Energy Use and CO_2 Emissions in China: Retrospect and Prospect

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Abstract

For more than two decades after the 'opening to the market' in 1979 China achieved rapid expansion with low growth in energy use, the energy growth rate being only about half that of GDP. This has not continued in recent years; over 2001-05 real GDP grew by 45% and energy use by 57%. During 1979-2001 falling energy intensities, in both secondary and tertiary industries, substantially offset the impact on energy demand of high growth and structural change, but the decline in sectoral intensities ceased after 2001. China will find difficult to achieve further reductions in energy intensity prior to 2010, and major policy initiatives or structural change may be necessary to return to an energy elasticity of GDP of much less than one. An unchanged policy projection shows growth in energy use and CO_2 emissions from fuel combustion in China over 2002-30 of 6.7% and 6.5% per annum respectively. Such growth will place heavy pressure on both Chinese and global supplies of energy, and will have major implications for the world's climate.

1. Introduction

There has been widespread discussion in recent years about the rapid rate of economic growth taking place in China, especially since China's entry into the World Trade Organisation in 2001, and about the impact of that development on world markets for coal, oil and natural gas. The rate of growth in GDP and in energy use has indeed been rapid. Official figures put real GDP growth for 2005 at 9.9%, with average growth over 2001-2005 of 9.8%, while growth in total energy consumption over the four-year period was 11.6% per annum (NBSC, 2006a).

Such explosive growth in energy use caught the Chinese Government, energy analysts and energy providers in China unaware, and severe shortages developed in 2004 and 2005. Since the 'opening to the market' in 1979 the energy intensity of China's GDP fell continuously through to 2001, as energy use became more efficient and grew less rapidly than GDP. This decline in energy intensity was especially marked in the second half of the 1990s, so that the shift to rates of growth in energy use in excess of GDP growth after 2001 had profound and unexpected implications in energy markets. China already accounted for 13.6% of total world primary energy consumption by 2004 (BP, 2005), so that understanding this change and its implications for past and prospective energy use

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and emissions in China is of considerable importance, both for China's development strategy and for the global community.

To contribute to greater understanding of these issues, this paper undertakes five tasks. In Section 2 existing projections of China's energy use and CO_2 emissions are reviewed in the light of recent developments. In Section 3, the different stages of China's growth since 1979 are examined, with emphasis on the special characteristics of the growth path since 2001. Building on this analysis, a decomposition of growth in China's energy use since 1980 is reported (Section 4), to quantify the contribution to increasing energy use, in different periods, of GDP growth and changes in sectoral shares and in sectoral energy intensities. Future trends in aggregate energy intensity, or in the energy elasticity of GDP, are vital to any projection of China's energy use and emissions, and this issue is examined in Section 5. Finally, in Section 6 we present an unchanged policy projection to 2030 for energy use and CO_2 emissions from fuel combustion in China that takes account of the implications of recent developments. The analysis is constrained by the quality and quantity of the available data, but understanding China's energy use and contribution to greenhouse gas emissions is too important to be left until richer data permit more sophisticated forms of analysis. Conclusions are presented in Section 7.

2. Existing Projections and Emerging Realities

On the basis of an assumed average growth rate of GDP (measured in constant purchasing power parity prices) of 5% per annum between 2002 and 2030, in the 2004 *World Energy Outlook* the IEA projected growth of only 2.6% per annum in total energy use (total primary energy supply, TPES), and of 2.8% in CO_2 emissions, in China over that period (IEA, 2004). This implies that each one percent growth in GDP generates only 0.52% growth in total energy use (an elasticity of energy demand with respect to GDP of 0.52). These projected figures for 2002-2030 are little more than half of the IEA figures for China over 1971-2002: 4.8% per annum growth in energy use and 4.9% growth in CO_2 emissions from fuel combustion.

The IEA is not alone in projecting a long run reference case rate of growth in energy demand in China over the next 25-30 years below that of 1971-2002, and a range of recent projections are summarised in Table 1 below. An authoritative study by the Energy Research Institute of the National Development Commission of China and the Lawrence Berkeley National Laboratory in the USA, released in October 2003, projected growth in energy demand in China of 3.8% per annum between 1998 and 2020 in their unchanged policy scenario (ERI, 2003). The latest projections from the Energy Information Agency of the US Department of Energy (DOE, 2005) show, for the reference case, annual growth in primary energy consumption in China of 4.1% per annum over 2002-2025. A regional study from the Asia Pacific Energy Research Council (APERC, 2002; see also APERC, 2004) projected lower average growth rates in the reference case of 2.7% over 1999-2020. Projections of growth in CO_2 emissions, where they are available, are a little lower than for energy use, except for the case of the IEA.

Several years ago the National Development Research Center (NDRC) of the State Council assembled leading energy research institutes in China to prepare a National Comprehensive Energy Strategy and Policy for China. This strategy, which consists of a main report and eleven supporting sub-reports, was released in Chinese in 2004 (NDRC, 2004), and an abridged English version was released (NDRC, 2004; see also Dai and Zhu, 2005). The report includes scenarios projecting energy use and CO_2 emissions for China to 2020 on three bases: existing policies (scenario A), alternative policies, focusing on energy efficiency and sustainability (scenario B), and an 'advanced policy scenario' (scenario C). Scenario A projects annual average growth in energy use and CO_2 emissions over 2000-2020 of 4.7% and 4.6% respectively (Table 1), very close to the outcomes for 1971-2002 noted above.

