Climate Change, Industrial Structure and the Knowledge Economy: Key Issues for an Effective Response on Greenhouse Gases

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1. Executive Summary

This project has been directed at analysing the impact of the global knowledge economy on future prospects for climate change. This impact is felt in different ways: accelerated growth in the global economy, and in many developing countries, structural change towards the service sector and the development and diffusion of new technologies. One key finding is that these effects will have their primary effects in different time frames. Emissions are rising rapidly at the present time but the expected effects of structural change are not being strongly felt, largely because of increased energy use in transport. The impact of major new technologies to reduce energy use and the carbon content of energy supply is not likely to be felt (on current policies) until after 2020-30.

Rather than using standard scenario approaches, we explore these matters further by using methods that make maximum use of existing knowledge – of the likely energy path over the next 25 years, of the minimum time-scales for new technology diffusion and of the likely impacts of climate change for given levels of global warming. Thus we develop a reference projection to 2030 for global CO_2 emissions from fuel combustion, with a lower bound extension to 2100 based on an assessment of the maximum impact of new technologies, and study the implications using a well-known climate model, MAGICC, and an analysis of the damage literature. Driven by increasing coal use, CO_2 emissions grow by 33% between 2002 and 2010, double before 2025 and decline (on the lower bound path) after 2050. Mean global temperature rises 3.2–5.5°C by 2100, implying large-scale climate damage and a high probability of abrupt, irreversible impacts.

The projection path for CO_2 emissions to 2030 lies well above all the SRES indicator scenarios by that time, implying that the SRES scenarios no longer provide a reliable basis for studying future trends. An international effort is required to construct a definitive projection to guide policy initiatives with immediate impact on global emissions.

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The decisive factor in these results is the doubling of emissions over the next two decades; urgent measures are necessary if these outcomes are to be averted. If emissions growth along the reference path is to be arrested in the near term, policy measures to reduce global energy consumption and to accelerate the diffusion of non-coal technologies are urgently needed. The most efficient option is likely to be some direct pricing measure for carbon content (such as a carbon tax), with the revenue invested in the development and diffusion of renewable energy sources.

2. Introduction

The Issues

Since the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) in 2001 certain global economic trends have become more firmly established. Adoption of advanced information and communications technologies and of more open, market-based economic policies has led to growing integration of the world economy, accelerating technological change and sustained rapid growth in countries such as China and India. The growth of these countries reflects in part a systematic transfer of energy and labour intensive industrial activities, backed by massive inflows of technology, resources, human capital and foreign direct investment. The forces driving greater integration, rising knowledge intensity and rapid growth now seem to be entrenched, and are likely to guide the evolution of the world economy for some time to come. This overall process is often referred to as the rise of the global knowledge economy (OECD 1996; World Bank 1999).

The implications of this process for the world's climate are uncertain (Chichilinsky 1998; Ehrlich et al. 1999). If much higher living standards are achieved quickly by an additional 30–40% of the world's population, using existing development patterns and without major reductions in energy use by the advanced countries, the pressure on energy supplies and the climate is likely to be intense. On the other hand, shifts in the structure of economic activity to more knowledge intensive activities (such as education and health) reduce the energy intensity of GDP, while rapid technological change offers the prospect of reduced emissions in the long term. These two quite different ways in which the global knowledge economy might impact on the world's climate – by facilitating more rapid global growth, especially in key developing countries, and by stimulating structural change to less energy intensive services sectors and the adoption of energy-saving technologies – are thus likely to work in opposing directions in terms of the future path of greenhouse gas emissions.

Growth and Structural Change

The growth dimension is taking on increasing urgency as it becomes increasingly evident that the world has indeed entered a new stage in recent years, especially since the entry of China into the World Trade Organisation in 2001 and the strong growth being achieved in India, as the UPA Government gives effect to its National Common Minimum Programme. Global economic growth has been higher than expected for some years and energy demand has been very strong, much greater than anticipated by markets, providers and analysts. As a result, long-term growth forecasts are being revised upwards. For example, the IMF *World Economic Outlook* (2006) projects global growth (in constant purchasing parity prices) of 4.7% per annum from 2002–

2011, by comparison with 3.4% over 1990–2002 and 3.7% over 1970–2002. This new growth path appears not simply to be another boom but to reflect long term factors, above all the sustained emergence of China and India as economic powers, the revival of Japan, better economic prospects in Russia and other CIS states, and more generally an open world economy with low inflation. Reflecting both current demand and revised expectations for the future, global market prices for oil, coal and resources have risen sharply and large scale investment plans are being put in place, both in key markets such as China and India and in supplier countries such as Australia, Brazil and Russia.

The evidence on the structural change dimension is less clear, although a continuing shift to the services sector is apparent in most developed countries. Reliable time series data on energy use and real value added by industry is difficult to obtain, but the IEA has made available unpublished data for five countries (USA, Japan, UK, France and Australia) for the period 1974–1995, together with data for Canada for 1984–1995, for these variables. Only the data for the five countries for the 1974–1995 period is used here. In Table 1 we group four industries together as the goods industries (manufacturing; agriculture, forestry and fishing; mining and construction) and examine the contribution of changes in value added and in energy intensity to energy use at the industry level, and of different industries to energy use at the aggregate level.

Table 1. Energy use, industry value added and energy intensity for five OECD countries,* 1974–1995

		1974	1995	Change in energy use 1974–1995	Annual change 1974–95 (% pa)
Goods industries					
	Energy used (PJ)[1]	28611.1	26692.2	-1918.9	-0.3
	Value added (US$b)[2]	2091.7	3209.0		2.1
	Intensity (MJ/US$)	13.7	8.3		-2.3
Services					
	Energy used (PJ)[1]	6024.7	7339.4	1314.7	0.9
	Value added (US$b)[2]	3428.4	6670.2		3.2
	Intensity (MJ/US$)	1.8	1.1		-2.2
Transport					
	Energy used (PJ)[1]	22367.0	34703.7	12336.7	2.1
	Value added (US$b)[2]	258.5	475.3		2.9
	Intensity (MJ/US$)	86.5	73.0		-0.8
Residential					
	Energy used (PJ)[1]	13828.9	16261.4	2432.5	0.8
	Value added (US$b)[2]	806.8	1973.1		4.4
	Intensity (MJ/US$)	17.1	8.2		-3.4
Total					
	Energy used (PJ)[1]	70831.6	84996.6	14165.0	0.9
	Value added (US$b)[2]	6585.4	12327.6		3.0
	Intensity (MJ/US$)	10.8	6.9		-2.1
Total ex transport					
	Energy Used (PJ)[1]	48464.7	50293.0	1828.3	0.2
	Value added (US$b)[2]	6326.9	11852.3		3.0
	Intensity (MJ/US$)	7.7	4.2		-2.8

Notes: *The countries included in this table are USA, Japan, UK, France and Australia. The goods industries consist of manufacturing; agriculture, forestry and fishing, mining and construction.
[1]Energy use is measured in petajoules (PJ).
[2]GDP is measured in US $billion in 1990 purchasing power parity prices.
Source: Unpublished data from the IEA.

