state-directed capital allocation allows investment to cluster in profit-maximizing sectors, thereby stimulating economic growth and energy usage. However, whereas forecasters predicted that "reductions in energy and carbon intensities will occur regardless of capital market reforms and privatization," China's carbon and energy intensity of GDP increased between 2002 and 2005 (12). Figure 10 shows the anomalous bounce of China's carbon intensity of GDP after more than twenty years of steady decline.

Figure 10: Carbon Intensity of China's GDP Growth, 1980-2006



Note: Figure 10 is calculated according to LBNL China emissions data and NBS revised GDP data deflated to year 2000 RMB values.

In order to differentiate efficiency and structural drivers of energy and carbon intensity change, the Laspeyres decomposition method has been used to quantify aggregate effects. This method indicates that declines of energy and carbon intensity of GDP during the 1980's and 1990's were largely due to improved industrial efficiency (13, 14). However, energy efficiency improvements were overtaken by structural shifts to heavy industry such as cement and steel production between 2002 and 2005 (15). Heavy industrialization is a common explanation for the above-one carbon elasticity of GDP illustrated in Figure 11.

Figure 11: Carbon Elasticity of GDP Growth, 1981-2006

Source: NBS revised deflated GDP data; LBNL emissions data.

4.2. Urbanization: Construction, Residential Consumption, and Electrification

Since 1978, institutional reforms, demographic shifts to smaller families, and increased receipts of foreign direct investment have stimulated rural-urban migration. On the institutional front, designation of all housing as "market" on July 1, 1998 and abolition of the work-unit-based household registration system removed previous barriers to rapid urbanization. Between 2000 and 2006 China's urban population expanded by 26%, from 459 to 577 million urban residents (16). Urbanization has contributed to energy-related carbon emissions growth through increased building and infrastructure construction, higher residential energy consumption, and surging electricity demand.

High economic growth and urbanization have fuelled a frenzied construction boom such that China now accounts for half of all new building area on earth (17). Cement industry growth is an emblematic example of China's urbanization-fuelled heavy industrialization. In order to sustain the construction of more than a billion square meters of completed floor space per year since 2001, China's cement production more than doubled from 597 million tons in 2000 to 1.24 billion tons in 2006 (18). Due to the prevalence of small-scale production plants and low-efficiency technology such as vertical shaft kilns, China's cement industry is 8% more carbon-intensive than the global average (19). The rapid growth of China's cement and construction industries has also challenged the government's ability to effectively monitor and enforce efficiency and environmental quality regulations.

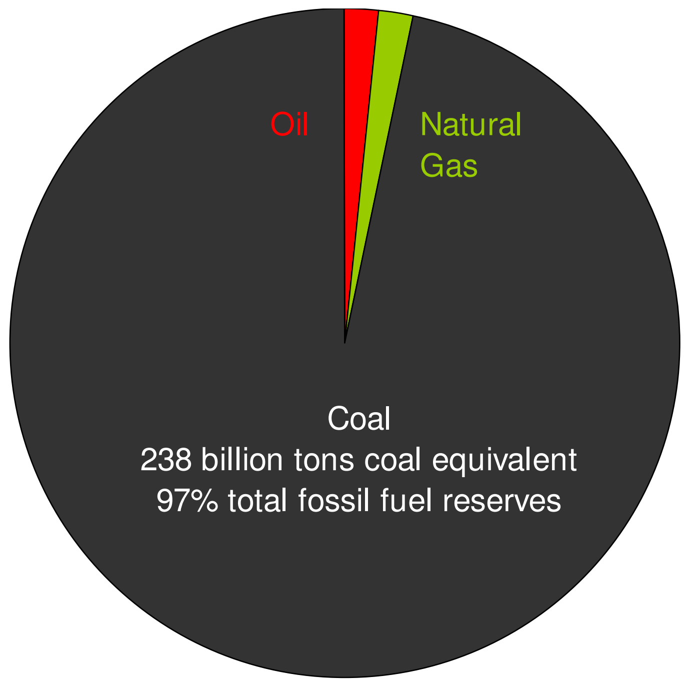
Residential energy consumption is driven by low-quality construction and improved living standards. According to one knowledgeable source, Chinese residential building heating energy consumption per unit area is twice as high as residential buildings in developed nations of similar climates (20). Residential and commercial efficiency improvements are offset by growing demand for higher levels of energy services as living standards rise, including more space heating and cooling, brighter lights, more hot water, and more office equipment (21). Indeed, annual per capita commercial energy consumption of households has grown by more than 7% annually since 2000, from 126 to 195 kg coal equivalent in 2006 (22).