Table 1. Projections of Primary Energy Use and CO_2 Emissions, China, various periods

	Timeframe	Reference projection		
		Growth in primary energy use (% pa)	Growth in CO_2 emissions (% pa)	Long-run energy elasticity of GDP
Panel A: Independent Projections				
ERI/LNBL (2003)	1998-2020	3.8	3.6	
EIA International Energy Outlook (DOE 2005)	2001-2025	4.1	3.6	0.66
APERC Outlook (2002)	1999-2020	2.7	na	
IEA World Energy Outlook (2004)	2002-2030	2.6	2.8	0.52
Panel B: China National Energy Strategy and Policy to 2020 (2004)				
Scenario A – Existing Policy	2000-2020	4.7	4.6	0.64
Scenario B – Alternative Policies	2000-2020	4.1	3.9	0.54
Scenario C – Advanced Policies	2000-2020	3.3	2.9	0.40

Although the NDRC current policy projection shows significantly higher rates of growth in energy use and emissions than the other projections, Table 2 shows clearly that energy use in the Chinese economy is expanding much more rapidly than envisaged in scenario A. In terms of the main aggregate indicator, primary energy demand, the first official estimate for 2005 (NBSC, 2006a) is about 4% greater than the projected figure for 2010, being 72% above the reported actual figure for 2000. Electricity generating capacity in 2005 was 26% above the projected level in scenario A, and only 10% below that projected for 2010. The demand for coal has been extremely strong, with the 2005 actual being 32% above the projected figure for 2005 and even 7% above that for 2010. Demand for oil was rising well ahead of the projections through to 2004, but grew by only 2.1% in 2005, as higher oil prices impacted on demand and led to fuel substitution. As a result the overall demand for oil was close to the projection for 2005. Demand for natural gas was 25% ahead of the projection in 2005, in spite of infrastructure problems hindering greater usage of gas.

Table 2. Projections for Selected Variables, Scenario A, National Comprehensive Energy Strategy and Policy to 2020, and Actual Values for 2005

	Actual	Strategy Report – Scenario			Actual
	2000	2005	2010	2020	2005
Primary energy demand (mtce)	1297	na	2137	3280	2225
Electricity generation capacity (GW)	319	402	559	947	505
Demand for fossil fuels					
Coal (100 m tons)	12.7	16.2	20.0	29.0	21.4
Oil (100 m tons)	2.3	2.9	3.8	6.1	3.0
Natural gas (100 m cubic	272	399	840	1654	500
Output of main energy intensive					
Iron and steel (m tons)	128.5	250	300	280	352
Cement (m tons)	597	680	790	1070	1060
Ethylene (10,000 tons)	450	790	1200	2000	756
Synthetic ammonia (10,000	3346	3600	3800	4000	4222[1]
Paper (10,000 tons)	2487	4000	5000	7500	4864[1]

Note: [1]2004 values.
Sources: For actual 2000 and strategy report values see. Actual data for 2005 from NBSC (2006a) and for 2004 from NBSC (2005a).

Some indication of what lies behind these surging energy demand numbers can be gleaned from comparing the projections for output of some energy intensive products that are provided in the report for scenario A with available data for 2005, or for 2004 where the 2005 data are not available (Table 2). For three of the products (iron and steel, cement and synthetic ammonia) the estimates for 2005 (or in one case 2004) are already well in advance of the projections for 2010, and this is likely to be the case for paper also, based on the 2004 figure. Only in the case of ethylene is the estimate for 2005 below the projection for that year. It is clear that, in the short run, energy demand and use in China is growing much more rapidly than envisaged in scenario A, and hence than over the previous thirty years.

3. Stages of Growth in China Since 1979

Since the beginning of reform in 1979 China's remarkable economic growth has been driven by both internal and external factors, with the balance of these factors changing over time. In 1978 the economy was dominated by a large, inward-looking and energy inefficient industrial sector, which accounted for nearly 50% of GDP in current prices. Exports were only 4.6% of GDP, and over half were from the primary sector. The initial impetus of the reforms was particularly favourable to the rural and services sectors, where loosening of the controls imposed in the command economy led to rapid expansion of activity. The growth rate of value added in both agriculture and services more than doubled in the 1980s relative to the 1970s, to 6.2% and 12.3% respectively, while there was little increase in the growth rate in industry (Table 3). As is evident from Table 3, the services share of GDP rose more than eight percentage points between 1980 and 1990, and over this time the primary and tertiary sectors contributed 62% of total growth. These dynamics changed substantially during the 1990s, as the expansion of industrial activity, linked into global markets and driven in significant part by foreign investment and by a more competitive currency, became the main source of growth. Between 1990 and 1997 real industrial GDP grew by 15.7% per annum, while growth in both the agricultural and services sectors slowed (Table 3). As a result, the industrial share of GDP rose sharply from 37.0% to 48.9% between 1990 and 1997, and secondary industry contributed just on 60% of the growth of real GDP during this period.

Table 3. Real GDP by Sector, 1970-2000, estimated 2000 values

	Agriculture	Industry	Services	Total
	(100 billion yuan, at 2000 values)			
1980	5.5	5.1	3.6	14.2
1990	10.1	12.6	11.4	34.1
1997	13.4	34.9	23.0	71.3
2001	15.0	48.7	33.0	96.7
2005	17.7	74.6	48.0	140.4
Share of total GDP	(per cent)			
1980	38.9	35.8	25.2	100
1990	29.6	37.0	33.4	100
1997	18.8	48.9	32.3	100
2001	15.6	50.4	34.1	100
2005	12.6	53.1	34.2	100
Annual growth rates	(per cent per annum)			
1970-1980	2.0	9.1	6.0	5.1
1980-1990	6.2	9.5	12.3	9.4
1990-1997	4.2	15.7	10.6	11.5
1997-2001	2.9	8.7	9.4	8.0
2001-2005	4.2	11.2	9.9	9.8

Sources: NBSC (2005a), NBSC (2006a) and estimates of the authors.

