Energy Use in China: Interpreting Changing Trends and Future Directions

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ABSTRACT

Energy use grew at only half the rate of GDP growth in China over 1980-2001, but has grown faster than GDP over 2001-06. This paper explores the reasons for that change, and its implications for China's future energy use and energy policy. Based on the existing literature and a new decomposition analysis, we find that structural change increased energy use over the whole period. But sectoral energy intensities fell sharply over 1980-2000, mainly due to strong incentives for technical change and increased energy efficiency in a command economy with energy rationing, supplemented by rising relative energy prices in the 1990s. With the command economy mechanisms supplanted by the reforms of the late 1990s and rapid growth in energy intensive industries after entry to the WTO in 2001, China has reverted to the normal developing economy case of an elasticity of over one. Based on a simple projection model, we find that, on the policies in force in 2005, China's energy use and CO_2 emissions from fuel combustion are likely to grow by more than 6% per annum over 2005-30. But the Government is now actively implementing a wide range of policies to reduce the growth in energy use. Our simulations indicate that achieving major reductions will be difficult, but that a sustained policy process involving use of the full range of instruments could reduce China's energy use and CO_2 emissions by 35-40% by 2030.

1. INTRODUCTION

Since China's entry into the World Trade Organisation in 2001 energy use has grown very rapidly - over the five years 2001-06 total energy consumption grew by 71.5% (11.4% per annum), with GDP growth of 10.0% per annum. This explosive growth in energy use was in sharp contrast with earlier trends. From the 'opening to the market' in 1979 to 2001 energy use grew at a much lower rate than GDP, with average rates of growth of 4.1% and 9.7% for energy use and GDP respectively, implying that the energy intensity of China's GDP fell continuously through to 2001 and that the elasticity of energy use with respect to GDP was less that 0.5 on average over the period (Figure 1). This decline in reported 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, and led to severe shortages in 2003 and subsequent years.

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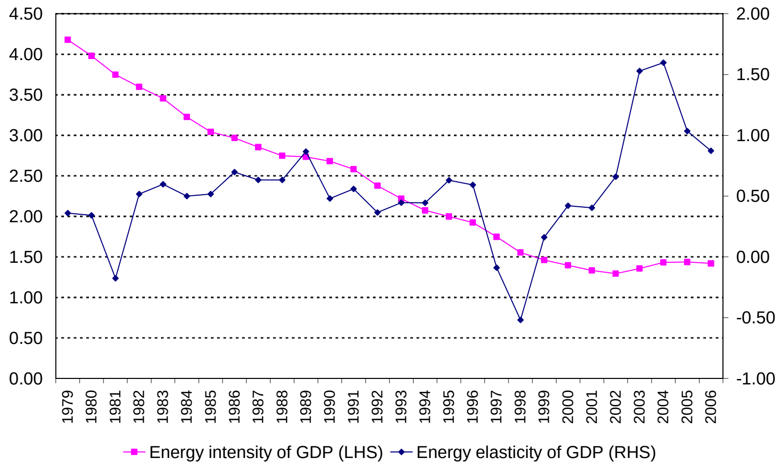
This apparent structural shift in the relationship between GDP growth and energy use in China raises serious questions in several areas. Is this a temporary aberration or a fundamental structural shift, and if so what has caused it? What basis should we use to interpret China's likely future energy demand on existing policies? What policies are likely to be most effective in reducing the rate of growth of China's demand for energy, in the light of this shift? What does this apparent shift mean for China's future emissions of greenhouse gases, especially CO_2 from fuel combustion? Given that China accounted for 14.7% of total world primary energy consumption by 2005 (BP, 2006) and is the world's largest user of coal, understanding this change and its implications for prospective energy use in China is of considerable importance, both for China's development strategy and for the global community.

Figure 1. Energy Intensity and the Energy Elasticity of GDP, China, 1979-2006



Note: Energy intensity is measured in terms of units of energy use (in hundred thousand tons of standard coal equivalent) per unit of GDP (in billion yuan in 2000 values).
Source: NBSC (2006; 2007).

The importance of understanding these issues is highlighted by reviewing the existing projections of China's energy use over the next 15-25 years. Most of the existing projections assume that, on unchanged policies, the elasticity of energy use with respect to GDP will return to 0.5-0.7 over the projection period (see Table 1). Internationally, the most well-known projections are those of the International Energy Agency (IEA), published in its biennial *World Energy Outlook*. In the 2006 edition, with an assumed average growth rate of GDP (in constant purchasing power parity prices) of 5.5% per annum over 2004-30, the IEA projected growth of only 3.2% per annum in total primary energy use (TPES) in China over that period (IEA, 2006), with a growth rate of 4.5% over 2004-2015 falling to 2.2% over 2015-2030. This implies an elasticity of energy use with respect to GDP of 0.58 over 2004-30, and that the TPES growth rate for China over 2004-2030 will be little more than half its rate over 1971-2002 (5.5%). Similar results from projections from other international groups are shown in Panel A of Table 1.

Table 1. Recent International Projections of Primary Energy, China

	Timeframe	Growth in primary energy use (% pa)	Long-run energy elasticity of GDP
Panel A: Independent Projections			
ERI/LNBL (2003)	1998-2020	3.8	0.54
EIA International Energy Outlook (DOE) (2006)	2003-2030	4.2	0.70
IEA World Energy Outlook (2004)	2002-2030	2.6	0.52
IEA World Energy Outlook (2006)	2004-2030	3.2	0.58
Panel B: China National Energy Strategy and Policy to 2020 (NDRC 2004)			
Scenario A – Existing Policy	2000-2020	4.7	0.64
Scenario B – Alternative Policies	2000-2020	4.1	0.54
Scenario C – Advanced Policies	2000-2020	3.3	0.40

Sources: References cited in the table.

Within China, the main projection exercise has been that coordinated by the National Development Research Center (NDRC) of the State Council, which assembled leading energy research institutes in China to prepare a National Comprehensive Energy Strategy and Policy for China. This strategy was released in Chinese in 2004, with an abridged English version also being released (NDRC, 2004; see also Dai and Zhu, 2005). It 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 over 2000-2020 of 4.7%, implying an elasticity of energy use of 0.64, with lower rates of growth in TPES for the two policy scenarios (see Panel B of Table 1).

Although the NDRC unchanged policy projection contains a significantly higher rate of growth in energy use than the other projections, Table 2 shows clearly that energy use in China is expanding much more rapidly than envisaged in scenario A. In terms of the main aggregate indicator, primary energy consumption, the actual 2006 figure is about 15% above the 2010 projection. For electricity generating capacity the actual for 2006 is 11.2% above the projection for 2010, while coal use in 2006 was 19% above the projected 2010 level. Oil consumption was broadly in line with the projection, with growth in demand slowing sharply in 2005, as higher oil prices impacted on demand and led to fuel substitution, but usage of natural gas in 2005 was 25% higher than the projected figure.