This table provides three clear messages, for the period and the countries covered. First, in each of the industry sectors other than transport, energy intensity, defined as energy use per unit of real value added, has fallen sharply between 1974 and 1995. The residential sector had the largest fall of 3.4% per annum, although the interpretation of this result is uncertain in the light of the limited methods currently employed to measure value added in the residential sector. But energy intensity in the goods industries fell by 2.3% per annum, and in services by 2.2% per annum, in both cases amounting to a fall of nearly 40% over the 1974–1995 period. This is suggestive of both the use of new, more energy efficient technologies in both sectors and of structural shifts within the sectors towards less energy intensive activities. By contrast, the transport sector saw only about a 15% fall in energy intensity over more than two decades, with a decline of 0.8% per annum.

Second, the differences between the industry sectors in terms of measured energy intensity are substantial. Energy use per unit of value added in the goods industries is 7–8 times that in the services sector, implying that, other things being equal, a shift from goods to services would reduce energy use sharply. But energy use per unit of value added in transport is in turn about 8–9 times that of the goods industries, and is falling much less rapidly than in other sectors. Thus trends in energy intensity and value added in transport are very important for overall energy use. But the simple picture of only two sectors – goods and services – with value added shifting strongly to service industries with low energy use as the knowledge economy develops is misleading. Value added did grow more slowly in the goods industries than in the other three sectors shown in Table 1, with the share of the goods industries falling from 33.1% of total GDP in 1974 to 27.1% in 1995, but the other three sectors are very different in their energy intensity. By 1995 the energy intensity of GDP excluding the goods industries, at 6.4 MJ/US$, was only 23% lower than that of the goods industries.

Reflecting these factors, the third and most important message of Table 1 is the dominant role of transport, and to a lesser extent the residential sector, in increasing energy use in these five countries over the 1974–1995 period. The two factors of reduced energy use within individual goods and services industries and the structural shift from goods to services have indeed operated to reduce energy use – in these two industries taken together energy use was lower in 1995 than in 1974, even though real value added had increased by 87%. But energy use by transport surged, growing by 55% over the period, while residential energy use grew by 17.6%. Overall, transport energy use contributed 87.1% of the total increase in energy use between 1974 and 1995, while contributing only 3.8% of the increase in value added.

The continued rapid growth in energy use in transport reflects two factors: continued strong growth in value added, presumably connected in part with the implications of globalisation in terms of the movement of both people and goods, and only modest improvements in energy efficiency. There is considerable evidence that, over this period, advances in transport technologies have been reflected more in increased power, weight and service quality than in greater fuel efficiency.

This limited evidence suggests that, for the five developed countries covered and for the 1974–1995 period, some of the key mechanisms that have been suggested in the literature have indeed been operating in goods and service industries. There has been a rapid fall in energy intensity in both the goods and service sectors, and a shift in the distribution of value added from goods to services is also apparent. As a result, the total energy use from the goods and services sectors fell over a period of more than two decades. But these factors have been offset by rapid growth in energy use in transport, with value added rising in line with GDP and with little reduction in the high level of energy intensity. Continued growth also took place in residential energy use, in spite of a sharp decline in energy intensity.

Thus a sectoral analysis offers no easy way forward in understanding the implications of the knowledge economy for the climate. While sectoral shifts with implications for global energy use are under way, some of the growing sectors have high levels of energy use, so that both aggregate and sectoral growth rates will be prime determinants of growth in energy use. Given this fact, and the limitations on the availability of sectoral data, especially on value added, across countries, throughout this report we adopt a forward looking approach at a fairly aggregate level. That is, we study the prospects for emissions, global warming and impacts in the 21st century in a world shaped by the key characteristics of the global knowledge economy: greater integration, rising knowledge intensity, strong growth in key developing countries and rapid technological change.

A Projection Approach to Addressing Uncertainty

The first step in developing such an approach is to determine the method to be used to address the inevitable uncertainty about the future. Uncertainty about climate outcomes arises in part from limited knowledge of the physical processes at work, but even more so from uncertainty about the economic, social and technological evolution of human societies and of their impact on the climate. How this latter dimension of uncertainty is addressed is a key issue of methodological debate. In 1996 the IPCC – accepting the view that uncertainty in socio-economic variables needs to be represented by a range of systemic, consistent scenarios covering both socio-economic variables and an explicit representation of how the variables interact – decided to establish a new set of emissions scenarios to provide input to the TAR. The Special Report on Emissions Scenarios (the SRES scenarios) (Nakicenovic and Swart 2000) encapsulates four ‘storylines’ that describe quite different social, economic and emissions outcomes over this century. The SRES authors did not assign likelihoods to these outcomes beyond their being plausible. This approach, again using the SRES scenarios, will be repeated in the Fourth Assessment Report to be published in 2007 (IPCC 2005a), in spite of considerable debate about this method (Schneider 2001; Schiermeier 2006). Debate concerns the use of probabilities to assess risk (Schneider 2001; Pittock et al. 2001) and the suitability of the scenarios themselves to adequately describe the future.

The key discipline in scenario building is internal consistency, to ensure that a given scenario does indeed describe one possible way in which the world *might* develop. Thus a multi-scenario approach seeks to cover the range of possible futures but gives limited attention to information about how the world *will* develop in the future. In the climate change context, one deficiency of this approach is that it does not give sufficient weight to what is or can be known about emerging trends in global economic and energy systems and in the development and diffusion of energy technologies. For example, asset lives of plant and equipment (e.g. of power stations) are very long, fuel types used and technologies in place change slowly, development trajectories in some countries seem well established and many complex social, economic and technological factors dampen rapid change at the system level. Thus trends in the global energy system over a 25–30 year period are much better understood than longer term ones. Similarly, while there is much uncertainty about the development of new energy technologies, about which technologies will prevail in the marketplace and how rapidly they will diffuse to general use, the stages of the process from initial idea to general use are well understood. Thus, for each specific technology, there is a considerable body of knowledge about the steps required to bring it to market leadership, and about the minimum timeframes that might be involved.

Thus an alternative approach to scenario building is to project likely outcomes using unchanged policies, making use of the information about the future embedded in global economic and energy systems and in studies of the development and diffusion of energy technologies. Projections based on unchanged policies are widely used in government and business circles, and the scenario approach as encapsulated by SRES has had limited effect in influencing the policy community about climate change. We show that robust conclusions can be obtained by drawing on existing knowledge – of the likely energy path over the next 25–30 years, of the minimum time-scales for new technology diffusion and of the critical thresholds for major climate damage.

To achieve these ends, we build a simple unchanged policy projection out to 2030 for global energy use and CO_2 emissions from fuel combustion and cement production, with a lower bound extension to 2100 based on the projection dynamics and on evidence about the development and diffusion of many technologies. The resulting emissions path – the reference path – represents projected emissions to 2030 and the minimum achievable level of emissions to 2100 consistent with the projection to 2030, and is used to study the risk of not implementing new climate policies in different time frames. The climate outcomes of the reference path to 2100 are derived using a simple climate model, MAGICC, and the risks associated with those outcomes are examined by comparing likely outcomes with information from the literature on the critical thresholds for major climate damage.