Between 1997 and 2001 the Chinese economy experienced a period of somewhat slower growth by its own lofty standards, with GDP growth averaging ‘only’ 7.9% and growth in industrial GDP being in single digit figures for four consecutive years for the first time since 1979. This reflected in part the turbulent international environment associated with the East Asian crisis of 1997-98 and the recession in the USA after the collapse of the high tech boom. Exports in current prices amounted to only 14.8% of GDP over 1997-2001. In November 1999 China reached a bilateral agreement with the USA about the terms on which China would enter the WTO. The full WTO membership formally approved China’s entry two years later at Doha in Qatar, and China became a member in 2002. The emergence from that relative slowdown over 1997-2001, ushered in another stage of China’s growth, one that is still continuing.

Table 4. Trends in Fixed Asset Investment and Exports, China, 1991-2005

	Investment in fixed assets (billion yuan, 1991 prices)	Ratio of investment in fixed assets to household consumption (real terms, %)	Exports (US$billion)	Exports/GDP (yuan, %)	Ratio of change in exports to change in GDP over period (yuan, %)
1993	896.0	69.7	91.7	15.0	15.0
1997	1382.5	78.3	182.8	19.2	18.9[1]
2001	2044.7	86.9	266.1	20.1	14.8[2]
2002	2384.9	94.4	325.6	22.4	46.1
2003	2981.0	110.8	438.2	26.7	60.3
2004	3581.1	114.2	593.4	30.7	53.3
2005	4263.5	123.6	762.0	35.6	70.0

Notes: [1]For the period 1993-1996 inclusive. [2] For the period 1997-2000 inclusive.
Sources: NBSC (2005a), NBSC (2006a) and estimates of the authors.

In this new stage of China's development three inter-related features stand out. The first is the extremely rapid growth in exports. In just four years between 2001 and 2005 China's exports in US dollar terms increased nearly threefold, growing by 30% per annum and rising from US$288 billion in 2001 to US$762 billion in 2005. The share of exports in GDP increased from 20.1% in 2001 to 35.5% in 2005 and the increase in exports over the four years amounted to 59% of the growth in GDP, and to 70% in 2005. The second feature of this period has been heavy investment in fixed assets, which has increased sharply in recent years and surpassed household consumption spending as the dominant factor in domestic demand. Real fixed asset investment has more than doubled between 2001 and 2005, growing at an average annual rate of 20.2%. These two factors of burgeoning exports and high levels of fixed asset investment are undoubtedly closely related. Creating the capacity for such a high level of exports required heavy investment in fixed assets, not only within firms but also in a wide range of economic and social infrastructure, ranging from power stations, ports and railways to housing and urban facilities. Revenues being received by various parties, both firms and government agencies, from the export boom would also assist with the financing of that infrastructure. The third feature of this period is perhaps an inevitable result of these two, namely a further rise in the role of the industrial sector in driving China's growth. Measured in 2000 values, the share of secondary industry in GDP rose from 46.0% in 2001 to 48.5% in 2005 (Table 3), with virtually all the decline in the primary sector being taken up by industry.

Thus the combination of China's entry into the WTO and a strong global economy has produced since 2001 a striking new stage in China's development. The economy is being driven hard by very rapid growth in exports and in fixed asset investment, which are reflected in the growth in industrial output. Each of the three measures highlighted here – exports as a share of GDP, the ratio of fixed asset investment to household consumption spending and the secondary industry share of GDP – are at historically high levels, and are likely to increase further in the immediate future. There are undoubtedly many speculative elements in the current Chinese expansion. But the main driving forces – the transformation of China into the major trading nation on the globe and the investment implications of that transformation – are real. While growth in the world economy continues, and while China's strategy and competitiveness foster further increases in China's share of world markets, export led, energy intensive growth is likely to continue at a high level in China.

4. A Sectoral Decomposition of China's Energy Use, 1980-2005

One valuable tool for understanding China's energy use is a sectoral decomposition of that use (Wu et al., 2005). Given data limitations, the analysis here is limited to the three sectors discussed in the preceding section, namely primary, secondary and tertiary industry. For these three sectors, and for several periods, the objective is to decompose the increase in energy use in China into components reflecting growth in GDP, changes in energy intensity within sectors and changes in the sectoral composition of GDP.

The total energy use in period *t* is given by:

$$E = \sum_i y_{ti} \,.\, \varepsilon_{ti}$$

$$= \sum_i (y_{0i} + \Delta y_{ti}) \,.\, (\varepsilon_{0i} + \Delta\varepsilon_{ti}), \qquad (1)$$

where Δy_{ti} and $\Delta\varepsilon_{ti}$ are the change in value-added in sector i (y_i) and in the energy intensity of sector i (ε_i) in period t respectively. This implies:

$$\Delta E = \sum_i (y_{0i} \,.\, \varepsilon_{0i} + \Delta\varepsilon_{ti} \,.\, y_{0i} + \Delta y_{ti} \,.\, (\varepsilon_{0i} + \Delta\varepsilon_{ti}) - \sum_i y_{0i} \,.\, \varepsilon_{0i}$$

$$= \sum_i (\Delta\varepsilon_{ti} \,.\, y_{0i} + \Delta y_{ti} \,.\, (\varepsilon_{0i} + \Delta\varepsilon_{ti}). \qquad (2)$$