Residential energy services require electricity—annual household per capita electricity consumption grew by more than 11% per year between 2000 and 2006 (23). Thermal electricity generation capacity increased from 74% to 78% of total generation capacity between 2000 and 2006. Within China's thermal electricity generation, coal-fired plants accounted for more than 95% in 2005, followed by petroleum-fueled plants with 3% total thermal capacity (24). In 2003, the energy efficiency of China's fossil-fired power generation was 6% less than average efficiency among countries of comparable size and development (25). Through increased thermal electricity generation and heavy industrialization, China's urbanization has accelerated the growth of energy-related carbon dioxide emissions.

4.3. Fuel Mix and Energy Supply

China's fossil fuel reserves are completely dominated by coal. Estimates of recoverable coal reserves vary between 115 and 333 billion tons of raw coal (26). Figure 12 illustrates the distribution of China's fossil fuel reserve base according to NBS data published in 2007 (27). Perhaps as a result of coal's prevalence in China, the ratio of total primary energy supply to total final energy consumption is higher in China than other less-coal-dependent countries (28).

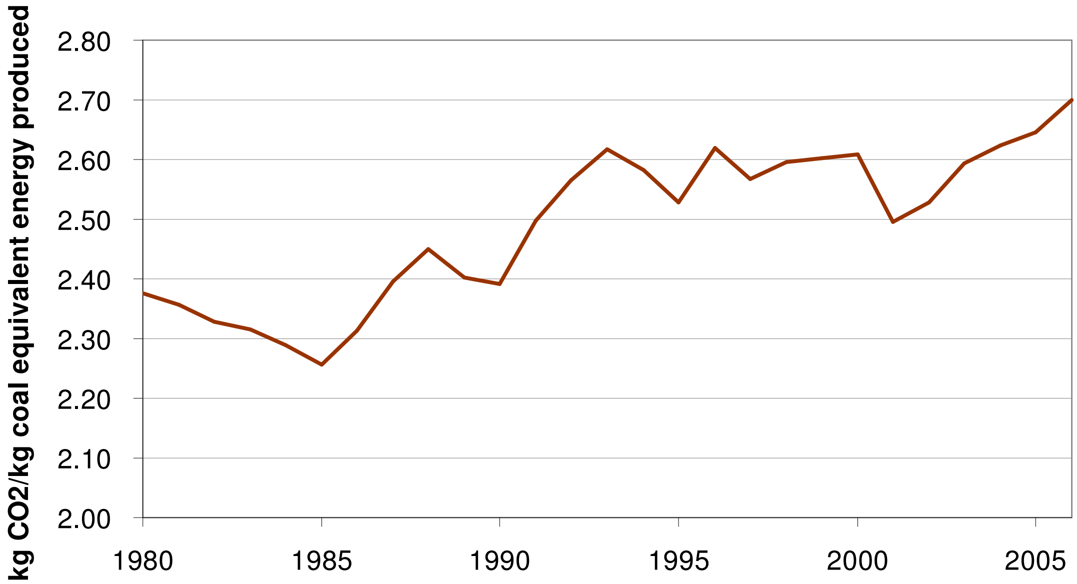
Figure 12: China Fossil Fuel Reserve Base, 2006



Source: NBS, 2007.

Coal is China's most carbon-intensive primary energy source. According to the IPCC, coal generates an average 95 tonnes of CO_2 emissions per terajoule of energy, compared to 73 t CO_2/TJ for oil and 56 t CO_2/TJ of natural gas (29). The coal share of China's energy-related carbon emissions increased from 78% to 80% between 2000 and 2006. China's increasing reliance on coal is further illustrated in the rising carbon intensity of energy production between 2001 and 2006 (Figure 13).