Table 2. Projections for Selected Variables, Scenario A, National Comprehensive Energy Strategy and Policy to 2020, and Actual Values for 2005 and 2006

	Actual	Strategy Report – Scenario A			Actual	Actual
	2000	**2005**	**2010**	**2020**	**2005**	**2006**
Primary energy demand (mtce)	1297	na	2137	3280	2223	2460
Electricity generation capacity (GW)	319	402	559	947	505	622
Demand for fossil fuels						
Coal (100 m tons)	12.7	16.2	20.0	29.0	21.4	23.7
Oil (100 m tons)	2.3	2.9	3.8	6.1	3.0	3.2
Natural gas (100 m cubic metres)	272	399	840	1654	500	556
Output of main energy intensive products						
Iron and steel (m tons)	128.5	250	300	280	353	423
Cement (m tons)	597	680	790	1070	1060	1235
Ethylene (10,000 tons)	450	790	1200	2000	756	941
Synthetic ammonia (10,000 tons)	3346	3600	3800	4000	4596	na
Paper (10,000 tons)	2487	4000	5000	7500	5670	6804

Sources: For actual 2000 and strategy report values see NDRC (2004). Actual data for 2005 are from NBSC (2006) and for 2006 are from NBSC (2007), except for electricity generation capacity; the figure for electricity generation capacity is an official one (People's Daily Online, 2007).

Table 2 also illustrates one of the main reasons for growth in energy demand ahead of the projection. It shows the actual output data for 2005 and 2006 for five energy intensive industries for which output projections were provided in the NDRC report. Clearly output is running well ahead of expectations in these industries: for three industries (iron and steel, cement and synthetic ammonia) output in 2006 (in 2005 for ammonia) was ahead of the 2020 projected level, while paper production in 2006 was closer to the 2020 than to the 2010 projection. Consistent with these data, many observers (e.g. CASS, 2007) believe that a structural shift towards energy intensive industries is the main reason for rapid growth in energy use since 2001.

The Chinese Government has expressed concern about the economic, environmental and social impact of continuing high rates of growth of energy demand. In the 11th Five Year Plan (2006-10) the Government included as a priority target a reduction of 20% in energy use per unit of real GDP over the five-year period (Wen Jiabao, 2006). The precise implications of this target for the growth in energy use and the energy elasticity of GDP depend on the rate of growth of GDP achieved, but the implied elasticities range from 0.41 with 8% per annum GDP growth to 0.52 with 10% growth. Thus the current target also implies a return to the elasticity levels achieved over the 1979-2001 period.

The strategy adopted in this paper to throw light on these important questions is as follows. We start in Section 2 by reviewing the literature on the decline in China's energy use per unit of GDP over 1980-2001, covering both decomposition analysis and other studies of the reasons for this decline. Section 3 reviews some of the data constraints on energy studies in China and outlines the methodologies to be used in our empirical analysis. In Section 4 we report the results of decomposition analyses for the full 1980-2005 period, using two different datasets, one of which involves some disaggregation of the industrial sector, and assess the reasons for the return to higher elasticities of energy use after 2001. In Section 5 we use the more detailed data set to construct a simple model of China's energy use and CO_2 emissions, and use it to generate an unchanged policy projection of these variables to 2030 and to assess the potential impact of various policies to reduce energy use. Conclusions are summarised in Section 6.

2. UNDERSTANDING THE DECLINE IN ENERGY INTENSITY, 1980-2001

The Structural Change or Sectoral Intensity Debate

Much of the literature on the decline in aggregate energy intensity in China over 1980-2001 has focused on the structural change/energy efficiency issue: is this decline mainly due to a shift in the structure of activity towards less energy intensive sectors (such as light industry or services) or does it mainly reflect reduced energy use per unit of value added in individual sectors of the economy?[1] It is widely recognised that the answer to this question is sensitive to the level of disaggregation, in an asymmetric sense. At any given level the contribution of changing sectoral intensities may be overstated, as these may result from compositional change at lower levels. Hence, especially with fairly high levels of aggregation, it needs to be recognised that the results may be biased towards changing intensities, with the contribution of structural change underestimated.

Early discussion of these issues placed considerable emphasis on the role of structural change. Sinton and Levine (1994) and Garbaccio et al. (1999) report work undertaken within the Energy Research Institute in China in relation to the 6th Five Year Plan period (1981-85), which found that one half of energy savings were due to structural changes, evaluated at very detailed levels of disaggregation, with one-third due to improved energy efficiencies and the balance due to imports of energy intensive products. Smil (1990) and Kambara (1992) reported similar conclusions, and in 1993 the World Bank concluded that 55-65% of energy savings were due to structural factors over the 1980s (World Bank, 1992).

By contrast, the pioneering papers in the international literature applying decomposition methodologies to detailed data sets – Lin (1991), Lin and Polenske (1995), Huang (1993) and Sinton and Levine (1994) – all emphasised the reduction in sectoral intensities as the central factor in the fall in overall energy intensity in China in

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[1] This question is often framed in terms of a structure/technology distinction, where the effects of technological change are measured in terms of changes in energy use per unit of output within sectors. We use more general terms such as energy intensity or energy efficiency for this within-sector effect, and leave open the question as to whether a given reduction in energy use per unit of output is due to technological change or other factors.

the 1980s (see Table 3). Lin and Polenske studied the overall economy on the basis of 18 sectors between 1981 and 1987, and found energy efficiency changes somewhat greater than total energy savings, implying a small increase in energy use from structural factors. Huang focused on a six-sector decomposition of the industrial sector for 1980-88, finding that at this level increasing sectoral efficiencies was the dominant effect.

Sinton and Levine studied energy use in the industrial sector through a careful analysis of three different databases. For the period 1980-85 they found that sectoral energy intensity effects accounted for 72% of energy savings with an 11 sector database and 58% with a 267 sub-sector breakdown, and concluded that about two-thirds of the energy savings were due sectoral effects in the second half of the 1980s also. Garbaccio et al. (1999) extended this analysis by a study based on the input-output tables for 1987 and 1992, using 29 sectors across the whole economy. For this period they found that sectoral intensity effects accounted for most of the reduction in aggregate energy intensity, with structural change actually increasing the use of energy.