The first term in the summation represents the change in total energy use due to changes in energy intensity in the industry sectors, for opening levels of GDP in the sectors, and the second term represents the combined effects of changes in the aggregate level and the composition of GDP, and their interaction with changes in sectoral energy intensities. Let sti be the share of sector i in total GDP at time t, and Y_t be total GDP at t, so that:

$$\Delta y_{ti} = s_{ti} \,.\, Y_t - s_{0i} \,.\, Y_0 = (s_{0i} + \Delta s_{ti}) \,.\, (Y_0 + \Delta Y_t) - s_{0i} \,.\, Y_0$$

$$= s_{0i} \,.\, \Delta Y_t + \Delta s_{ti} \,.\, Y_t \,. \qquad (3)$$

Thus, substituting (3) into (2),

$$\Delta E = \sum_i (\Delta\varepsilon_{ti} \,.\, y_{0i} + (s_{0i} \,.\, \Delta Y_t + \Delta s_{ti} \,.\, Y_t) \,.\, (\varepsilon_{0i} + \Delta\varepsilon_{ti}))$$

$$= \sum_i \Delta\varepsilon_{ti} \,.\, y_{0i} + (s_{0i} \,.\, \varepsilon_{0i} \,.\, \Delta Y_t + \Delta s_{ti} \,.\, \varepsilon_{0i} \,.\, Y_t) + s_{0i} \,.\, \Delta Y_t \,.\, \Delta\varepsilon_{ti}$$

$$+ \Delta s_{ti} \,.\, \Delta\varepsilon_{ti} \,.\, (Y_0 + \Delta Y_t) \quad = \sum_i s_{0i} \,.\, \varepsilon_{0i} \,.\, \Delta Y_t + (\Delta\varepsilon_{ti} \,.\, y_{0i} + s_{0i} \,.\, \Delta Y_t$$

$$.\, \Delta\varepsilon_{ti}) + \Delta s_{ti} \,.\, \varepsilon_{0i} \,.\, Y_t$$

$$+ \Delta s_{ti} \,.\, \Delta\varepsilon_{ti} \,.\, (Y_0 + \Delta Y_t). \qquad (4)$$

This decomposition breaks the total change in energy use down into four effects, each summed across industry sectors, namely:

- *the pure growth effect* – $s_{0i} \,.\, \varepsilon_{0i} \,.\, \Delta Y_t$ – that due to the increase in total GDP, for opening sectoral shares and energy intensities;
- *the pure intensity effect* – $(\Delta\varepsilon_{ti} \,.\, y_{0i} + s_{0i} \,.\, \Delta Y_t \,.\, \Delta\varepsilon_{ti})$ – that due to changes in sectoral energy intensities, at opening GDP levels by sector, and that due to the product of the change in GDP in sectors, for given GDP shares, and in sectoral energy intensities;
- *the pure sectoral effect* – $\Delta s_{ti} \,.\, \varepsilon_{0i} \,.\, Y_t$ – that due to the change in sectoral GDP shares, for opening energy intensities; and
- *the interaction effect* – $\Delta s_{ti} \,.\, \Delta\varepsilon_{ti} \,.\, (Y_0 + \Delta Y_t)$ – that due to the joint interaction of the changes in sectoral shares and intensities, in relation to both the opening level of total GDP and its change.

Given the interaction between the variables in determining final energy use, the various effects cannot be fully isolated, so that the interaction effect measures the change in energy use due to the combined change in sectoral shares and in sectoral intensities.

The results of the decomposition analysis are summarised in Table 5 and provided in full in the Appendix, Table A1. It should be noted that here energy use excludes energy from traditional biomass and waste.

In the 1980s, the pure growth effect, the growth in energy use from increased GDP at opening intensities and sectoral shares, was substantial, equal by 1990 to 1.4 times energy use in 1980 and generating, if nothing else changed, annual growth in energy use over the period of 9.2%. But energy intensities did fall in each of the three sectors, and especially in industry, so that falling sector intensities offset 62% of the growth effect. There were also some small savings from the interaction effect, mainly arising also from falling energy intensity. Sectoral changes, notably the big fall in the primary industry share of GDP largely offset by the rise in the tertiary sector share, contributed to increased energy use, to the extent of 22% of 1980 energy use. The main factors, however, were the strong growth effect offset to a significant degree by falling energy intensities, so that overall energy consumption increased by 5.1% per annum.

Table 5. Components of Increase in Energy Use, Selected Periods, 1980-2005, as a proportion of opening total energy use

	1980s	1990s	2000-05
	(Increase in energy use over the period, as a proportion of opening energy use)		
Growth component	1.40	1.63	0.57
Intensity component	-0.87	-1.39	0.05
Sectoral component	0.22	0.58	0.06
Interaction component	-0.10	-0.37	0.00
Total	0.64	0.45	0.67
	(% per annum)		
Growth of total energy use in period	5.1	3.8	10.9

Source: Estimates of the authors, based on data from NSBC (2005a) and NSBC (2006a). For details see Table A1.

In the 1990s, growth in GDP was even stronger (at 10.1%) than in the 1980s so that, in spite of the lower level of energy intensities in the opening year, the growth effect was large (163% of 1990 energy use by 2000 – Table 5). During this decade the share of secondary industry rose rapidly, so that sectoral effects also contributed strongly to growth in energy use (to the extent of 58% of 1990 energy use). Other things being equal, the growth and sectoral effects would have led to an increase of 12.4% per annum in total energy use during the 1990s. But again other things were not equal, and the decade saw very large falls in energy intensities – energy use per unit of real value added in secondary industry fell by 59% between 1990 and 2000, and that in tertiary industry by 45%. The impact of these falls in intensity, both directly and through the interaction component, were such as to offset substantially the growth and sectoral effects, so that total energy use in China grew by only 3.8% per annum over the decade. The implied energy elasticities for the decade are thus very low, being 0.28 for secondary industry and 0.37 for the economy.

Thus in the dynamics of Chinese energy use in the 1990s two powerful forces were opposed – strong GDP growth and the changing structure of the economy, on the one hand, and sharp falls in energy use per unit of value added, especially in secondary and tertiary industries, on the other. The balance between these forces was always precarious – if falling intensities were no longer achieved, rapid growth in energy use would result. Indeed, the speed of the decline in energy intensity – especially in secondary industry, where value added increased by 60% over 1995-2000 with only a 1% increase in recorded energy use – was one of several factors casting doubt on the energy statistics for that period. This issue is discussed in the next section.