Figure 13: Carbon Intensity of Energy Production, 1980-2006

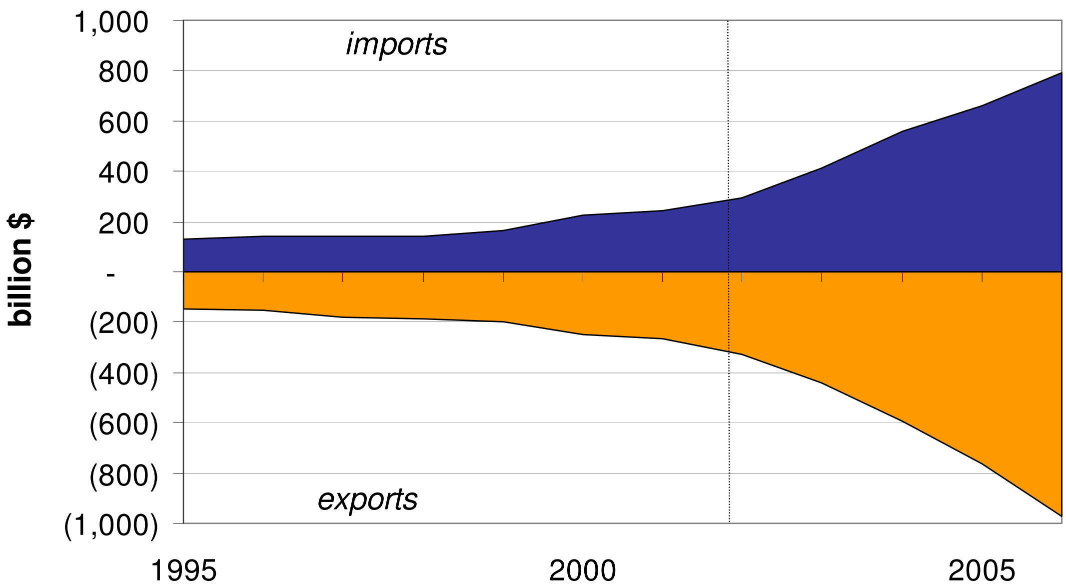


Note: LBNL China emissions are derived from revised total energy consumption data published in the 2007 China Statistical Yearbook using revised 1996 IPCC carbon emission coefficients; energy production data from NBS 2007.

4.4. Trade

The opening and reform of China's economy has resulted in rapid growth of external trade. From 1995 to 2001, the value of China's total imports and exports grew at an average annual growth rate of 10%. Since joining the World Trade Organization, the average annual growth of China's trade jumped up to 28% between 2001 and 2006 (Figure 14). On aggregate terms, the value of China's trade surplus expanded from $17 billion in 1995 to $178 billion in 2006. While these figures illustrate the rapid growth of international trade with China, there is not a simple relationship between the value of trade, economic growth, domestic energy usage, and carbon emissions.

Figure 14: China Global Trade by Value (current dollars), 1995-2006



Source: China Customs Bureau.

By converting export revenue data to value-added terms, economists have estimated that 10% of China's GDP can be traced to exports (30, 31). The dollar value of exports has also been used to estimate the carbon embodiment of Chinese exports (32). On the basis of carbon intensities and trade data, the IEA has estimated that the energy-related CO_2 emissions embedded in China's domestic production for exports accounted for 34% of total emissions in 2004 (33). This estimate does not include the net carbon effects of international trade, because it does not count the CO_2 embedded in imports. Using weighted average carbon intensity of countries from which China imports goods, the estimate of CO_2 China's **net** exports might be reduced to somewhat more than half of the 34% figure (Ke J. 2008. personal communication). If these estimates hold up – and they are very preliminary at present – they suggest that a substantial fraction of China's CO2 emissions can be attributed to consumption in other countries of products manufactured in China. Further research on this topic is needed, especially as economic trade data are not a good basis for understanding energy consumption and carbon emissions effects.