Table 3: Structural Change or Increasing Energy Efficiency in China? Selected Studies

Study	Period covered	Data and methods used	Overall result
Kambara (1992)	1980-90	1980-90; analysis of broad sectoral data	Over half intensity change due to structural shift (to services and light industry)
World Bank (1993)	1980-90	Structural shift analysis at fine levels of aggregation	55-65% due to structural shifts
Huang (1993)	1980-88	Divisia method for six industrial sectors	73-87% due to change in sectoral intensities
Sinton and Levine (1994)	1980-90	Laspeyres method for three detailed industrial data sets within 1980s	58-85% due to change in sectoral intensities
Lin (1991) and Lin and Polenske (1995)	1981-87	Full economy (18 sectors); use of input-output tables and Laspeyres decomposition	All intensity change due to change in sectoral intensities
Garbaccio et al. (1999)	1987-92	Full economy (29 sectors); use of input-output tables and Divisia decomposition	Most change due to sectoral intensities, and to imports; structural effect positive
Zhang (2003)	1991-97	Modified Laspeyres analysis of 29 industrial sectors	88% of energy intensity savings from sectoral effects
Fisher-Vanden et al. (2004)	1997-99	Divisia analysis of 2582 larger industrial enterprises: panel regression analysis at firm level	At firm and 4-digit industry level, sectoral shifts and higher energy efficiencies each for about 50% of the decline
Steenhof (2006)	1998-2002	Modified Laspeyres analysis of electricity use in 37 industrial sectors	Energy efficiency the dominant factor in changes in electricity intensity

More recent studies have focused primarily on the 1990s. Zhang (2003) examined value added and energy use in 29 industrial sectors for the period 1991-97, and found that the predominant trends of the 1980s – that overall energy savings were mainly due to reduced sectoral intensities – prevailed also in this period, accounting for 88% of reduced energy use per unit of value added in industry. Fisher-Vanden et al. (2004) took a different approach for the period 1997-1999, undertaking both a decomposition and a panel regression analysis of output and energy use in 2582 large and medium-sized Chinese industrial enterprises. This approach is especially interesting as it uses firm-level data for a period (1997-99) for which China's aggregate energy data are regarded as unreliable (Sinton and Fridley, 2002), and because it enables the decomposition analysis to be undertaken at different levels of disaggregation. They find that at both the four-digit industry and the firm level the contributions of falling sectoral intensities and structural change are approximately equal, with structural change accounting for 52.9% of energy savings at the firm level over 1997-99. In terms of the reduction in energy use per unit of output at the firm level, they find that rising relative energy prices, R&D and ownership form were the principal causal factors. Finally, Steenhof (2006) analysed the demand for electricity in 37 industrial sectors over 1998-2002, and found that reduced sectoral intensities accounted for almost all of the reduction in electricity use per unit of value added (after adjusting for effects due to fuel use shifts).

These various studies are heavily constrained by data issues, and report results for different sub-periods within 1980-2002. But in spite of their diversity, all of the studies cited from Huang (1993) onwards find a major role for reduced energy intensities at the sectoral level, even allowing for the fact that this role may be overstated in high level studies. In terms of structural effects the results are much more mixed, with some studies finding negative effects of structural change on overall energy intensity but others (such as Lin and Polenske (1995) and Garbaccio (1999)) finding positive effects.

Explaining the Decline in Energy Intensity, 1980-2001

Much of the literature cited above does not address the underlying reasons for the increased energy efficiency within sectors in China over 1980-2001. In the broader literature three main reasons have been given for these sectoral effects: the impact of rationing and energy conservation programs in a planned economy with an initial high level of energy use and limited growth in energy supplies; the impact of technology, broadly defined, on energy use; and the impact of higher energy prices on the demand for energy.

In the 1980s the Chinese economy remained a planned economy, with most industrial output coming from state-owned enterprises. Energy prices and energy quotas for enterprises were under direct government control, energy use per unit of output was very high and energy supplies were limited (Sinton and Levine, 1994; Sinton et al., 1998; Andrews-Speed, 2004). In the early 1980s the Government established some major energy conservation programs, together with new institutions to administer them, and these continued to be important well into the 1990s (Sinton et al., 1998; Lin, 2005). Lin points out that investment in energy conservation in China averaged about 11% of energy infrastructure investment over 1981-84 and about 7.5% of that investment over 1991-1995, but fell to less than 4% over 1996-2000. This mix of planning controls, quotas and energy conservation programs in a context of energy scarcity clearly provided a powerful incentive for enterprises to reduce energy use: if the quota was exceeded the supply of energy was simply cut off, while supportive programs were available to reduce energy consumption before this occurred (see also CASS, 2007).

Many authors have interpreted the falling sectoral intensities as a technology effect, and it is clear that after 1980 the technological level of Chinese enterprises increased rapidly as new plants embodied technologies closer to international best practice than those inherited from the pre-1980 period. Many studies have documented the improved technological level of Chinese enterprises (e.g. NDRC, 2004). As Sinton et al. (1998) point out, in China this improved technology was likely to reduce energy use per unit of output in two ways: better technology would reduce the energy required to make a given physical product, but would also improve the quality (and hence the value in constant prices) of the physical product relative to that produced in the planned economy. Thus the numerator would be reduced and the denominator increased, augmenting the reduction in energy use per unit of real output or value added.

Fisher-Vanden et al. (2004) estimate a price elasticity of 0.368 for energy use in 1997-99, by panel regression across the firms within their overall sample for which data are available for all three years. They find that the change in relative prices explains 54% of the decline in aggregate energy intensity over this limited period. Time series data on relative prices is limited for China, but Table 4 provides summary data for the ex-factory prices for power, coal and petroleum relative to the general ex-factory price index, together with a constructed weighted relative price index for energy. During the 1980s relative prices for all energy products fell, but during the 1990s they rose strongly and consistently. Thus while there can be no overall relative price role in reducing energy intensities in the 1980s, it is likely that this was an important factor during the 1990s.

Table 4: Ex-Factory Prices for Power and Coal, Relative to the Ex-Factory Price for all Output, China, 1980-2005

	Power prices	Coal prices	Petroleum prices	Weighted average energy prices
		(per cent per annum)		
1980-90	-2.4	-0.4	-0.2	-1.2
1990-2000	6.9	3.7	13.9	7.9
2000-05	0.2	9.6	6.8	5.6

Sources: NBSC (2006) and NBSC (2000).

Thus our interpretation of the literature is that, during the 1980s, the fall in sectoral intensities is to be ascribed to a combination of both energy conservation programs and technological change being driven by a planned economy with energy rationing. In the 1990s those factors continued to be of importance, while rising relative energy prices also began to play a significant role as the economy was freed up. The literature does not give an unequivocal answer as to the role of structural change in reinforcing or partially offsetting these declining sectoral intensities.