3. The Unchanged Policy Projection to 2030

Projection Framework

The basic framework within which the projections are undertaken is as follows. For a given country *i* in year *t*, *n* years from some initial period, real GDP in international purchasing power parity prices (Y^t_i) is given by:

$$Y^t_i \;=\; Y_0\,(1 \;+\; \alpha^t_i)^n,$$

where Y_0 is opening period real GDP and α^t_i 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^t_i) is defined as the ratio of the average annual rate of growth of total primary energy supply (e^t_i) to the average annual rate of growth of GDP (α^t_i). That is:

$$\varepsilon^t_i \;=\; e^t_i \,/\, \alpha^t_i\,.$$

Hence the rate of growth of total energy use (e^t_i) over the period is $\varepsilon^t_i.\alpha^t_i$, and total energy use by country *i* in year *t* is:

$$E^t_i = E^0_i(1 + \varepsilon^t_i.\alpha^t_i)^n.$$

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^j_i) 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:

$$E^{tj}_i = E^t_i . s^{tj}_i = E^0_i(1 + \varepsilon^t_i.\alpha^t_i)^n . s^{tj}_i .$$

Finally, CO_2 emissions per unit of fuel use (m^{tj}_i) 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:

$$M^{tj}_i = m^{tj}_i . E^{tj}_i = m^{tj}_i . s^{tj}_i . E^t_i .$$

Thus total CO_2 emissions in country *i* in year *t* (M^t_i) are given by:

$$M^t_i = \sum_j m^{tj}_i . s^{tj}_i . E^0_i(1 + \varepsilon^t_i.\alpha^t_i)^n .$$

Given this relationship, the projection methodology focuses on four key parameters for a given country or region: α^t_i, the rate of growth of real GDP; ε^t_i, the elasticity of energy use (total primary energy supply) with respect to GDP; s^{tj}_i, the shares of various fuel types in total energy use and m^{tj}_i, 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.

Implementing the Framework

The most authoritative global energy projections are those of the International Energy Agency, last published in November 2004 (IEA 2004a). These provide our starting point, although substantial revision is necessary for key developing countries, in part to take account of recent information concerning growth in GDP and energy use in China (NBSC 2005a; Aldhous 2005), India (Central Statistical Organisation 2005) and other countries. In implementing the framework to create the projection, values of the four parameters from IEA (2004a) are used except where new data or other information make this no longer appropriate. For the OECD countries except Japan, Korea, Australia and New Zealand, and for the transition economies, the IEA forecasts are retained in full. Key areas where variations from the IEA (2004a) forecasts occur are noted in subsequent sections below.

Historical data for GDP, energy use and CO_2 emissions up to 2003 are available from the IEA website (http://data.iea.org/ieastore/statslisting.asp). To ensure consistency, these data have been used throughout this paper, although national sources have been examined to guide the projection process. The data available from this source now contains some revisions to the historical data to 2002 for GDP, energy use and CO_2 emissions outcomes relative to the data that were used in preparing the IEA (2004a) forecasts. These revised data have been used both to replicate the IEA projections and as a basis for the revised projections. For each of these three variables the published projected growth rates for periods between 2002 and 2030 have been applied to the revised figures for 2002. This means that some small discrepancies can arise in replicating those projections, between the published projections and their replication on the new data.

One limitation of this approach is that, for those countries and regions for which the IEA (2004a) projections are adopted in full, it is not possible to take account of developments since 2004. This relates in particular to the widespread expectation of higher fossil fuel prices in the long run and to higher growth rates, both relative to those assumed in IEA (2004a). The net effect of these offsetting variations is not likely to be large. One indication of this is that the long-term growth rates for total energy use for both the OECD and for the transition economies are lower in the projection of this paper than in those of the US Energy Information Administration released in July 2005 (http://www.eia.doe.gov/oiaf/ieo/ieorefcase.html). Another potential limitation is the general equilibrium effect: rapid growth in specific countries will influence, both positively and negatively, growth and energy use in all other countries. Again the net direction of this effect is not apparent on an a priori basis. For example, rapid growth in China will, in some industries, be at the expense of growth in the USA, but it will also provide a strong market for other US products. These limitations need to be kept in mind in interpreting the analysis below.

GDP Growth Projections (α^t_i)

The main area of variance from IEA (2004a) is in the GDP growth and energy elasticity assumptions, particularly for the major developing countries. The GDP assumptions are provided in Table 2, which also shows a comparison of the current projected growth rates with those of IEA (2004a) for the period 2002–30.

Table 2. GDP in constant US dollars (year 2000 purchasing power parity values), actual 1971–2002 and projected 2002–2030

	GDP in US $2000 PPPs			Annual change (% per annum)					
	1971	2002	2030	1971-2002	2002-10	2010-20	2020-30	2002-30	IEA (2004a) 2002-30
		(US$trillion)				(% per annum)			
OECD	11.5	27.9	53.1	2.9	2.8	2.3	1.9	2.3	2.2
North America	4.5	11.8	23.3	3.2	3.2	2.4	1.9	2.4	2.4
Europe	5.3	11.2	20.0	2.4	2.4	2.2	1.7	2.1	2.1
Asia	1.4	4.2	8.4	3.5	2.7	2.4	2.5	2.5	1.9
Oceania	0.2	0.6	1.4	3.0	3.4	2.9	2.4	2.9	2.3
Transition economies	1.8	2.1	5.7	0.4	4.6	3.7	2.9	3.7	3.7
Developing countries	4.1	17.0	84.5	4.7	6.6	5.8	5.4	5.9	4.3
China	0.5	5.8	41.1	8.5	9.3	7.0	6.0	7.3	5.0
India	0.6	2.7	16.7	4.9	7.3	6.5	6.5	6.7	4.7
SE Asia	0.4	1.9	6.4	5.4	5.0	4.5	4.0	4.5	3.8
Other	2.6	6.7	20.0	3.1	4.0	4.0	4.0	4.0	3.4
Other countries	0.1	0.6	1.4	6.4	3.7	3.2	2.7	3.2	3.2
World	17.4	47.5	144.6	3.3	4.4	4.0	3.8	4.1	3.2

Source: Historical data to 2003 is from IEA website (http://data.iea.org/ieastore/statslisting.asp) with projections by the authors.

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, and real GDP 10.9% higher in the first half of 2006 than in the same period of 2005 (http://www.stats.gov.cn). 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. These assumptions involve a considerable slowing of Chinese growth from its current hectic pace, but continued fairly strong growth over the longer term. On 20 December 2005 the Chinese Government announced that, as a result of the National Economic Census undertaken in 2004, the estimate of China's GDP for 2004 had been increased by 16.8%, and that both historical data and data for 2005 will be revised in due course (NBSC 2005b). As the new revisions have not yet been incorporated into the IEA data, these projections are based on the existing data. Given that 93% of the higher GDP value is located in the tertiary sector, the implications of this change for the analysis of energy use and emissions should be limited.