Aside from aggregate economic-based studies, input-output and ecological footprint-types of analysis have also been used to examine the energy and CO_2 embodiment of international trade (34). Using input-output-oriented analysis, the Tyndall Center has produced a first-order estimate of energy-related CO_2 emissions embedded in China's net exports amounting to 23% of total emissions in 2004 (35). Because this estimate does not count exports in terms of value added, in order to be comparable to GDP estimates, it may represent an overestimate of the contribution of net exports to China's CO2 emissions. Ecological footprint analysis provides a macro, resource-oriented view of total trade—including goods and fuels—for which carbon emissions effects are not isolated or specifically analyzed (36). Among these methodologies the frequency of outsourcing—trade in intermediate goods, rather than final products—and unclear boundaries among industrial sectors in China make it difficult to reliably calculate embedded energy and carbon of trade.

While it is difficult to generate reliable estimates of Chinese carbon embodiments, the rapid growth of trade in highly carbon-intensive goods and commodities points to a larger question of emissions accounting. Under the current producer-oriented system of carbon emissions accounting, there is an inherent conflict between national CO_2 emissions targets and the aim of improving foreign trade balances (37). Switching to a consumption-oriented carbon accounting methodology would change national incentives and carbon-emissions estimates (38). This is an area of continuing research, but for the time being it is clear that international trade is playing a significant role in China's energy-related carbon dioxide emissions.

Whereas GDP and population growth are often used to forecast energy-related carbon emissions, this review shows that recent trends can be traced to structural change in the Chinese economy with increasing output of energy-intensive industry, ongoing urbanization, increased carbon intensity of energy usage, and rapidly expanding international trade. None of these factors alone account for carbon emissions growth; rather their separate influences underscore the complexity of historical and forecasted energy-related carbon emissions in China.

5. ENERGY EFFICIENCY POLICIES LEADING TO REDUCED GROWTH OF EMISSIONS

5.1. Historical Period: 1980-2000 and Before (39, 40, 41, 42)

In the early days of the Peoples Republic, industry was modeled after the Soviet approach. This meant that energy was priced very low, so that it was available especially to support the development of heavy industry. The result was that energy demand grew substantially faster than economic growth, in some years twice as fast.

In a trend not matched by any other country at a similar stage of industrialization, the carbon intensity of China's economy fell rapidly from 1980 to 2001. China's actual energy-related carbon emissions in 2001 were 3.43 billion tons CO_2. If year 2001 economic output had been produced at the intensity prevailing in 1980 –at which point major reforms in energy and economic policy were enacted– carbon emissions would have been 10.75 billion tons carbon dioxide.

One cannot be certain how much of this decline in intensity was due to policies, but it had to be a great deal. In 1980, the government of China called for GNP to quadruple from 1980 to 2000 while energy demand only doubled. Thus, the declining E/GNP ratio was a goal of a government that had substantial control over its economy.

In 1981, the first year of the Sixth 5-Year Plan, China increased state investment in energy conservation from essentially zero to 10% of all energy-related investment. To carry out these investments, the China Energy Conservation Investment Corporation was created, with local offices throughout China.

A national network of energy conservation technology service centers was set up, with trained personnel to assist industry in energy efficiency. The first was created in 1983. By 1995, there were more than 200 of these centers throughout the nation employing 7,000 staff.

A third area was energy management in industry. This included requirements for energy monitoring, establishment of energy efficiency requirements for equipment, and the imposition of energy quotas. The latter, while possible under a controlled economy, was eventually dismantled in the middle and late 1990s.

5.2. Eleventh Five-Year Plan Energy Intensity Reduction Targets

We have observed that in 2001 – 2005, energy demand in China grew faster than GDP which itself was growing at a very rapid rate. This has led to a serious situation in China, with very high levels of investment going to power plants (and not to other uses) and contributing to major concerns about China's environment. The country has found itself at a place similar to where it was in the late 1970s. It has responded in a similar way. The highest levels of the Chinese government have called for a 20% reduction in energy intensity between 2005 and 2010. This came first from the Politburo, then the State Council, and finally from the National Peoples Congress. This has been followed by a flurry of activity in which officials at all levels were informed that their advancement depended on meeting these goals (Zhou, DD. 2006. personal communication). The National Development and Reform Commission has become deeply engaged in energy efficiency again (albeit with very small staff), and investment funds for energy efficiency now flow from central and provincial governments.