3. DATA AND METHOLOGY

Data Issues

The key requirements for an energy decomposition analysis are real value added and energy consumption by industry. Most of the studies referred to above use the gross value of production as the output variable, because of the difficulties of obtaining data on value added by industry. But value added, which excludes inputs to the production process, is much to be preferred as the output variable, as the energy embodied in inputs to production is not counted as energy consumption by the industry in question, and may change significantly over time as the structure of production changes. The Chinese national accounts data provide consistent real value-added series for six sectors (agriculture, industry, construction, transport, storage and post, wholesale and retail trade, and other tertiary industries) for the full 1980-2005 period, consistent with the revisions to the national accounts as a result of the National Economic Census in 2004 (NBSC, 2005). But with over 60% of China's energy use taking place in industry (excluding construction but including mining) it is important to disaggregate this sector, and here problems arise.

Value-added data by detailed industry are available only from 1994, in current prices and for 'designated enterprises', the criteria for which changed in 1998. Prior to 1998, this description covered all enterprises with an independent accounting system which were owned or regulated at or above the township level, whereas from 1998 it covered all state-owned enterprises (SOEs) with an independent accounting system and all non-SOEs with an independent accounting system and annual sales revenue in excess of 5 million yuan (Holz and Lin, 2001). The independent accounting system test is common to both periods, so the critical change is from being owned or regulated at the township level or above before 1998 to being either an SOE or having sales over 5 million yuan after 1998. As Holz and Lin point out, the gross value of production of designated firms by the pre-1998 test amounted to over 90% of that for all industry in 1980, but fell to only about 60% in 1997, prompting the change. While there seems to have been little impact of the change on this share in 1998, the effect of moving to a fixed monetary limit was to increase the coverage of 'designated enterprises' as both inflation and rapid growth eroded the impact of that limit. By 2004 this ratio had recovered to be over 90%, and a similar pattern is evident for value added.[2] This means that studies that use either gross value of production or value added for designated firms in relation to total energy use by industry may generate seriously misleading results.

The methodology adopted to assemble real value added by detailed industry is as follows. The starting point is three data sources: the current price series on value added by industry for designated enterprises for 1994-2005; total industry value added for all enterprises from the national accounts for 1994-2005, together the implicit

[2] Being data collected from a specific group of enterprises, it must be assumed that these data do not reflect the additional industrial output detected in the 2004 National Economic Census. As the denominator of this ratio incorporates the post-2004 adjustments, the value of the ratio in recent years will also reflect these adjustments to the aggregate data for industrial value added. The major part of the increase in value added detected in the 2004 Census was, however, in the services sector.

price index for this aggregate; and gross industry output value (GIOV) data for all industries for 2004 and for designated enterprises in 2003 and 2005.[3] The relationship for individual industries between the output data for designated enterprises and for all enterprises in 2003-05 is used to gross up the value-added data for designated firms over 1994-2005 to create industry value-added estimates consistent with the national accounts total. Value added for each industry is then deflated by the overall price index for industrial value added. With data on energy consumption by sector available from successive years of the *China Statistical Yearbook*, this allows the series for energy consumption per unit of value added to be constructed.

Within the industrial sector, we concentrate on six industries (mining, petroleum and coking, chemicals, non-metal mineral products, ferrous metals and non-ferrous metals) which together accounted for 78% of China's industrial energy use in 2005, along with separate categories for other manufacturing and for electricity, gas and water. With the other five broader sectors, there are energy intensity data for 13 sectors over 1994-2005.

Decomposition Methodologies

As noted above, decomposition analysis has been widely used to interpret changes in energy intensity in China. Ang and Zhang recently surveyed 124 international studies using decomposition techniques in energy and environmental analysis (Ang and Zhang, 2000). Although many variants are employed, most studies use one of three methods: a Laspeyres approach using base year weights, an arithmetic mean Divisia approach, in which the weights in the Divisia formula are approximated by an average of initial year and final year values, and the input-output decomposition methodology which is an elaboration of the Laspeyres approach in an input-output context. Each of these three methods is represented in the China studies noted in Table 3.

Ang and Zhang reviewed the various decomposition methods and the problems they face (particularly the issue of a residual and of handling zero numbers), and assessed them in the context of index number theory. They concluded that two approaches which both give a complete decomposition are to be preferred, although there was little to choose between them. One is the Divisia index using logarithmic means of the opening and closing values as the weight, where the logarithmic mean of two positive numbers x and y is given by:

$$L(x, y) = (y - x) / \ln(y/x).$$

Using E_{it} as the energy use in sector i in period t (where T is the closing period), Y_{it} as output in i at t and S_{it} as the share of total output in sector i in t, the change in overall energy intensity due to structural change (ΔI_{str}) is given by:

[3] GIOV for designated enterprises has not been published for 2004, so the average of 2003 and 2005 is used.

$$\Delta I_{str} = \sum_i L(E_{iT}/Y_T,\ E_{iO}/Y_O)\ \ln(S_{iT}/S_{iO}), \tag{1}$$

and the change due to changes in sectoral intensities (ΔI_{int}) is given by:

$$\Delta I_{int} = \sum_i L(E_{iT}/Y_T,\ E_{iO}/Y_O)\ \ln(I_{iT}/I_{iO}). \tag{2}$$

The other preferred method is the refined Laspeyres method proposed by Sun (1998). In this approach the normal Laspeyres residual, the interaction term, is distributed equally between the two effects, on the principle of 'jointly created and jointly distributed'. Then the structural change effect (ΔI_{str}) is given by:

$$\Delta I_{str} = \sum_i (S_{iT} - S_{iO})\, I_{iO} + \tfrac{1}{2} \sum_i (S_{iT} - S_{iO})(I_{iT} - I_{iO}) \tag{3}$$

and the sectoral intensities effect (ΔI_{int}) is given by:

$$\Delta I_{str} = \sum_i (I_{iT} - I_{iO})\, S_{iO} + \tfrac{1}{2} \sum_i (S_{iT} - S_{iO})(I_{iT} - I_{iO}). \tag{4}$$

Both of these preferred methods are used in the empirical analysis below.

The Projection Model

Studies of the demand for energy frequently use a standard framework such as:

$$E_{it} = f(Y_{it}, P_{it}, Z_{it}), \tag{5}$$

where E_{ti} is the demand for energy in industry sector i in period t, Y_{it} is an income or output variable relevant to sector i, P_{it} is the relative price of energy in sector i in period t, and Z_{it} is a vector of other variables affecting energy demand in sector i, such as technological change and government policy initiatives related to energy conservation. Assuming that from 2006 onwards supply constraints on energy demand in China have been removed, so that actual energy use can be treated as demand determined, we use this framework to construct the projection model for China, applying it to the 13 sectors outlined above. In a log-linear specification (5) becomes:

$$\mathrm{Ln}(E_{it}) = \alpha_{it} \ln Y_{it} + \beta_{it} \ln P_{it} + \gamma_{it} \ln Z_{it}, \tag{6}$$

where α_{it}, β_{it} and γ_{it} are the elasticities of energy use with respect to Y, P and Z respectively. Partial differentiation of (6) with respect to time and rearrangement gives:

$$\delta E_{it} = \alpha_{it}\, \delta Y_{it} + \beta_{it}\, \delta P_{it} + \gamma_{it}\, \delta Z_{it}, \tag{7}$$

where in the projection model the change variables (δE etc.) represent rates of change with respect to time.