India's growth has been accelerating since the late 1970s, and reached 5.4% in the Ninth Plan period, 1997–2002. The Planning Commission estimates that the outcome for the Tenth Plan period, 2002–07, will be 7% per annum, by comparison with a target of 8.1% (IPC 2005). and is using a growth rate of 8.5% as the working basis for the Eleventh Plan period, 2007–12 (IPC 2006). The initial estimate of real growth for 2005–06 was 8.4% (www.mospi.nic.in). India's growth has traditionally been driven by services rather than industry, and a notable feature of recent trends has been an increase in the growth of secondary industry relative to the overall growth of GDP. Thus for the Eleventh Plan period the initial target working basis for industry is 10% per annum, and for manufacturing 12% per annum, by comparison with the GDP rate of 8.5% (IPC 2006). For the projections we use lower figures than those foreshadowed by the Planning Commission, but ones that still imply strong growth out to 2030: 7% for the next two years, 7% for the Eleventh Plan period, 6.5% from 2012–20 and also for 2020–30. These projections imply convergence of growth rates in the two countries, with China's long-run growth rate slowing from that of recent decades, with the underlying rate of growth in India continuing to increase for some time.

For other OECD regions (Asia and Oceania) and other developing countries projected growth rates are about 0.5 percentage points higher than in IEA (2004a), reflecting factors such as the emergence of Japan from its long period of stagnation, the impact of resources and other demand from China on Australia's growth prospects and improved prospects for the developing countries generally.

Elasticity of Energy Use (ε^t_i) and Total Primary Energy Supply

It is widely held that, during the development phase, the elasticity of total primary energy use with respect to GDP is equal to or greater than one, but that once societies achieve higher living standards this elasticity becomes significantly less that one, and indeed less than 0.5. The assumptions made in relation to this variable are critical to long run projections of energy use. During the nineteenth century the elasticity of energy use was substantially greater than one for what are now the developed countries but the elasticity was 0.5 for the OECD countries as a whole over 1971–

2002, with higher values only for OECD–Asia (Japan and Korea, 0.84) and for OECD–Oceania (Australia and New Zealand, 0.85). The IEA projections use a set of country specific figures that imply an overall OECD elasticity of 0.39 for 2002–2030, and our projections imply a similar figure (0.43), even after allowing for somewhat higher elasticities in the OECD–Asia and Oceania regions.

Table 3. 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: Data from the IEA website (http://data.iea.org/ieastore/statslisting.asp), with analysis by the authors.

A critical issue, however, is the value of the elasticity parameter for developing countries. As is evident from Table 3, the energy elasticity of GDP for the developing countries as a whole was 1.04 over 1971–2002, in spite of an elasticity for China of only 0.57. For all developing countries other than China the elasticity over this period was 1.34. Prior to the opening up of the Chinese economy after 1979, it was both highly energy intensive and highly inefficient in its use of energy. As a result, energy use rose more slowly than GDP for the first two decades of the new expansion, implying a fall in the energy intensity of GDP and an elasticity well below one. Interpretation of trends became more complex in the second half of the 1990s, as the official Chinese energy data became unrealistic (Sinton and Fridley 2003). Between 1996 and 2001 real Chinese GDP was reported to have increased by 46%, but total energy consumption was reported to be 3% lower in 2001 than in 1996, implying a negative value for energy elasticity. Since 2001 energy use in China has surged, with reported energy use growing by 11.6% between 2001 and 2005, implying an elasticity of 1.2 over this period (NBSC 2006).

With continued energy shortages and massive construction programs in place to build more electricity generating capacity and to utilise foreign sources of energy, we assume an average elasticity for China of 1.0 through to 2010. Given that shortages will have been met, that government programs and higher prices will moderate demand and that the structure of the economy will increasingly shift to the knowledge intensive service sector, we assume that the elasticity will fall steadily after 2010, to average 0.85 and 0.75 during the next two decades respectively (Table 4). For a full discussion of these and related issues, including a discussion of other projections of China's energy use, see Sheehan and Sun (2006). On the basis of these assumptions, total primary energy use in China is projected to grow by 10.6% per annum between 2002 and 2010, but with growth slowing appreciably after 2010, to 6.0% per annum and 4.2% per annum in the next two decades respectively (Table 5). For the period 2002–2030 annual growth in energy use is projected to average 6.7%, by comparison with 4.8% over 1971–2002.

Table 4. Elasticity of energy use (TPES) with respect to GDP, actual 1971–2002 and projected 2002–2030

	Actual	Current projection				IEA (2004a)
	1971-2002	2002-10	2010-20	2020-30	2002-30	2002-30
OECD	0.50	0.51	0.43	0.35	0.43	0.39
North America	0.42	0.45	0.42	0.36	0.42	0.42
Europe	0.45	0.43	0.27	0.14	0.28	0.28
Asia	0.84	0.80	0.70	0.60	0.70	0.50
Oceania	0.85	0.60	0.50	0.40	0.50	0.44
Transition economies	1.37	0.43	0.39	0.26	0.36	0.36
Developing countries	1.04	1.05	0.89	0.78	0.91	0.70
China	0.57	1.14	0.85	0.75	0.92	0.58
India	1.15	0.85	1.00	0.90	0.92	0.65
SE Asia	1.28	1.00	0.90	0.80	0.90	0.85
Other developing	1.46	0.90	0.90	0.80	0.86	0.87
Other countries	0.99	0.53	0.47	0.47	0.49	0.49
World	0.63	0.77	0.71	0.68	0.72	0.54

Source: Historical data to 2003 is from IEA website (http://data.iea.org/ieastore/statslisting.asp) with projections by the authors.

Another important case is that of India. The energy elasticity of GDP (excluding biomass) for India was 1.15 over the period 1971–2005, although lower over 1990–2002 than in the earlier period. Energy use in India has been limited to date by a focus on service industries and by supply shortages, and half the country's population remains without electricity (IPC 2006). But industrial and household demand is increasing and sustained efforts are being made to increase electricity generation, primarily through coal-fired power stations. The Planning Commission projects that the demand for coal will rise by 7.6% per annum between 2005–06 and 2011–12 (IPC 2006). India has also been highly dependent on energy from biomass and waste. But with expansion possibilities limited in these traditional areas, growing demand for energy will need to be increasingly met from commercial sources.

The Draft Report of the Expert Committee on Integrated Energy Policy, presented to the Indian Planning Commission in December 2005 (Parikh 2005), outlines both India's growing energy needs and the programs that are being put in place to ensure that they are met. We assume that the energy elasticity of GDP in India will gradually return to an average of 1.0 over the 2010–2020 period, but decline after 2020. The net result is projected average annual growth in TPES in India of 6.2% over 2002–2030, with some slowing in the final decade of the projection period (Table 5). This is broadly consistent with the projections of the Expert Group, who use a lower elasticity but higher growth assumptions to generate a range of projected growth rates in TPES for India of 5.1%–6.0% over the period 2006–07 to 2031–32. The elasticity assumptions for other developing country regions can also be found in Table 4 and the TPES projections in Table 5.