But there are significant differences between 1980 and today. China has moved a good deal of the way to a market economy. The top 1,000 Program (explained further in Section 5.3) is in many ways an effort to reinstitute the old energy quota system for industry. This may be possible for state-owned enterprises; it is much harder to envision for private companies. China's energy data system has been allowed to deteriorate, and it will need to be very good if energy performance is graded and the grades matter. Achieving reductions in energy (and CO_2) growth also requires a shift from highly energy-intensive to less energy-intensive industry. There was once a time when the government of China could make that happen; that time is no longer. And, perhaps most importantly, making money matters to many people in present-day China; policies that conflict with that goal are particularly difficult to put into practice.

In spite of these difficulties, the Chinese government is determined to advance its goal of declining energy intensity. While there is some debate on the efficacy of intensity targets in achieving emissions reductions targets, one does not wish to underestimate the ability of the government to achieve large goals through governmental programs or simply through exhortation at work and play (43).

5.3. Top-1,000 Enterprise Program

As a major part of its energy intensity reduction program, China has initiated a new industrial energy efficiency program. The program takes advantage of the fact that the 1,000 largest energy-using enterprises in China accounted for 33% of national and 47% of industrial energy usage in 2004 (44). Activities under this program include benchmarking, energy audits, development of energy saving action plans, information and training workshops, and annual reporting of energy consumption. Supporting programs and policies, such as facility audits, assessments, benchmarking, monitoring, information dissemination, and financial incentives all play an important role in assisting the participants in understanding and managing their energy use and GHG emissions in order to meet the target goals. The goal of the Top-1,000 Energy-Consuming Enterprises program is to realize savings of 100 Mtce (2.8 Quads, 2.9 EJ) (45).

The industries included in the Top-1,000 Energy-Consuming Enterprise program are large-scale, financially independent enterprises in nine major energy consuming industries: iron and steel, petroleum and petrochemicals, chemicals, electric power generation, non-ferrous metals, coal mining, construction materials, textiles, and pulp and paper.

The Top-1,000 Enterprise Program is based partially on energy efficiency pilot projects with two iron and steel enterprises -- Jinan Iron and Steel (Jigang) and Laiwu Iron and Steel (Laigang) -- in Shandong Province initiated in 2003. This program was in turn modeled after international voluntary agreement programs. The pilot was considered a success due to the achievement of the targets along with the knowledge gained related to establishing targets, energy management within the company, making energy-efficiency investments, and establishing energy efficiency policies at the provincial level (46).

Parts of the new program seem much like the approaches of the 1980s and 1990s, in which the government was very active in setting energy consumption targets for industry. However, an important difference now is the relatively softer role of the government, which has less authority and ability to enforce requirements than it had in the past. At the same time, the government has used encouragement (in the form of low interest loans) and pressure (in the form of evaluations in which responsible individuals will be assessed on an annual basis regarding achievement of energy intensity goals). As an example, China's National Development and Reform Commission (NDRC) signed an agreement with the Beijing Municipal Government covering ten enterprises within Beijing's jurisdiction. The Beijing Municipal Government, in turn, signed energy-efficiency target contracts that include energy saving amounts with each of the ten enterprises.