To enable examination of issues concerning the impact of the pattern of growth on energy use, we define two new elasticities relating the rate of growth of value added in sector *i* in period *t* to the growth rate of a higher level variable: A_{it}, the ratio of the growth rate of value added in aggregate sector *i* in period *t* to growth in total GDP in that period and I_{it}, the ratio of the growth rate of value added in industry sector *i* in period *t* to growth in total industry value added in that period (for the eight sectors within industry). Thus A_{it} defines the pattern of growth across the six aggregate sectors for a given rate of growth of aggregate GDP, and I_{it} defines the pattern of growth across the eight industry sectors for a given rate of growth of industry value added. That is:

$$\delta Y_{it} = \delta Y_t \, . \, A_{it} \, . \, I_{it} \, , \tag{8}$$

where A_{it} takes a value of one if *i* is a disaggregated industry sector and I_{it} takes a value of one if *i* is an aggregate sector.

Substituting (8) into (7), converting growth rates into levels and aggregating over sectors gives the following expression for total energy use in China in period *t*:

$$E_t = \sum_i E_{t-1} (1 + \alpha_{it} \, \delta Y_t \, . \, A_{it} \, . \, I_{it} + \beta_{it} \, \delta P_{it} + \gamma_{it} \, \delta Z_{it}). \tag{9}$$

Energy use involves different types of fuels (coal, oil, natural gas and various types of non-fossil and renewable fuel types), and each of the fossil fuels has a different propensity to generate CO_2 emissions. The share of fuel type *j* in total energy use in China (s_j) will vary over time, depending on availability, relative prices, investment patterns, policy initiatives and other factors. The energy use met by fuel *j* in year *t* can then be denoted by $E_{tj} = E_t \, . \, s_{ti}$. Finally, CO_2 emissions per unit of use of fuel *j* (m_{tj}) in China will also vary over time, depending for example on the quality of fuel used and the technological processes involved. Total CO_2 emissions from the use of fuel *j* in year *t* with then be given by:

$$M_{tj} = m_{tj} \, . \, E_{tj} = m_{tj} . \, s_{tj} \, . \, E_t \, . \tag{10}$$

The model comprising equations (9) and (10) is used below to analyse and project China's future energy use and CO_2 emissions from energy use, given suitable projections or assumptions for the many parameters involved.

4. ECONOMIC STRUCTURE AND SECTORAL INTENSITY IN CHINA'S ENERGY USE, 1980-2005

The results of the decomposition analysis for the two different datasets and for the two preferred decomposition methods for various periods are summarised in Table 5. The energy use variable excludes energy from traditional biomass and waste, and the electricity, gas and water industry is excluded from the more detailed decomposition analysis. The results for the logarithmic Divisia method and for the revised Laspeyres method are very similar in all cases.

The six sector results show a very similar pattern for both the 1980s and the 1990s – a rise in overall energy intensity from a structural shift to more energy intensive industries much more than offset by the decline in sectoral intensities. A shift out of agriculture towards industries with higher energy intensities (mainly industry but also other tertiary industries[4]) contributed an increase of 0.4-0.5 percentage points to the overall level of energy intensity in each decade. But the fall in sectoral intensities led to a reduction of over 2 percentage points in the 1980s and of about 1.7 percentage points in the 1990s. A fall in energy intensity is evident across all six sectors over the two decades, with the decline particularly marked in industry (78%), construction (72%) and other tertiary industries (87%). This pattern is also evident at the twelve sector level over 1994-2001, with the relative importance of declining sectoral intensities even more pronounced. A sharp decline in energy use per unit of value added is evident across all sectors except petroleum processing and coking, where the intensity rose, and agriculture and wholesale and retail trade, where there was only a small decline.

Table 5. Components of Increase in Energy Intensity, China, Selected Periods, 1980-2005

	Six sector decomposition			Twelve sector decomposition	
	1980-90	1990-2000	2000-05	1994-2001	2001-2005
	(Change in energy intensity of GDP – percentage points)				
Logarithmic Divisia method					
Structural component	0.49	0.41	0.06	0.04	0.13
Intensity component	-2.19	-1.70	-0.03	-0.82	0.02
Total	-1.69	-1.29	0.03	-0.79	0.16
Revised Laspeyres method					
Structural component	0.55	0.46	0.06	0.04	0.13
Intensity component	-2.24	-1.75	-0.03	-0.83	0.02
Total	-1.69	-1.29	0.03	-0.79	0.16

Sources: Estimates of the authors, based on data from NSBC (2005a) and NSBC (2006a).

The picture is quite different in recent years. At the six-sector level there are some continuing structural effects contributing to rising energy intensity (arising from the rise in the industrial share of GDP from 40.4% to 42.9% over 2000-05, and contributing 0.06 percentage points to the overall energy intensity), but only a very small negative contribution from declining sectoral intensities. For twelve sectors and the period 2001-05, the structural effect is more pronounced (driven by an increasing share for most of the energy intensive industries covered) and the change in sectoral intensities makes a small

[4] Measured at 2000 values, the value added share of agriculture fell from 40.8% in 1980 to 14.8% in 2000 while the share of industry rose from 27.4% to 40.4% and that of other tertiary industries rose from 11.6% to 22.2%.

positive contribution to the overall intensity level. In both cases, while the structural effect remains significant, the dominant effect in relation to trends in the previous decades is the cessation of the large negative contribution of sectoral intensities. Over 2001-05, energy use per unit of value added rose in 8 of the 12 industries, but continued to fall substantially in some energy intensive sectors, such as mining, petrochemical process and iron and steel production.