This balance between these two forces did shift indeed abruptly over 2000-2005. GDP growth continued to be strong, and the share of secondary industry rose further, so both the growth and sectoral effects again contributed to a rapid increase in energy use. But the energy intensity of all three sectors rose slightly in this period, rather than continuing to fall, so that total energy use rose by 67%, or by 10.9% per annum over 2000-05. While the current development pattern – based on rapid growth in industrial production, exports and fixed asset investment – continues, the growth and sectoral effects will continue to favour rapid growth in energy use. So the key issue, both for interpreting the past and for future projections, is an understanding of the changes in the energy intensity of GDP, or in the energy elasticity of GDP, in China.

5. Interpreting Changes in the Energy Intensity of GDP

To facilitate international comparisons in terms of the energy intensity and elasticity of GDP, we shift from Chinese official data to series based on IEA data for the remainder of the paper. For energy use from 1977 to 2001 the data are from the IEA, and are extended to 2005 using the growth rates for the years 2001-2005 provided in NBSC (2006a). For GDP the data are from the IEA to 1992 in purchasing power parity prices, and are extended from 1993 to 2005 by the growth rates provided in NBSC (2006b),[1] so as to account for the recent revisions to China's GDP data.[2] The questions are: why did the energy intensity of GDP fall so sharply over the 1980s and the 1990s and what is the most reasonable basis for future projection of it?

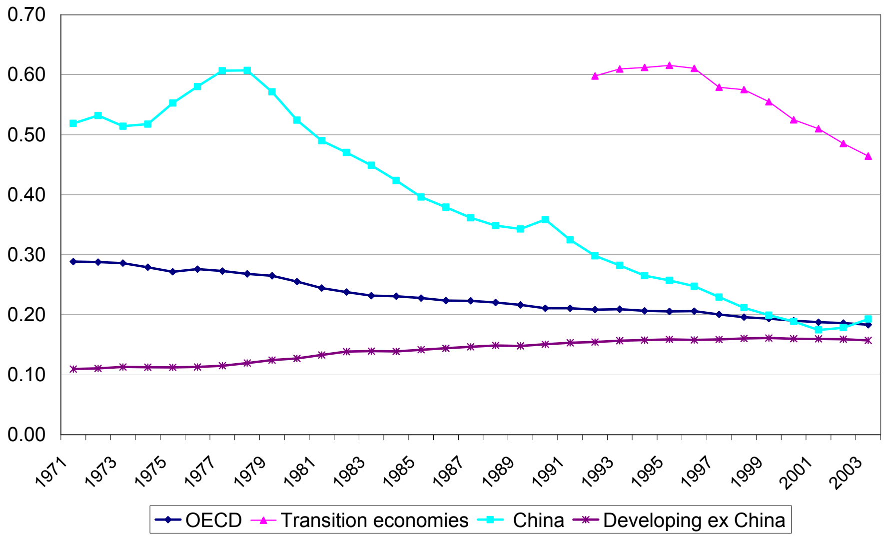
We start from the very high energy intensity of China's GDP in the late 1970s. Figure 1 summarises the IEA data in relation to the energy intensity of GDP over 1971-2002 for three main country groupings and China. Here energy intensity is defined as the ratio of total primary energy supply, measured in million tonnes of oil equivalent, per US$ billion of GDP, measured in 2000 purchasing power parity prices. At its peak in 1978 China's energy intensity of 0.61 mtoe per billion US$ GDP was five times that of other developing countries taken as a whole (0.12) and more than twice that of the OECD countries (0.27). But, given the long decline described earlier, by 2001 China's energy intensity had fallen to 0.175 mtoe per US$billion, below that of the OECD countries (0.187) and close to that of the other developing countries taken as a whole (0.160). The speed and extent of the fall in China's energy intensity is notable also compared to other transition economies (data for which are available only from 1992). For 27 other transition economies as a group, energy intensity in 1992, at 0.60, was close to China's 1978 level and fell to 0.51 in 2001, remaining nearly three times China's level in the latter year. It should also be noted that the fall in energy intensity in China has been almost identical in secondary and tertiary industry – the energy intensity of value added in 2001 being 26% of that in 1980 for the secondary sector and 28% of the 1980 level for

[1] No distortion is introduced into the PPP data by this procedure, for there is virtually no difference in the growth rates of China's real GDP reported in the IEA PPP statistics and in the NBSC data.

[2] In 2005 China's First National Economic Census was undertaken, and the results were released in relation to the reference year of 2004 on 20 December 2005 (NBSC, 2005b). The main result of the census was to increase the recorded level of tertiary sector GDP by nearly 50%, and hence to raise recorded Chinese GDP for 2004 by 16.8%, with 93% of this increase being in the tertiary sector. GDP data on a production basis have been revised back to 1993 (see NBSC, 2006b), and these revised data are used in this paper.

the tertiary sector. In this context, China's long-run reduction in energy intensity is a striking achievement.

Figure 1. Energy Intensity of GDP: China, Other Developing Countries and Transition Economies, actual 1971–2002, mtoe per billion US$ GDP, in 2000 PPPs



Source: IEA database.