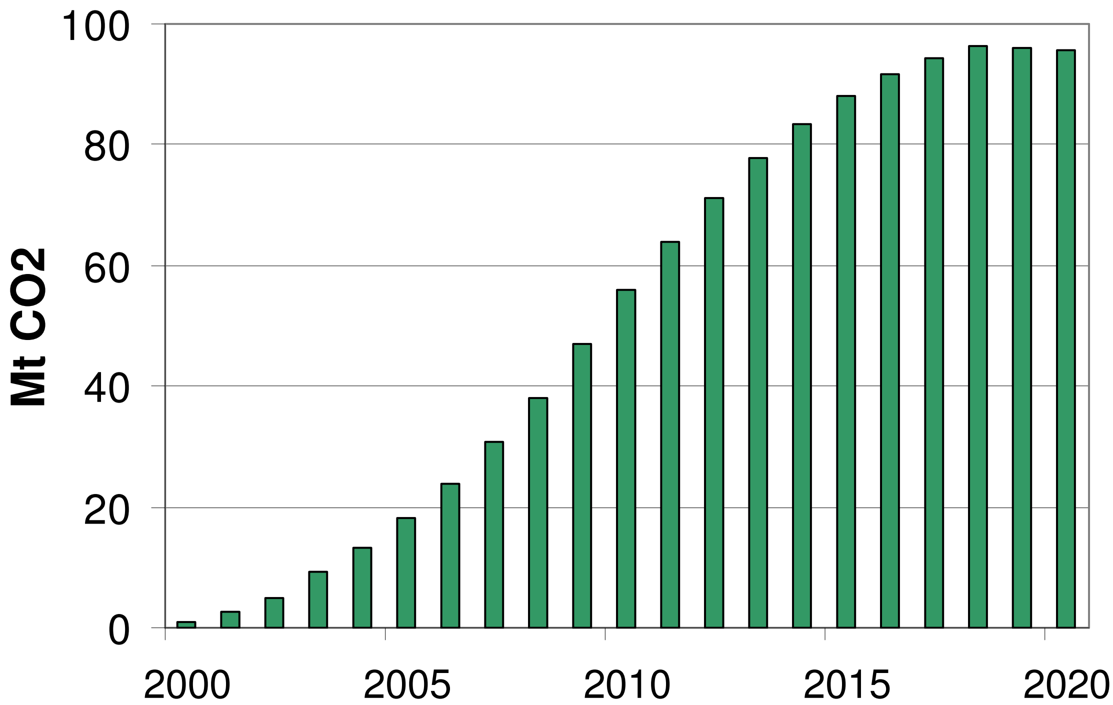
In 2006, the energy consumption per unit of GDP declined 1.23% compared with 2005 (47). Although the annual target of 4% reduction in energy intensity was not reached, this is the first drop in this metric since it began to increase in 2002. Since the Top-1,000 program and other efforts to reduce energy intensity 20% were just launched in early- to mid-2006, it is expected that their impact will increase over time in pursuit of the 4% per year energy intensity reduction goal. In fact, NDRC recently reported that the steel industry – which is the sector with the largest number of enterprises and highest total energy consumption in the Top-1,000 program – experienced a decrease in overall energy consumption of 8.8% between 2005 and 2006 and unit energy consumption for producing one ton of steel declined 7.1% (48).

5.4. Appliance Standards

China's modern standards and labeling programs have been in effect for less than a decade, but the impact is already beginning to be felt in terms of energy savings. In a rapidly growing economy like China's, energy savings serve more to bring down the rate of demand growth rather than to reduce consumption. Nonetheless, these efficiency programs have resulted in a lower amount of emissions of CO_2, NO_x, SO_x and particulate matter than would have otherwise occurred if the programs had not been developed. Moreover, they have saved Chinese consumers a lot of money.

In total, the programs currently in place are expected to save a cumulative 1143 TWh by 2020, or 9% of the cumulative consumption of residential electricity to that year. In 2020 alone, annual savings are expected to be equivalent to 11% of residential electricity use. In average generation terms, this is equivalent to 27 1-GW coal fired plants that would have required around 75 million tonnes of coal to operate. In comparison, savings from the US appliance standards program is expected to save 10% of residential electricity consumption in 2020. Given the dominance of coal-fired electricity generation in China, appliance standards and labeling programs also help to mitigate air-pollution problems. Between 2000 and 2020, improved efficiency among electric appliances and gas water heaters will reduce carbon emissions by more than 1.1 billion tons carbon dioxide. Figure 15 illustrates annual carbon dioxide emission reductions from China's electric-appliance and gas water heater programs. These reductions are calculated assuming thermal marginal power generation and future improvements in generation efficiency, as well as diminishing losses in electricity transmission and distribution (49).