As noted above, our interpretation of the literature is that several inter-related factors were responsible for the widespread fall in sectoral energy intensities over 1980-2000: a combination of energy rationing and strong energy conservation programs in a planned economy with limited energy supplies; ongoing technological upgrading, in part spurred by these circumstances; and, in the 1990s, the impact of rising relative prices for energy. But by the end of the 1990s fundamental changes in the structure, ownership and operation of Chinese industry, including in the energy sector, had taken place, so that the mechanisms of the planned economy were no longer relevant. Energy use per unit of GDP had been reduced by two-thirds between 1980 and 2000, and much technological upgrading had taken place. But without the control mechanisms of the planned economy further major reductions in energy intensity could only be achieved by market forces and by strong policy initiatives. There are many reasons why, in developing countries, energy is normally a superior good[5], as the development process shifts the pattern of production and of lifestyles towards more energy intensive activities and products. Beyond the command economy, strong market and policy effects would be needed in China to offset this development effect.

In the aftermath of China's entry to the WTO in 2001 demand for China's products was very strong, the supply of energy increased rapidly and the policy focus on energy efficiency was limited. With structural effects contributing to rising energy use and the command economy mechanisms generating falling sectoral intensities no longer operational, it is not surprising that an aggregate energy intensity of one or more re-emerged. This analysis implies that, going ahead, there is no reason for expecting a return to an aggregate energy elasticity of 0.5-0.6 to emerge 'naturally'; achieving an aggregate elasticity well below one will need to be hard won by sustained policy initiatives, especially while structural change continues to contribute to increased energy use.

5. PROJECTIONS OF CHINA'S ENERGY USE AND CO_2 EMISSIONS TO 2030

As outlined in Section 3, we use a simple model consisting of equations (9) and (10), namely:

$$E_t = \sum_i E_{t-1} (1 + \alpha_{it} \delta Y_t . A_{it} . I_{it} + \beta_{it} \delta P_{it} + \gamma_{it} \delta Z_{it}) \qquad (9)$$

[5] For example, for eight countries of South East Asia (excluding China) the unweighted mean elasticity of energy use with respect to GDP over 1971-2002 was 1.12, while for another 61 developing countries for which data are available the unweighted mean elasticity over this period was 1.45 (IEA 2006 database). These figures exclude traditional biomass energy, as do the figures used for China.

$$M_{tj} = m_{tj} . E_{tj} = m_{tj}. s_{tj} . E_t , \qquad (10)$$

to project China's energy use over 2006-2030 and to undertake a preliminary analysis of policy options. Equation (9) is an energy demand equation, and its use is based on the premise that after 2006 energy supply constraints in China have been removed so that energy use is demand determined. In this section we summarise the assumptions and parameters used in the unchanged policy projection, based on an interpretation of policies in place in 2005, and in the policy analysis, before outlining the projection results. In view of the adoption of the target of a 20% reduction in aggregate energy intensity in the 11th Five Year Plan, the policy environment in China has been in flux in 2006 and 2007; new initiatives implemented in these years are included in the policy options cases. The policy stance in 2005 is interpreted as one of continued but modest efforts to contain energy use and CO_2 emissions from fuel use, through the introduction of market mechanisms, of increased energy prices and of programs to encourage energy conservation and the use of advanced technologies.

Four intermediate policy variables are included in the model: the rate of growth in value added in industry relative to that of overall GDP; the industry composition of the growth in industrial output; the rate of growth of energy prices relative to general output prices; and the reduction in energy use from programs to promote energy conservation and the adoption of new technologies. We distinguish these policy variables from the specific policy instruments (such as export tariffs, energy taxes or R&D subsidies) that might be used to achieve a given value of the policy variable; policy instruments are not addressed here. Two alternative policy cases are constructed, one in which both the relative role of industry in total output and the role of energy intensive industries in industrial output are reduced rapidly (the 'new industry structure' case), and another in which, in addition to this, there is a more rapid increase in relative energy prices and more aggressive action to promote energy conservation and the use of new technologies (the 'full strategy' case). The full set of assumptions and parameter specifications is provided in Table 6 and described briefly below.

GDP growth rate (ΔY_t). We assume that, following growth of 10.0% per annum between 2001 and 2006, existing policy achieves a gradual moderation of growth to 7.5% over the five years to 2011, with further reductions in the growth rate of 0.5 percentage points per five-year period to 2030. This implies an average rate of growth of 7.1% over 2006-2030, consistent with a reduction in the rate of growth as the Chinese economy matures. This GDP profile is used for all three cases.

Sectoral growth elasticities (A_{it} and I_{it}). At the aggregate level the key variable is the rate of growth of industry value added (excluding construction) relative to the overall GDP growth rate. In 2006, and over 2001-06, growth in industry value added was 16% greater than in GDP (elasticity of 1.16). It is assumed, in the base case, that the relative growth rate of industry falls to parity with the GDP over ten years, and then declines further (elasticity falls to 1.0 by 2016, and to 0.9 by 2030). Growth in agricultural value added is set at 40% of GDP growth, and tertiary sector growth is the residual. These assumptions imply a gradual retreat from industry-driven growth, with the growth in the tertiary sector exceeding that of industry in 2013 and beyond. The new industry structure option involves a much more rapid move to a service-oriented economy, with the elasticity of industrial growth with respect to GDP being reduced rapidly to 1.0 by 2010, to 0.9 by 2015 and to 0.8 by 2020, and being held at that level over the next decade.

The sectoral growth elasticities relate to relative rates of growth within the industrial sector (excluding construction). Over 2001-05 real value added in the six energy intensive industries taken as a whole grew by 15.4% by comparison with overall industrial growth of 11.5%, implying a growth elasticity of 1.32, although growth patterns were variable across the industries. For individual energy-intensive industries the elasticities of growth relative to all industry are set initially at the average for 2001-05, bounded at 1.5 where the historical figure exceeds that level. In the base case these elasticities are assumed to decline gradually to 1.0 by 2015, and then to decline further to 0.85 by 2030. In other words, these industries will continue to provide a rising share of industrial value added up to 2015, with the rate of increase slowing; after 2015 they will provide a declining share, with the rate of decline rising over time. In the new industry structure case the pattern of change is more rapid, with the growth elasticities of these industries being reduced rapidly to 1.0 by 2010, to 0.9 by 2015 and to 0.8 by 2020. In this case, the structure of the Chinese economy changes profoundly over the next decade or more; by 2020 the growth rate of the energy intensive industries is just 4.9%, only 70% of the assumed GDP growth rate of 7% per annum at that time.

Elasticities of energy use with respect to value added (α_{it}). For the critical issue of elasticities of energy use with respect to value added, we specify a pattern of underlying elasticities that remains unchanged over the projection period, even though the actual elasticities of energy use change as a result of the policies that are in force, in both the unchanged policy and alternative policy cases. Consistent with the argument of this paper, for the thirteen industries we use the average elasticity value for the industry over 2001-05 as the underlying rate, with an upper bound of 1.2. The upper bound is used to ensure that unusually high elasticity values in particular cases over 2001-05 do not distort the long-run picture. Even using this specification the overall projected elasticities of energy use with respect to GDP are much less than one over the longer term, falling over ten years to about 0.80 in the base case and to 0.75 and 0.60 in the two policy cases.