The measure used in Figure 1 – aggregate energy use per unit of GDP, measured in constant purchasing power parity prices – is a simple measure that conceals many complexities, both of measurement and aggregation. For example, there are clearly many areas in which China can achieve much increased energy efficiency (NDRC, 2004), and the use of market exchange rates rather than PPPs for GDP would increase China's reported energy intensity, although it would introduce other distortions. High levels of investment in focused policies and management strategies directed at energy efficiency appear to have played a significant role in the process of declining intensity (Lin, 2005), as did the ability to ration energy supply to enterprises still largely under direct government control, and hence to force increase efficiency (Andrews-Speed, 2004). But, as Lin (2005) has shown, investment on energy conservation projects in China has fallen from over 8% of total energy investment over 1981-1995 to only 4% over 1996-2003, and rationing is no longer a viable option in the new economy.

Another key issue in interpreting trends in the 1990s has been data quality. Between 1996 and 1999, according to official figures, real GDP grew by 26.4% but total energy use fell by 1%. Sinton and Fridley (2003) point out there were many problems in the late 1990s with Chinese energy statistics. In 1997 the government began a campaign to close down small, unsafe coal mines, reported that many such mines had been closed and published figures showing that coal production fell by 27% per cent between 1997 and 2000. But there have been continuing doubts about how many of these mines closed, or stayed closed for any length of time. So the reported decline in coal production and consumption over 1997 to 2001 may be overstated, with the very rapid growth since 2002 being in part a return to more accurate reporting. Further, many of those small mines that were in fact closed may have been pressed back into service in the period of high energy demand and energy shortages after 2003.

To attempt an empirical estimate of the importance of the data problems we applied the following test to the data for secondary industry. Assume that, in the period in which intensity is declining as a result of increased operating efficiency, investment in new plant and equipment and energy programs, the rate of decline is greater when the economy is growing more rapidly, both relative to trend rates. More rapid growth provides scope for higher investment in more efficient equipment, and for utilising energy more efficiently over a higher level of output. Secondly, assume that the misreporting of data commences in 1997 and continues with cumulative effect to 2001 before being eliminated over the next three years, so that there is no under-reporting by 2004. On this basis we estimate for secondary industry the following equation:

$$\Delta_T \ln (I_t) = \alpha + \beta \Delta_T \ln (Y_t) + \gamma D_t + \varepsilon_t , \qquad (5)$$

$$\Delta_T \ln (I_t) = \underset{(2.29)}{0.030} - \underset{(4.13)}{0.741} \Delta_T \ln (Y_t) - \underset{(3.50)}{0.0461} D_t, \qquad \bar{R}^2 = 0.49 \qquad (6)$$

with t-values in brackets. The results imply that the model is consistent with the data, explaining 49% of the deviation of ln (I_t) from trend, with the value added variable significant and of the correct sign (when value added is above trend the falls in energy intensity are larger). The dummy variable is significant and implies that, at the peak level in 2001, energy intensity was nearly 15% lower than it would otherwise have been. This simple empirical test thus supports the view of Sinton and Fridley (2003) that data problems might have significantly influenced both the reported decline in energy use over 1996-2001 and the subsequent surge in reported energy use over 2001-2004, but that the data should be clear of the problem by 2004. Making this correction to the 2001 data implies an elasticity of energy use over 2001-2005 of close to one.

Table 6. Elasticity of energy use (TPES) with respect to GDP, developing countries, actual 1971-2002

	Annual GDP growth rate (% pa)			Annual TPES growth rate (% pa)			Elasticity of TPES with respect to GDP		
	1971-2002	1971-1990	1990-2002	1971-2002	1971-1990	1990-2002	1971-2002	1971-1990	1990-2002
China	8.5	7.8	9.6	4.8	5.7	3.4	0.57	0.73	0.35
India	4.9	4.6	5.3	5.6	6.1	4.7	1.15	1.34	0.89
SE Asia	5.4	6.0	4.4	6.9	7.2	6.5	1.28	1.19	1.47
Other	3.1	3.1	3.0	4.5	5.1	3.5	1.46	1.64	1.18
All developing countries	4.7	4.4	5.3	4.9	5.9	3.4	1.04	1.35	0.64

Source: IEA database.

Finally, Table 6 places China's experience in the context of other developing countries. With the exception of India over 1990-2002, the experience of the developing countries has been of an energy elasticity of GDP significantly greater than one. The developing countries in South East Asia, many of whom follow a similar development model to China, have in aggregate had an energy elasticity of 1.28 over 1971-2002, while for 60 developing countries the figure was 1.46. India's energy elasticity over 1971-2002 was 1.15, although it was only 0.89 over 1990-2002. But over that period, India's growth has been driven by the service sector and India has suffered chronic energy shortages (IPC, 2005), so that this is not a representative case.

The evidence assembled here suggests that, while some of the recorded recent rise in energy use reflects data problems from the late 1990s, China will find it difficult to achieve significant further reductions in energy intensity (or an elasticity significantly less that one) in the immediate future. China is still following an energy intensive development strategy, based on exports, investment in fixed assets and rapid growth in secondary industry. Nevertheless, it has brought its energy intensity of GDP down, on one standard measure, to parity with the OECD countries and to close to that of the other developing countries as a whole, so that many of the easier gains have been made. Further, the current round of rapid expansion in China's energy production capability energy investment has taken place in a context of urgency arising from energy shortages, precluding careful exploitation of advanced technologies. Above all, China still faces many of the imperatives of a developing country, with energy use per capita still only 18% of the OECD average and little more than half the global average. The historic and unique phase of rapid growth in a large developing economy with an energy elasticity of only about 0.5 is almost certainly over. Until the economy matures or the development strategy changes, further reductions in energy intensity will need to be achieved through sustained policy initiatives in many areas.

6. A Changed Policy Projection of Energy Use and Co_2 Emissions, China 2002-2030

One way to explore the implications of current trends is to develop a simple projection for energy use and CO_2 emissions from fuel use in China for the period to 2030. This is an unchanged policy projection, and hence is based on an interpretation of the policies in force in 2006, but attempts to take account of the trends described and analysed above.