Figure 15: Annual Appliance-Related Carbon Emissions Reductions, 2000-2020



Source: Fridley, et al. 2007.

6. CONCLUSIONS

None of the major forecasts were able to pick up the dramatic increase in energy-related CO_2 emissions in China from 2002 to the present. (The three-year increase was equivalent to the increase projected to take place over a period of fifteen or more years!) The largest cause of this increase in CO_2 emissions in China is the growth in total output of energy-intensive goods. Although there are no reliable times series data – and even point estimates are uncertain – the carbon embodied in trade from China may have played an important role. Other factors of importance: rate of energy efficiency improvement, the carbon intensity of fuel, and the pace of urbanization. In a longer time horizon, the growth of the commercial transportation sectors can be expected to play an important role.

The carbon embodied in trade from China could also be important, although research of the magnitude of this effect to date is inconclusive.

Most of the models reviewed in this paper use GDP as the primary driver of energy demand in China. They have other drivers including stock turnover, equipment saturation, and urbanization. But the leading models internationally (IEA), in China, and in the United States (EIA) all failed to predict the major change in energy demand trends after 2001 in China which appear to be the most significant of all trend lines for overall global energy demand since before the OPEC oil embargo (and likely much longer, see Figure 2) .

We believe that it would have been difficult for any model to have picked this up in 2000 or earlier. The period 2001-2005 has seen an enormous growth of heavy industry in China. This in turn is the result of the demand for such products as iron and steel and concrete for construction of buildings, roads, and other infrastructure. China is at a place in its development when it can afford to build this infrastructure, when the government restrictions are largely removed, and when a newly open market economy permits individuals and companies to gain substantial profits from these opportunities.

All of this suggests that predicting China's growth in energy demand and related carbon dioxide emissions will be precarious in the coming decades. We identify two major unknowns that, in our view, will play a major role in the outcome. The first is policy. The goal of 20% intensity reduction over five years will not be a one-time goal. China can be expected to pursue such policies into the indefinite future. Some of the intensity reduction (as we have seen) can be achieved with energy efficiency. Some of it will require structural change to a mix of less energy-intensive industries. The second major unknown goes deeper into drivers of demand. At what point will China have enough building space for its people – or at least enough for construction activity to diminish? When will there be enough roadways, rail lines, automobiles, buses, trains, trucks (and in what mix) to support personal and freight transport?

All of this – along with the factors in the first paragraph of this section – needs to be overlaid onto the projected economic growth of China to gain an understanding of the major drivers of CO2 emissions in China.

In light of the difficulties that have emerged for those forecasting CO2 emissions in China, it is not surprising that China would be especially loath to submit to a fixed target. Their own CO2 forecasts have failed to capture the dramatic growth of CO2 emissions in the past five years. Those from outside China have been inadequate to the task. The forecasts for industrialized countries on the other hand have been much more robust.

How does this relate to the most recent IEA projections that, in the base case, China is expected to account for 42% of incremental global energy-related CO2 emissions – and about 50% in both higher and lower scenarios? The problem with these emissions forecasts, in the view of the authors, is that they assume the China will follow the world and have a base (low or high) growth case if the rest of the world follows these respective cases. As we have seen, policy in China will play an important role in future emissions. It is entirely possible for China to cut the growth rate of emissions (relative to GDP) while other countries do not. Unfortunately, it is impossible to predict such an outcome with any degree of confidence, as the degree to which China can tame its burgeoning energy demand is not at all clear.

Considering the energy sources available to China, very heavy reliance on coal can be expected for decades. This in spite of the desire that China has often expressed to diversify energy sources away from coal. CO2 emissions could, however, be affected dramatically if carbon capture and storage becomes affordable (with a carbon tax) or if significant breakthroughs in renewable or nuclear power costs occur. The authors do not expect either to occur in the coming decades in a magnitude that will impact overall energy-related CO2 emissions from China.