Table 6: Model Parameters and Assumptions for Alternative Energy Runs: Specifications for Base Case and Policy Options to 2030

Parameter/Assumptions	**Base Case**	**New Industry Structure**	**Full Strategy: New Industry Structure plus Energy Measures**
Total GDP growth	Growth rate falling from 10.7% in 2006 to 7.5% by 2011, and then to 7.0% (2016), 6.5% (2021) and 6.0% (2026)	As for base case	As for base case
Elasticity of industry value added with respect to total GDP	Elasticity falls from 1.2 in 2006 to 1.0 over ten years to 2016, then to 0.9 by 2030.	Elasticity falls from 1.2 in 2006 to 1.0 in 2010; to 0.9 by 2015; to 0.8 by 2020, then fixed.	As for new industry structure case
Elasticities of four energy intensive industries with respect to total industry	Falling from average 2001-05 average (upper bound of 1.5) to 1.0 by 2015; then to 0.85 by 2030	Falling from average 2001-05 average (upper bound of 1.5) to 1.0 by 2012; then to 0.9 by 2017 and 0.8 by 2022; fixed after 2022	As for new industry structure case
Elasticity of energy use by industry	Average elasticities over 2001-05, to an upper bound of 1.2	As for base case	As for base case
Relative price changes for energy	6% per annum in 2006 and 2007, then 2.5% per annum increase in relative price of energy use to 2030		Additional 3% per annum increase (over base case) in relative price of energy use 2008-20
Price elasticity of energy use, by industry	Price elasticity of -0.4 in energy intensive industries, otherwise -0.2	As for base case	As for base case
Energy conservation and new technology effects	Reduction of energy use by 0.5% pa for energy intensive industries and by 0.25% pa otherwise		Additional reduction of energy use (over base case) by 0.5% pa for energy intensive industries and by 0.25% pa for others over 2008-20
Fuel use shares	Based on IEA (2006), adjusted for greater energy use based on coal and more aggressive growth of non-fossil fuels	Base case shares adjusted to lower energy use relative to base case by assuming that all the fall in energy use occurs in coal and oil, pro rata. Implies increased share for gas and renewables.	Base case shares adjusted to lower energy use relative to base case by assuming that all the fall in energy use occurs in coal and oil, pro rata. Implies increased share for gas and renewables.
Emission intensity of fuel use	As in IEA (2006)	As in IEA (2006)	As in IEA (2006)

Relative prices for energy. As shown in Table 4, weighted average energy prices in China fell marginally over the 1980s but rose strongly in the 1990s (7.9% per annum) and over 2000-05 (5.6% per annum). Looking ahead, the outlook for energy prices is more muted. While there is still a long way to go in some areas to adjust Chinese prices to world prices, and further price adjustments have been made in 2006 and 2007, a stronger supply-demand position within China and slower growth in world energy prices from recent peaks should moderate the rate of increase in prices. For the base case we assume a continuing increase in the relative price of energy of 2.5% per annum over the projection period, after increases of 6% in both 2006 and 2007. For the full strategy case, we assume an additional 3% per annum continuing increase (that is 5.5% per annum) over the period from 2008 to 2030.

Price elasticity of energy demand (β_{it}). The question of the price elasticity of energy demand is both an important and a vexed one. Estimating the price elasticity of demand is especially difficult when, as in China over much of the 1980-2005 period, actual energy use is supply constrained and prices are partly responsive to the underlying supply-demand gap arising from supply constraints. In view of this fact, estimates of the price elasticity in the literature based on demand equations estimated on historical data must be treated with caution for our purposes.

There is an extensive international literature on the estimation of energy price elasticities across countries. For example, Gately and Huntington (2002) found that the long-run price elasticity for the OECD region for 1971-97 was –0.24, and that it was –0.08 for fourteen developing countries (not including China) with above average per capita income growth, with evidence in both cases of asymmetric responses to rising and falling prices. Pesaran et al. (1998) found that the long-run elasticity was about –0.3 for ten Asian countries (again excluding China). For China, Fisher-Vanden et al. (2004) find an elasticity of -0.368 from their cross-sectional analysis of manufacturing firms in 1997-99; Shi and Polenske (2006) find a long-run price elasticity for the industry sector of –0.78 over 1980-2002; Hang and Tu (2007) find an elasticity of –0.54 for 1985-95 and of –0.65 for 1995-2005; while Chen et al. (2007) use a range of elasticities from –0.1 to –0.5 in their MARKAL model analysis. In the light of the international literature and of concerns about estimating demand elasticities for China in a supply constrained market, we use an elasticity of –0.4 for the energy intensive industries and of –0.2 for other industries.

Technology and energy conservation policies ($\gamma_{it}\Delta Z_{it}$): While there is clear evidence that during the period of limited energy supplies and a command economy technology and energy conservation policies had a substantial impact on energy use, no quantitative measure of that impact is available. Failing more precise information, we assume that the more limited policies included in the base use reduce energy use by 0.5 percentage points per annum in energy intensive industries and by 0.25 points in other industries, and that in the full strategy these effects are doubled in both industry types. Clearly this is only a preliminary specification, and requires further work.

Fuel use by type (s_{tj}*) and emissions intensities of fuel types (*m_{tj}*)*. The values for China over the projection period of s_{tj}, the shares of various fuel types in total energy use, and of m_{tj}, the emissions intensity of different fuel types, are based on the values used in IEA (2006), 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. Massive expansion of coal production and of coal-fired power stations has been under way in China in recent years, while there is clear evidence of fuel substitution away from oil and considerable attention being given to renewables and to nuclear energy. Thus for the base case coal's share of total energy use by 2030 is higher than in IEA (2006) (66% in 2030 rather than 64.5%) as is the share of natural gas (8.0% rather than 4.9%) and non-fossil fuel (9.0% rather than 5.7%), with these increases being mainly offset by a much lower oil share (17.0% compared to 24.0%). The IEA projections of CO_2 emissions per unit of fuel type use are adopted in full, and held fixed for all scenarios.

For the alternative policy cases, the fuel-use shares are calculated by assuming that the absolute level of energy production from natural gas and renewable sources in the base case is maintained in the two policy cases, so that all of reduction in energy use falls in the coal and oil sectors, pro-rata to their shares in energy use. This means that the effect of reducing energy use on emissions is magnified, by the reduction being concentrated in the most emissions intensive fuel types.