Table 5. Energy use (Total Primary Energy Supply – TPES), actual 1971–2002 and projected 2002–2030

	Total primary energy supply						Annual change (% per annum)				
	1971	2002	2010	2020	2030	1971-2002	2002-10	2010-20	2020-30	2002-30	IEA (2004a) 2002-30
			(mtoe)					(% per annum)			
OECD	3,309	5,177	5,801	6,405	6,857	1.5	1.4	1.0	0.7	1.0	0.9
North America	1,730	2,608	2,927	3,239	3,465	1.3	1.5	1.0	0.7	1.0	1.0
Europe	1,237	1,730	1,880	1,993	2,041	1.1	1.0	0.6	0.2	0.6	0.6
Asia	287	714	849	1,005	1,166	3.0	2.2	1.7	1.5	1.8	1.0
Oceania	56	124	145	168	185	2.6	2.1	1.5	1.0	1.5	1.0
Transition economies	851	1,012	1,169	1,309	1,467	0.6	1.8	1.1	1.1	1.3	1.3
Developing countries	633	2,816	4,820	7,962	12,059	4.9	6.9	5.1	4.2	5.3	3.0
China	241	1,030	2,307	4,112	6,386	4.8	10.6	6.0	4.5	6.7	2.9
India	61	330	534	1,003	1,771	5.6	6.2	6.5	5.9	6.2	3.1
SE Asia	39	311	459	683	935	6.9	5.0	4.1	3.2	4.0	3.2
Other	292	1,145	1,520	2,165	2,966	4.5	3.6	3.6	3.2	3.5	3.0
Other countries	17	114	133	155	175	6.4	2.0	1.5	1.3	1.6	1.6
Bunkers	106	146	158	175	193	1.0	1.0	1.0	1.0	1.0	
World	4,916	9,264	12,082	16,006	20,752	2.1	3.4	2.9	2.6	2.9	1.7

Source: Historical data to 2003 is from IEA website (http://data.iea.org/ieastore/statslisting.asp) with projections by the authors.

Fuel Use Type (s^{j}_{i}) and Emissions Intensity of Fuel Type (m^{tj}_{i})

The values of s^{tj}_{i}, the shares of various fuel types in total energy use, are varied from the IEA (2004a) estimates only for two countries, India and China, where later information and increased knowledge of the emerging energy use path are available. For China, one key change is that, given the large-scale expansion of coal-fired electricity generation capacity that is currently underway, the decline in coal's share of TPES is less rapid than in IEA (2004a) – to 64% in 2030 rather than 59.2%. But a more rapid expansion of non-fossil fuel and renewable energy sector is also envisaged, given official commitments in this regard, with renewable sources providing 8% of TPES by 2030, by comparison with 5.8% in IEA (2004a). With the share of natural gas also marginally higher, the share of oil falls significantly in our projections (from 24.5% in 2002 to 21% in 2030), rather than rising to 28.5% in IEA (2004a). Similar, though more limited, adjustments are made for India, with the coal share somewhat higher by 2030 (49.0% as compared with 47.1%), the share of renewables higher also (8.0% as compared to 6.8%) and a sharper decline in the oil share.

In terms of aggregate fuel use, the most important factor is not these adjustments to fuel type shares for China and India, but the shift in the global pattern of energy use over the period 2002–30 to countries such as India and China that are heavy users of coal. In 2002 coal provided 69.2% of TPES in China and 49.0% in India, by comparison with 21.3% for the OECD countries. The result is a sharp shift in global energy supplies to coal over the period to 2030, with 33.8% of world TPES being provided by coal in 2030, by comparison with 25.9% in 2002 and 24.5% in 2030 on the IEA (2004a) projection. On our projection, as with IEA (2004a), the share of world

TPES met from renewable sources falls, from 10.5% in 2002 to 9.1% in 2030. This is the net effect of rapid growth in coal use, the long-term effects of the closure of nuclear power plants in the developed countries and rapid growth in many forms of renewable energy from a very low base in 2002.

For all countries/regions, the values of m^{tj}_{i}, the level of CO_2 emissions per unit of energy supply for different fuel types, from IEA (2004a) are used.

The Projections

Global CO_2 emissions are projected to rise from 6.7 billon tonnes of carbon in 2002 to just on 16 billion tonnes by 2030, an increase of 137% or 3.1% per annum (Table 6). Growth in the current decade is particularly strong (3.7% per annum over 2002–10) and continues at a slowing rate over the next two decades. Emissions from the OECD and the transition economy regions both grow at 1% per annum or more over 2002–30, reflecting increasing energy use with limited transition to renewable energy sources. Nevertheless, the major increase in emissions comes from the developing countries, whose emissions are projected to grow at a somewhat faster rate (5.4% per annum) over 2002–30 than over 1971–2002 (4.8%). China generates over the half of the increase in global emissions to 2030, but India will also be important as its power generation system develops, and the two countries together account for 65% of the emissions to 2030.

Table 6. CO_2 Emissions from fuel combustion and cement production, actual 1971–2002, projected to 2030 (GtC)

	1971	2020	2030	1971-2002	2002-10	2010-20	2020-30	2002-30
	(Gigatonnes of carbon)				(Per cent per annum)			
OECD	2.6	4.3	4.6	0.9	1.4	1.0	0.6	1.0
North America	1.3	2.2	2.4	1.0	1.5	1.0	0.7	1.0
Europe	1.0	1.3	1.3	0.2	1.1	0.8	0.2	0.7
Asia	0.2	0.6	0.7	2.3	1.7	1.6	1.1	1.4
Oceania	0.0	0.1	0.1	2.8	1.7	1.4	0.6	1.2
Transition economies	0.6	0.9	1.0	0.2	1.7	1.3	0.9	1.3
Developing countries	0.5	6.7	10.0	4.8	7.0	5.3	4.1	5.4
China	0.2	3.9	5.8	4.9	10.2	5.9	4.2	6.5
India	0.1	0.9	1.5	5.4	5.9	6.4	5.5	5.9
SE Asia	0.0	0.5	0.7	6.9	4.8	4.1	3.3	4.0
Other developing	0.2	1.5	2.1	4.0	3.4	3.6	3.2	3.4
Other countries	0.0	0.1	0.2	6.3	3.0	2.7	2.2	2.6
Bunkers	0.1	0.2	0.2	1.0	1.0	1.0	1.0	1.0
World	3.9	12.4	15.9	1.8	3.7	3.7	2.7	3.1

Source: Historical data to 2003 is from IEA website (http://data.iea.org/ieastore/statslisting.asp) with projections by the authors.

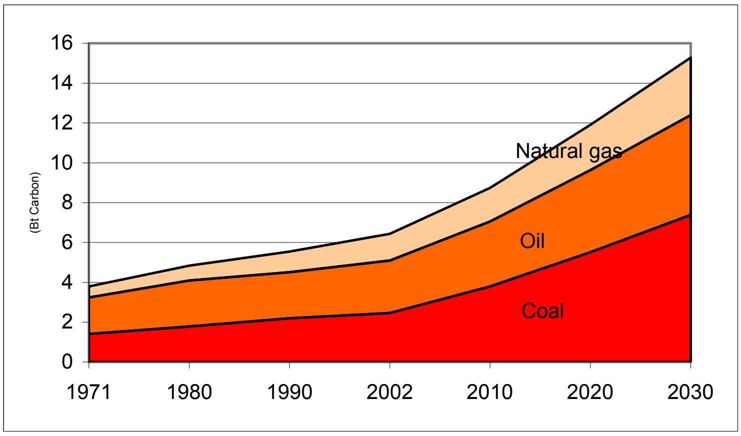
Rising emissions from developing countries reflect the combination of strong growth in energy demand and heavy reliance on coal for fuel supply, especially in China and India. Increased use of coal accounts for 55% of the global increase in CO_2 emissions to 2030 (Figure 1, upper panel); emissions from coal use rise at 5.6% per annum over

2002–10 and 4.0% per annum over 2002–30. This is a continuation of recent trends: global consumption of coal rose by 5.3% per annum between 2000 and 2005 (British Petroleum 2006).