SUMMARY POINTS

1. China's growth in carbon dioxide emissions since 2002 has confounded the expectations of the world. During this period, energy use grew much faster than GDP. More than half of all increased carbon dioxide emissions globally between 2000 and 2006 came from China.
2. This dramatic increase in emissions from China is in direct contrast to the period between 1980 and 2000, where China was able to limit emissions to about 40% of the growth of GDP.

3. Thus, GDP growth has not been a reliable indicator of carbon emissions growth in China.
4. The major models applied internationally and in China missed the dramatic changes in the emissions in China, as did most analysts studying the issue. **Total** CO2 emissions forecasts for China in 2010 increased by more than 50% between the 2004 and 2007 forecasts of the International Energy Agency and the U.S. Energy Information Administration. (The Chinese forecasts completed before 2004 were comparably low.)
5. The major factor in the dramatic energy demand growth that the models did not capture is the huge increase in the output of heavy industry in China. This confounded the expectations of Chinese policy makers as well as international observers.
6. None of the models captures the effect of policies on energy demand (and thus CO2 emissions) growth in China. Policies had a dominant effect in the period 1980-2000; the Chinese government expects policies to play a major role in constraining demand growth in the future.
7. China's per capita emissions of energy-related carbon dioxide were less than 20% of the United States' per capita levels. With its population of 1.3 billion people, China is far from its peak in total emissions.
8. With coal as the major energy source, and no alternative likely to play a dominant role in replacing coal, increasing energy demand means disproportionately increasing CO2 emissions.

FUTURE ISSUES

1. For short-term modeling, it is critical to understand the factors that have led to the rapid growth of heavy industry in spite of the government support for light industry. This is a very complex area for research to which little attention has been devoted.
2. Comprehensive, physically-based energy-intensity analysis must be performed to understand the role of trade and export-oriented industries in China's emissions growth.
3. For personal transportation, it will be important to understand the degree to which congestion may (or may not) limit the use of automobiles, as well as the aggressiveness (or lack thereof) of government in providing public transit alternatives.
4. The role of increasing urbanization will have considerable influence on China's CO2 emissions. Research is needed to understand the implications of different patterns of urban growth on energy and carbon dioxide emissions.
5. In the longer term, the saturation of energy-using equipment, efficiency of the equipment, lifestyles of the Chinese, and the overall needs for infrastructure (buildings, highways, rail, etc.), and population will establish energy demand. Research is needed to understand the types of Chinese social and economic organization consistent with different values of these determinants of energy demand.
6. Research is needed to understand the opportunities to reduce CO2 emissions through alternatives to coal as a source of energy supply in the longer term.

ABBREVIATIONS, ACRONYMS, and DEFINITIONS

Carbon elasticity: the ratio of energy-related carbon emissions growth to GDP growth.

Carbon intensity: the amount of energy-related carbon emissions per unit GDP.

Energy intensity: the amount of energy consumed per unit GDP.

IPCC: Intergovernmental Panel for Climate Change; panel set up by the United Nations in 1988 to review scientific information on climate change.

Laspeyres decomposition: a method of index decomposition analysis used to quantify structural and efficiency effects in changes of energy intensity of GDP. The modified equation is expressed as follows,

$E_t = Q_t I(t\text{-}1) + Q_t \sum S_i^0 \Delta I_i + Q_t \sum \Delta s_i I_i^0 + Q_t \sum \Delta s_i \Delta I_i^0$

where

E_t = energy actually consumed by industrial sector (in Mtce) in year t

Q_t = GDP or Value-Added (in 2000 yuan)

I_i = intensity of energy use in the ith sector in year t

S_i = the ith sector's share of GDP

i = reference number for sector

T = the time period.

RNECSPC: Research on National Energy Comprehensive Strategy and Policy of China [in Chinese]; energy strategy document jointly formulated by the China Development Research Center and the Energy Research Institute published in 2004.

SRES: Special Report on Emissions Scenarios; published by the IPCC in 2000.

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