6.1 Projection Framework

For a given country *i* in year *t*, *n* years from some initial period, real GDP in international purchasing power parity prices (Y_{ti}) is given by:

$$Y_{ti} = Y_0 (1 + \alpha_{ti})^n,$$

where Y_0 is opening period real GDP and α_{ti} is the average annual growth rate of real GDP for country *i* from the initial year to year *t*. The elasticity of energy use with respect to GDP in country *i* over to period to year *t* (ε_{ti}) is defined as the ratio of the average annual rate of growth of total primary energy supply (e_{ti}) to the average annual rate of growth of GDP (α_{ti}). That is:

$$\varepsilon_{ti} = e_{ti} / \alpha_{ti} .$$

Hence the rate of growth of total energy use (e_{ti}) over the period is $\varepsilon_{ti}.\alpha_{ti}$, and total energy use by country *i* in year *t* is:

$$E_{ti} = E_{0i}\,(1 + \varepsilon_{ti}.\alpha_{ti})^{n}. \tag{7}$$

Energy use involves different types of fuels (coal, oil, natural gas and various types of non-fossil and renewable fuel types), each with a different propensity to generate CO_2 emissions. The share of fuel type *j* in total energy use in country *i* (s_{ji}) will vary over time, depending on availability, relative prices, investment patterns, policy initiatives and other factors. The energy use met by fuel *j* in country *i* in year *t* can then be denoted by:

$$E_{tji} = E_{ti} \,.\, s_{tji} = E_{0i}\,(1 + \varepsilon_{ti}.\alpha_{ti})^{n} .\, s_{tji} . \tag{8}$$

Finally, CO_2 emissions per unit of fuel use (m_{tji}) will vary across countries, depending for example on the quality of fuel used and the technological processes involved, and over time within a given country. Total CO_2 emissions from the use of fuel *j* in country *i* in year *t* with then be given by:

$$M_{tji} = m_{tji} \,.\, E_{tji} = m_{tji} .\, s_{tji} \,.\, E_{ti} .$$

Thus total CO_2 emissions in country *i* in year *t* (M_{ti}) are given by:

$$M_{ti} = \sum_{j} m_{tji} .\, s_{tji} \,.\, E_{0i}\,(1 + \varepsilon_{ti}.\alpha_{ti})^{n} . \tag{9}$$

Given this relationship, the projection methodology focuses on four key parameters for a given country or region: α_{ti}, the rate of growth of real GDP; ε_{ti}, the elasticity of energy use (total primary energy supply) with respect to GDP; s_{tji}, the shares of various fuel types in total energy use and m_{tji}, the level of CO_2 emissions per unit of energy supply for different fuel types. In aggregating emissions energy use from fossil fuels only (coal, oil and natural gas) is included, as non-fossil fuel use generates no CO_2 emissions and biomass and waste are excluded by convention.

6.2 GDP Growth Projections (α_{ti})

China has grown 9.8% per annum between 2001 and 2005, following growth of nearly 10% per annum between 1980 and 2001. The available data suggest that strong growth is continuing in 2006, with exports, investment in fixed assets and increases in industrial production driving growth. In projecting that growth forward we assume a gradual moderation of growth to 8% by 2010, a reduction of that growth rate to 7% on average through to 2020, and an annual rate of 6% per annum over 2020-30. This assumption involves a considerable slowing of Chinese growth from its current hectic pace, but continued fairly strong growth over the longer term.

6.3 Elasticity of Energy Use (ε_{ti}) and Total Primary Energy Supply

Consistent with the discussion above, we assume an energy elasticity of one for the period 2006-2010, with a gradual subsequent decline as the economy matures and as current renewable energy and price reform measures take effect, to 0.85 over 2010-20 and to 0.75 over 2020-30. Together with the GDP profile described above, these assumptions imply that growth in TPES in China of 10.6% per annum over 2002-2010, but with growth slowing to less than half that rate (5.2% per annum) over 2010-2030, giving 6.7% per annum growth over 2002-2030. This projection means that China's energy use would increase more than six-fold between 2002 and 2030 and account for more than 30% of global energy use by 2030, as China takes an ever larger share of global production of energy intensive products, as well as providing higher living standards for its people.

6.4 Fuel Use Type (s_{ji}) and Emissions Intensity of Different Fuel Types (m_{tji})

The values for China over the projection period of s_{tji}, the shares of various fuel types in total energy use, and of m_{tji}, the emissions intensity of different fuel types, are based on the values used in IEA (2004), being varied from those estimates only for fuel use by type, where later information and increased knowledge of the emerging energy use path is available. Certain recent trends are clear, although quantifying them in the absence of more detailed information is difficult. Massive expansion of coal production and of coal-fired power stations is under way, so that the coal share of energy use is unlikely to fall significantly over the current decade, in spite of high profile hydro projects such as the Three Gorges dam. There is also clear evidence of fuel substitution away from oil at the present time, although road transport continues to increase rapidly. Currently policy also gives considerable attention to renewables and to nuclear energy, although it will take some time before these are major components of energy use. Thus in the projection the change in the fuel type use profile differs significantly from that of IEA (2004). Coal's share of total energy use by 2030 is higher than in IEA (2004) – 64% in 2030 rather than 59.2% - as is the share of non-fossil fuels - 8% by comparison with 5.8% in IEA (2004), with these increases being mainly offset by a much lower oil share (21% compared to 28.5%). The IEA projections of CO_2 emissions per unit of fuel type use are adopted in full.