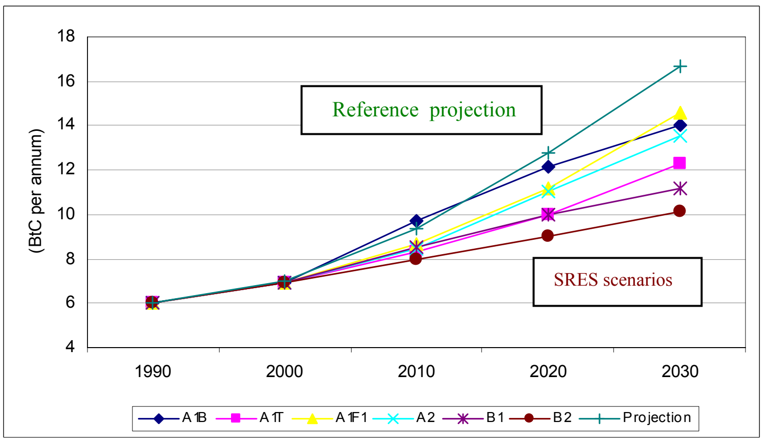
It is important to note that the main factor generating much faster growth in the projection period than over 1971–2002 is not increased growth in emissions in either developing countries (5.4% over 2002–30 compared with 4.8% over 1971–2002) or in the OECD countries (1.0% compared with 0.9%), but the much increased weight of the developing countries in world aggregates. In this respect the finding of more rapid growth in emissions over 2002–30 is very robust – even if emissions growth in developing countries over 2002–30 were at or below the 1971–2002 rate, an unlikely outcome given the rapid growth that is underway, global emissions growth over the projection period would still be much more rapid that over 1971–2002.

Figure 1. Global CO_2 emissions from fuel combustion, 1971–2030, by fuel type (upper panel) and comparison of projected CO_2 emissions with corresponding values for the six SRES scenarios, 1990s to 2030s (lower panel)

Unchanged policy CO_2 emissions projection, by fuel type



Comparison of projection with SRES scenarios paths, to 2030s



Note: Data for the upper panel exclude emissions from cement production and are for the calendar years shown, while the lower panel data include cement and are scaled to the common 1990s value used for the SRES scenarios.
Source: IPCC (Houghton et al. 2001, Appendix II) and estimates of the authors.

As shown in Figure 1 (lower panel), this unchanged policy projection is well above the envelope described by the six SRES marker scenarios over the next three decades, with average emissions for 2030, for example, being 14%–65% higher in the projections than in the SRES scenarios. This shows that the SRES scenarios, developed in the second half of the 1990s and representing the state of the art at that time, do not accurately describe emerging emissions trends over the next few decades. Hence they no longer provide a reliable tool for medium term analysis of human impacts on the climate.

4. Comparison with Other Reference Projections

Comparison with IEA (2004a), ABARE (2006a) and EIA (2006) Reference Case Projections

The CO_2 emissions projections to 2030 presented in Table 6 above cover emissions from fuel combustion, including bunkers and cement production, to be consistent with the data used by the IPCC. The IEA (2004a) projections do not include cement, and key statistics on our projections on this basis are provided in Table 7. As previously discussed, the current projections are close to IEA (2004a) for the OECD countries, the only variance being in somewhat stronger emissions from Japan and South Korea and from Oceania. The key differences are for India and China, where projected growth rates for CO_2 emissions are double (for India) and more than double (for China) those of IEA (2004a). The revised treatment of China and India accounts for over 90% of the variation between our projected value of emissions in 2030 and the IEA projections of 2004. Projected growth rates are also somewhat higher for other developing countries.

Table 7. Average annual rates of growth of CO_2 emissions from fuel combustion (excluding cement) and GDP, actual 1971–2002 and projected 2002–2030, and elasticity of energy use 2002–2030, IEA (2004a) and current report

	CO_2 emissions			GDP growth			Elasticity of energy use with respect to GDP		
	Actual	Projection		Actual	Projection		Actual	Projection	
		Current report	IEA (2004a)		Current report	IEA (2004a)		Current report	IEA (2004a)
	1971-2002	2002-30	2002-30	1971-2002	2002 -30	2002-30	1971-2002	2002 -30	2002-30
	Average annual percentage change (% pa)						Level		
OECD	0.9	1.0	0.9	2.9	2.3	2.2	0.50	0.43	0.39
North America	1.0	1.0	1.0	3.2	2.4	2.4	0.45	0.42	0.42
Europe	0.2	0.7	0.7	2.4	2.1	2.1	0.45	0.28	0.28
Asia	2.4	1.5	0.7	3.5	2.5	1.9	0.84	0.70	0.50
Oceania	2.8	1.2	0.8	3.0	2.9	2.3	0.85	0.50	0.44
Transition economies	0.2	1.3	1.3	0.4	3.7	3.7	1.37	0.36	0.36
Developing countries	4.6	5.4	2.9	4.7	5.9	4.3	1.04	0.91	0.70
China	4.6	6.6	2.8	8.5	7.3	5.0	0.57	0.92	0.58
India	5.4	6.0	2.9	4.9	6.5	4.7	1.15	0.92	0.65
SE Asia	6.8	4.1	3.3	5.4	4.5	3.8	1.28	0.90	0.85
Other	4.0	3.4	3.0	3.1	4.0	3.4	1.46	0.86	0.87
Other countries	6.3	2.6	2.6	6.4	3.2	3.2	0.99	0.49	0.49
Bunkers	1.0	1.0	0.4						
World	1.8	3.1	1.7	3.3	4.0	3.2	0.63	0.72	0.54

Source: IEA website (http://data.iea.org/ieastore/statslisting.asp), IEA (2004) and projections by the authors.

The upshot is projected growth in global CO_2 emissions of 3.1% per annum to 2030, by comparison with the IEA (2004a) figure of 1.7%, and also with growth over 1971–2002 of 1.8%. Given the point made above about the changing weight of developing countries, IEA (2004a) projects much the same growth rate of global over 2002–30 as over 1971–2002 only as a result of a projected sharp slowing of the growth of CO_2 emissions from developing countries, from 4.8% over 1971–2002 to 2.9% over 2002–30. For the critical cases of China and India, IEA (2004a) projects growth rates for CO_2 emissions over 2002-30 little over half those of the thirty years to 2002, whereas our projections show somewhat increased growth in emissions for these countries.

Table 8. Comparison of key reference case projection variables for ABARE (2006a), EIA (2006) and the current report

	Annual growth rate, 2002-30[1] (% pa)			
	China	India	Other countries	World
GDP				
- CSES	7.3	6.7	2.7	4.0
- ABARE	6.3	6.0	2.0	3.1
- EIA	6.1	5.5	3.2	3.8
Total primary energy supply				
- CSES	6.7	6.2	1.7	2.9
- ABARE	4.0	3.6	1.5	2.0
- EIA	4.4	3.1	1.6	2.0
CO_2 Emissions				
- CSES	6.5	5.9	1.7	3.1
- ABARE	4.2	3.7	1.7	2.3
- EIA	4.3	2.8	1.5	2.1
Memorandum Items				
Elasticity of energy use to GDP				
- CSES	0.92	0.92	0.63	0.72
- ABARE	0.67	0.62	0.75	0.65
- EIA	0.72	0.56	0.50	0.53
CO_2 emissions in 2030 (Gt C)				
- CSES	5.82	1.46	8.62	15.90
- ABARE	3.24	0.85	9.12	13.20
- EIA	2.92	0.60	8.38	11.90

[1]For ABARE projections, 2001-30.
Source: ABARE (2006a), EIA (2006) and estimates of the authors.