Projections of Energy Use and CO_2 Emissions from Fuel Combustion

The resulting projections for the base case are summarised in Table 7. By 2030 total primary energy use in China is projected to be 7.3 billion tons of oil equivalent, more than four five times the 2005 level and amounting to about 30% of global energy use by that time. The implied annual growth rate over 2005-30 is 6.4%, one percentage point higher than over 1980-2005, with all of that higher growth occurring over 2005-15 (an annual rate of 7.9%). Over the period 2005-30 as a whole the elasticity of energy use with respect to GDP is 0.87, with elasticities of 0.93 and 0.83 in the two sub-periods distinguished. Between 2005 and 2030 energy use per unit of GDP falls by about 25%. Thus the base case is one in which the rate of growth in energy use slows gradually, as the structure of the economy evolves and matures and as sectoral intensities fall gradually under the influence of the policies in force in 2005.

With over 80% of China's commercial energy use in the base case in 2030 still being provided from coal and oil, in spite of a projected double-digit growth rates for natural gas and non-fossil fuel sources, emissions from fuel combustion (excluding cement) are projected to grow by 6.1% per annum over 2005-30 and to total about 6.2 billion tonnes of carbon by 2030. For reference, total global emissions of CO_2 from fuel combustion (excluding cement) in 2000 were about 6.4 billion tonnes of carbon. Thus this level and structure of energy use in China, were it to come about, would lead to emissions from China itself doubling the global level of emissions from fuel combustion in 2000 by 2030.

The purpose of an unchanged policy projection is to guide the development of alternative policies, if the projected outcomes are seen as unacceptable. The Chinese

Government has certainly made it clear that recent trends in energy use should not be allowed to continue, and is putting in train policies to achieve lower rates of growth. The alternative policy projections (also shown in Table 7) give some preliminary estimates of what such policies might achieve. In the new industry structure case, the focus of policy is on rapidly shifting the pattern of economic growth from industry to services and on reducing the role of energy intensive industries within the industry total. Rapid structural change is assumed, with the rate of growth of the six energy intensive industries falling below the national growth rate by 2010 and to only 70% of that rate by 2020. In this case the rate of growth in energy consumption falls to 5.6% over 2005-30, with the rate of emissions growth slowing to 5.2%. Between 2005 and 2030 energy use per unit of GDP falls by nearly 40%. But energy consumption is still nearly four times its 2005 level in 2030, growing at 4.8% per annum over 2015-30, and CO_2 emissions in 2030 are at 5 billion tons of carbon.

Table 7. Summary of Unchanged Policy and Alternative Policy Projections

	Level (Mtoe and Mt C)				Annual rate of change (% pa)			
	1980	**2005**	**2015**	**2030**	**1980-2005**	**2005-30**	**2005-15**	**2015-30**
Energy consumption[1]								
Base case	424	1563	3336	7332	5.4	6.4	7.9	5.4
New industry structure	424	1563	3040	6139	5.4	5.6	6.9	4.8
Full strategy	424	1563	2771	4808	5.4	4.6	5.9	3.7
CO_2 emissions								
Base case	383	1415	3007	6185	5.4	6.1	7.8	4.9
New industry structure	383	1415	2723	5040	5.4	5.2	6.8	4.2
Full strategy	383	1415	2466	3761	5.4	4.0	5.7	2.9

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

In the full strategy case, these structural changes are supported by further action on energy pricing, technology policy and energy conservation programs. In this combined case, growth in energy use over 2005-30 slows further to 4.6%, with growth over 2015-30 down to 3.7%. In this case energy use per unit of GDP falls by 54% over 2005-30. With slower growth in energy use, and the assumption that all of the lower energy use is reflected in lower use of coal and oil, emissions growth comes down to 4.0% over 2005-30, with growth over 2015-30 held to 2.9%.

These preliminary simulations lead to a number of conclusions. On the policies in force in 2005, energy use would grow rapidly over the next quarter of a century, with CO_2 emissions from fuel combustion rising more than fourfold. Given the structure and continued growth of the Chinese economy, rising energy use will be difficult to contain, especially as the pressures of development lead to higher energy use in many sectors. But an urgent and sustained application of new policies – using structure, pricing and other policies – could reduce the rate of growth of energy use by about 2 percentage points, and reduce total energy use in 2030 by about 35% relative to the base case. On this integrated strategy emissions growth could fall to 4.0% over 2005-30, and be 40% or 2.4 GtC lower in 2030 than in the base case, if the savings in energy use are all reflected in lower use of coal and oil. Further reductions in emissions from this level of energy use could be achieved if the level of energy produced from renewables was increased relative to the base case or if the emissions intensity of fossil fuel use could be reduced (for example by clean coal technologies or by geosequestration techniques).

6. CONCLUSION

The literature on China's energy use after the 'opening to the market' in 1979 has mainly focused on explaining the low elasticity of energy use with respect to GDP over 1980-2001, whereas current policy issues centre on the fact that since 2001 energy use in China has been growing more rapidly than GDP. Here our main conclusions are that the low elasticity over 1980-2001 was primarily due to technological upgrading and energy conservation, stimulated by energy rationing in a command economy with limited energy supplies and high initial usage levels, but that increasing relative prices became of growing importance during the 1990s. The change to an elasticity at or over one after 2001, consistent with the experience of most other developing countries, reflects the shift from command economy to market structures after the reforms of the late 1990s, as well as lower attention to energy conservation programs and rapid expansion of energy intensive industries after China's entry to the WTO in 2001. While most existing projections assume a return to an aggregate elasticity of energy use in China close to the 1979-2001 average, as does the Government's 11th Plan target, our results imply that in the new economic structure an elasticity of significantly less than one will only be achieved by sustained and comprehensive policy implementation.

The base case projections, which use an interpretation of policies in force in 2005, show sustained growth in China's energy use and in CO_2 emissions from fuel combustion out to 2030. But the Government is now committed to substantial reductions in the rate of growth of energy use, and is actively implementing a wide range of policies to that end[6]. How successful these efforts will be remains to be seen, although the 11th Plan target of a 20% reduction in energy use per unit of GDP over 2006-10 implies an early return to the 1980-2001 elasticity of energy use with respect to GDP, and this is unlikely to be achieved. Nevertheless our simulations indicate that a sustained policy process involving use of the full range of instruments, such as is now being contemplated in China, can achieve major reductions in the growth of China's energy use and CO_2 emissions over the medium term.

[6] For example, in a succession of changes since 2004, the Government has reduced and then abolished the export tax rebate on products from energy intensive industries, and has put in place, effective from 1 June 2007, export tariffs of up to 15% on 142 products of these industries. The Government has also taken measures to rein in local government support for energy intensive industries, to accelerate the growth of the service sector, to close down inefficent production in the power industry and in energy intensive industries and to enforce penalties for violation of environmental regulations.

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