Table 7. Summary of Unchanged Policy Projections

	1971	2002	2010	2020	2030	1971-2002	2002-10	2010-20	2020-30	2002-30
						Change over period (% per annum)				
GDP PPP $2000USb	464	5780	11755	23124	41411	8.5	9.3	7.0	6.0	7.3
Total Primary Energy Supply[1] (excluding biomass; mtoe)										
Coal and coal products	192	713	1592	2755	4087	4.8	10.5	5.8	3.9	6.4
Oil	43	253	508	822	1149	6.5	9.7	5.5	4.0	6.1
Natural Gas	3	34	104	257	447	8.9	13.4	8.3	8.1	9.7
Non-fossil	3	31	104	278	702	9.3	16.2	8.1	8.5	10.5
Total	241	1030	2307	4112	6386	4.8	10.6	6.0	4.5	6.7
CO_2 emissions[2] (MtC)	224	997	2165	3858	5820	4.9	10.2	5.9	4.2	6.5
Elasticity of energy use with respect to GDP						0.57	1.14	0.85	0.75	0.92

Notes: [1]Excludes energy from traditional biomass. [2]Includes emissions from cement production.
Source: IEA database and estimates of the authors.

6.5 Emissions Projections

The resulting projections are summarised in Table 7. By 2030 total primary energy use in China is projected to be 6.4 btoe, about 30% of global energy use by that time and implying an increase of 6.7% per annum over 2002-30. With nearly 90% of energy use in 2030 still being provided from fossil fuel sources, in spite of a projected 10.5% per annum growth in energy from non-fossil fuel sources, emissions are projected to grow by 6.5% per annum and to total about 5.8 billion tonnes of carbon by 2030. For reference, total global emissions of CO_2 from fuel combustion and cement in 2000 were 6.4 billion tonnes of carbon.

7. Conclusion

It is apparent from the fate of earlier projections that the current understanding of China's energy system remains limited, as does our ability to project future developments. Data limitations and other factors also preclude the effective use of advanced modelling techniques. Nevertheless a number of things do seem to be clear. One is that the historic era of rapid economic expansion with low growth in energy use has come to an end, and that major reductions in energy intensity will now require new policy initiatives or changes in the structure of the economy. Another is that, since 2000, a striking new phase of China's development has been under way, driven by very rapid growth in exports, investment in fixed assets and in secondary industry. Failing a sharp adjustment in the global economy, this phase of growth seems set to continue through to at least the end of this decade. Given its energy intensive, and indeed coal intensive, character this will imply growth in energy use and in CO_2 emissions from fuel combustion in excess of 10%

per annum over 2002-2010. Longer term projections that involve a halving of these growth rates over 2010-2030 still imply very high levels of energy use and emissions in China by 2030. Such outcomes, if they come to pass, will have major ramifications for world energy markets and for the global climate.

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Appendix

Table A 1. Sectoral Decomposition of Energy Consumption, China, 1980-2005

		Total GDP	Primary industry	Secondary industry	Tertiary industry
		(components of change in energy use, mtce)			
1980-1990					
1. Growth effect	$s_{0i}.\varepsilon_{0i}.\Delta Y_t$	781.1	47.2	535.5	198.4
2. Intensity effects					
Change in intensities, opening sectoral GDP	$\Delta\varepsilon_{ti}.\ y_{0i}$	-202.6	-7.6	-128.4	-66.6
Change in intensities, change in total GDP	$s_{0i}.\Delta Y_t.\ \Delta\varepsilon_{ti}$	-283.5	-10.7	-179.7	-93.1
Total		-486.1	-18.3	-308.1	-159.7
3. Sectoral effects	$\Delta s_{ti}.\varepsilon_{0i}.Y_t$	121.5	-19.5	30.7	110.4
4. Interaction effects	$\Delta s_{ti}.\Delta\varepsilon_{ti}.Y_t$	-57.7	4.4	-10.3	-51.8
Total change in energy consumption		358.9	13.8	247.8	97.3
Annual percent change (%)		5.1	3.5	5.1	5.4
1990-2000					
1. Growth effect	$s_{0i}.\varepsilon_{0i}.\Delta Y_t$	1491.7	77.4	1025.5	388.9
2. Intensity effects					
Change in intensities, opening sectoral GDP	$\Delta\varepsilon_{ti}.\ y_{0i}$	-484.3	-5.0	-372.3	-106.9
Change in intensities, change in total GDP	$s_{0i}.\Delta Y_t.\ \Delta\varepsilon_{ti}$	-787.6	-8.2	-605.5	-173.9
Total		-1271.9	-13.2	-977.8	-280.8
3. Sectoral effects	$\Delta s_{ti}.\varepsilon_{0i}.Y_t$	534.6	-55.8	590.1	0.3
4. Interaction effects	$\Delta s_{ti}.\Delta\varepsilon_{ti}.Y_t$	-342.7	5.9	-348.5	-0.1
Total change in energy consumption		411.7	14.2	289.3	108.2
Annual percent change (%)		3.8	2.6	3.8	3.8
2000-2005					
1. Growth effect	$s_{0i}.\varepsilon_{0i}.\Delta Y_t$	756.0	35.1	523.3	197.6
2. Intensity effects					
Change in intensities, opening sectoral GDP	$\Delta\varepsilon_{ti}.\ y_{0i}$	39.6	0.4	27.6	11.5
Change in intensities, change in total GDP	$s_{0i}.\Delta Y_t.\ \Delta\varepsilon_{ti}$	22.5	0.2	15.7	6.6
Total		62.1	0.6	43.3	18.1
3. Sectoral effects	$\Delta s_{ti}.\varepsilon_{0i}.Y_t$	74.9	-22.0	84.0	12.9
4. Interaction effects	$\Delta s_{ti}.\Delta\varepsilon_{ti}.Y_t$	2.8	-0.1	2.5	0.4
Total change in energy consumption		895.8	13.6	653.1	229.0
Annual percent change (%)		10.9	4.1	11.3	10.7

Source: As for Table 5.