It is also useful to compare our projections with the reference case projections in two other sets issued in mid 2006 – the International Energy Outlook projections prepared by the Energy Information Agency (EIA) of the US Department of Energy (EIA 2006) and those issued by the Australian Bureau of Agricultural and Resource Economics (ABARE 2006a). It is again apparent from the summary provided in Table 8 that, for CO_2 emissions from fuel combustion in 2030, the projections in the current report are significantly higher than those of either ABARE or IEA, the differential being 20.5% with respect to ABARE and 33.6% with respect to IEA. Table 8 reports growth rates for an aggregate for all countries other than China and India, which is a very diverse group including the OECD and all other developing countries, as well as some countries not included in either group. While there are various differences between the projections in handling these countries, the net effect in terms of emissions in 2030 is relative small. The key difference again remains in the projections for China and India

– our projections for CO_2 emissions in 2030 from these two countries taken together (7.3 Gt C) are 78% higher than those of ABARE and 107% higher than those of EIA. While there are some significant differences in projected growth rates, and some minor differences in the transition from energy use to emissions, the major source of difference lies in the energy intensity of growth, measured here by the elasticity of energy use with respect to GDP.

Recognising the New Growth Path – the Case of China and India

It is widely accepted that the world has entered a new growth path, with that growth being driven substantially by an historic, long-run process of re-emergence of China and India as global economic powers. The analysis above shows that the main outstanding issue in projecting emissions is the quantitative interpretation of this new growth path, and of its implications for energy use, especially for these two countries. In terms of energy use, for China this is a matter of interpreting the dramatic changes in industrial production and energy use actually taking place, while for India it involves assessing the likely implications of current plans to expand energy production sharply to meet to needs of a burgeoning economy. These matters are discussed briefly below.

The pace of developments in China can be illustrated by reference to the latest official projection of China's energy use and emissions. 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, very close to the outcomes for 1971–2002 noted above.

Table 9 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 2006) 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. A senior official of the National Development and Reform Commission expects the figure to reach 575 GW by the end of 2006 and 800 GW by 2010, 43% above the projection for that year (*People's Daily Online* 2006a). 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, and still rising strongly in 2006. 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 9. Projections for selected variables, reference scenario, national comprehensive energy strategy and policy to 2020, and actual values for 2005

	Actual 2000	Strategy Report – Scenario A 2005	2010	2020	Actual 2005	Growth rate 1st half 2006[2]
Primary energy demand (mtce)	1297	na	2137	3280	2225	na
Electricity generation capacity (GW)	319	402	559	947	505	na
Demand for fossil fuels						
Coal (100 m tons)	12.7	16.2	20.0	29.0	21.4	13.8[3]
Oil (100 m tons)	2.3	2.9	3.8	6.1	3.0	na
Natural gas (100 m cubic metres)	272	399	840	1654	500	na
Output of main energy intensive products						
Iron and steel (m tons)	128.5	250	300	280	352	18.3
Cement (m tons)	597	680	790	1070	1060	20.8
Ethylene (10,000 tons)	450	790	1200	2000	756	18.2
Synthetic ammonia (10,000 tons)	3346	3600	3800	4000	4222[1]	na
Paper (10,000 tons)	2487	4000	5000	7500	4864[1]	24.9

Note: [1]2004 values. [2]Relative to the same period in 2005. [3] For the first four months of 2006.
Sources: For actual 2000 and strategy report values see. Actual data for 2005 from NBSC (2006) and for 2004 from NBSC (2005a). Coal consumption growth in 2006 from Zhou (*People's Daily Online* 2006b).

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 9). 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. Indeed, for four of the five cases, the 2006 figure will exceed the projection for the year 2020. 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 in the EIA and ABARE scenarios.

In China, energy intensive development has now proceeded for some time, and there has been massive investment in the energy infrastructure necessary to fuel that growth. In the case of India the issue is one of prospect rather than present reality, and hence of the view taken of India's commitment to rapid economic growth, to increased industrial capacity and to building the energy system to support such growth. As noted above, the Indian Government is seriously targeting 8–9% growth for the 11th Plan period (2006–07 to 2011–12), with an increased emphasis on industry, recognises rapid expansion in energy infrastructure and energy supplies as critical to that target, and is pursuing a wide range of measures to increase energy supplies. For example, in its initial approach to the 11th Plan, the Planning Commission notes that growth in energy generating capacity of about 7.5% per annum will be necessary if the growth target is to be achieved, and that coal demand is likely to rise at about the same rate. Given recent initiatives, heavy investment is taking place in both coal production and electricity generation capacity, and a vast array of projects have been approved by the Central Electricity Authority (www.cea.nic.in).

It is possible to discount heavily India's prospects for rapid growth, and also its ability to address historical problems so as to expand energy supplies rapidly. Such discounting is implicit in the ABARE and EIA projections, which imply growth in

TPES in India to 2030, at 3.6% and 3.1% respectively, is well below the average growth rate for 1971–2002 of 5.4%. Our projections are based on the view that such large discounting is unrealistic, and that India will in fact achieve a substantial expansion in its energy supplies, from both domestic and foreign sources, to fuel strong growth. The Government has clearly identified the expansion of power supplies as critical to achieving sustained economic growth, and its recent record suggests that much will be achieved to this end.

5. Technology and Emissions to 2100 – A Lower Bound Approach

An unchanged policy projection is not possible beyond 2030, but we construct a reasonable lower bound to emissions beyond 2030. Use of fossil fuels after 2030 will be further constrained by rising prices and supply limitations, even though under these conditions advanced technologies could bring large additional supplies of oil and gas into play (IEA 2005a), and supplies of coal are plentiful. The dominant factor for CO_2 emissions is likely to be the development and diffusion of technologies related to energy production and use, which will also be spurred by higher fossil fuel prices.

There is now an extensive literature on energy related technologies, which includes fourteen IEA reports (IEA 2003, 2004b, 2004c, 2004d, 2005b, 2005c, 2005d, 2005e, 2005f, 2005g, 2005h, 2005i; Riis and Hagen 2005; Riis and Sandrock 2005), two OECD studies (2004, 2005), one recent IPCC report (2005b) and several other sources (*Technology Quarterly* 2005; *The Economist* 2001). These sources have been drawn on to assemble the summary of the status of the major new technologies affecting energy use and emissions from fuel combustion (other than for energy use in industrial processes or in buildings) provided in Table 10. For a detailed discussion of these and related issues, see Supporting Papers 3-7.

While much R&D is being undertaken, few technologies under development are the subject of truly large-scale, focused efforts. New products and processes need critical mass to reduce costs to competitive levels, but achieving critical mass is constrained by long asset lives for existing plant and by the wealth of competing technologies. The result is that, on unchanged policies, gradual diffusion of more efficient technologies for producing and using energy, and of non-fossil fuel methods of energy production, will continue through to about 2030, but this will remain a limited process in OECD countries. For developing countries the aggregate effects of advanced technologies are likely to be modest through to 2030. This gradual diffusion of more efficient technologies for producing and using energy is embodied in the reference projection to 2030.

In the longer term the situation is likely to be quite different. By about 2030 many technologies – such as ultra light weight hybrid or fuel cell vehicles, much improved buildings systems, advanced fossil fuel power generation, carbon capture and storage, energyplexes and a wide array of renewable energy technologies – are likely to be commercially proven and becoming increasingly used, especially in OECD countries. By about 2050 the most successful of these technologies should be mature, with growing market share in OECD countries and, in due course, in developing countries. Other new technologies, such as nuclear fusion or advanced hydrogen technologies, are likely to become commercially viable in the second half of the century. The factors stressed above constrain the technology diffusion process – cost competitiveness, critical mass, slow turnover of capital stock, parallel advances in fossil fuel and renewable technologies and delayed adoption in the developing countries – will all continue to be operative, even in the context of rising fossil fuel prices.

Table 10. The status of selected new technologies for energy production and use: A summary of recent reviews

Transport	Buildings	Non-renewable energy	Renewable energy
Currently In Commercial Use – Diffusion Underway			
Biofuels from sugar	Building energy management	Efficient power plants	Wind energy - onshore
Advanced two- stroke engines	Commercial energy efficiency – design and retrofit	Combined Heat and Power (CHP) systems	Solar photovoltaics
Hybrid electric vehicles	Advanced lighting and hot water technologies		Geothermal energy
Non-engine technologies for road vehicles; advances in aerospace technologies	Energy efficiency – equipment and appliances		
Commercially Available – Diffusion Beginning			
Light weight materials technologies	Advanced heating/cooling systems	Advanced sensors and controls	Advanced hydropower systems
Advanced people-mover systems	Residential energy efficiency – design and retrofit	Improved electricity transmission/distribution	Geothermal energy
Electronic road pricing		Advanced gas turbines	
Advanced transit systems			
Commercial Prospects Beyond 2020/2030			
Biofuels from cellulosic fibres	Distributed energy systems (solar, fuel cells) in buildings	Advanced CHP systems	New designs for nuclear power/waste storage
Fuel-cell road vehicles	Further advances in heating, cooling, refrigeration systems	Power electronics	Advanced bioenergy and biomass systems
Intelligent vehicle highway systems	Further advances in lighting, hot water, equipment, appliance technologies	Integrated energy production and use systems (energyplexes)	Production of hydrogen from fossil fuels
			Advanced solar photovoltaics
Self-driving cars	Insulation in windows, panels	Superconducting cables	Advanced energy storage
Ultra light weight vehicles		Carbon capture/storage	Solar thermal energy
			Wave energy, marine currents
			Wind energy – offshore
			Geothermal hot dry rock technology
			Integrated hydrogen systems
			Liquid hydrogen storage
Commercial Prospects Beyond 2050			
Hydrogen-fuelled aircraft		Wide diffusion of energyplexes	Nuclear fusion technologies
Alternative fuel marine vessels		Diffusion of carbon capture and storage technologies	Tapping the ocean salt-gradient
New types of urban freight systems			New hydrogen production methods
			Solid hydrogen storage

Source: Seventeen international agency review studies between 2003 and 2005: fourteen from the IEA, two OECD studies, one IPCC report plus other sources. For details of these and other sources see text. The table does not cover technologies related to energy use in industrial processes or in buildings: many energy saving technologies are being introduced progressively here, and will continue to be introduced over forthcoming decades.

A matrix of emissions growth rates has been developed to create a path through to 2100 that provides a reasonable lower bound to CO_2 emissions, in the context of the factors discussed above and of the dynamics of the projection path to 2030 (see Table 11). Emissions are assumed to stabilise in the OECD countries in the decade after 2030, and then to fall at an accelerating rate. The transition economies follow a similar path with a lag of a decade or more. Given the underlying momentum of their development processes, together with a higher emissions elasticity of GDP, a slower path of adoption of advanced technologies and their heavy reliance on coal, emissions from China, India and other developing countries continue to increase over 2030–2060, but at a slowing rate. As new technologies become increasingly adopted emissions fall at an increasingly rapid rate after 2070. On this path global CO_2 emissions from fuel combustion peak at 22.6 Gt C in 2060 but falls to about one quarter of that level by 2100. Even as a lower bound, the emissions path beyond 2030 is indicative only, and other specifications for such a path could be provided. On this reference path, emissions from the OECD and transition economies are virtually eliminated by 2100, and global emissions by 2100 are only 63% of their level in 2030, and falling rapidly. Given the projection to 2030 and the ongoing dynamics of the knowledge economy, this would be a substantial achievement.

Table 11. Growth rate matrix for CO_2 emissions from fuel combustion beyond 2030, and resulting emissions reference path, to 2100

	1971-2002	2002-10	2010-20	2020-30	2030-40	2040-50	2050-60	2060-70	2070-80	2080-90	2090-2100
Growth in emissions											
OECD	0.9	1.4	1.0	0.6	0.0	-1.0	-2.0	-3.5	-5.0	-7.5	-7.5
Transition economies	0.3	1.7	1.3	0.9	0.7	0.3	0.0	-1.0	-2.0	-3.5	-5.0
China	4.9	10.2	5.9	4.2	3.0	2.0	1.0	0.0	-1.0	-2.0	-3.5
India	5.5	5.9	6.4	5.5	3.0	2.0	1.0	0.0	-1.0	-2.0	-3.5
Other	3.8	3.4	3.7	2.2	2.0	1.7	1.1	0.0	-1.0	-2.0	-3.5
	2002	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
CO_2 emissions											
OECD	3.5	3.9	4.3	4.6	4.6	4.2	3.4	2.4	1.4	0.6	0.3
Transition economies	0.7	0.8	0.9	1.0	1.0	1.1	1.1	1.0	0.8	0.5	0.3
China	1.0	2.2	3.9	5.8	7.8	9.3	10.5	10.5	9.5	7.8	5.4
India	0.3	0.4	0.9	1.5	2.0	2.3	2.6	2.6	2.4	1.9	1.4
Other	1.3	1.4	2.0	2.8	3.4	4.0	4.5	4.5	4.1	3.3	2.3
World	6.7	8.9	12.2	15.9	19.1	21.3	22.5	21.4	18.6	14.6	10.0

Source: Historical data to 2002 is from IEA website (http://data.iea.org/ieastore/statslisting.asp) with projections by the authors.

The lower bound characteristic of the overall path in the long term can be brought out by comparing it to the reference path to 2100 recently provided, but not published in any detail, by the Australian Bureau of Agricultural and Resource Economics for the first meeting of the Asia-Pacific Partnership on Clean Development and Climate (ABARE 2006b). The ABARE path is somewhat lower than that of Table 11 in the earlier decades, with emissions of about 17.5 billion tonnes by 2050, but in it emissions continue to increase after 2050, and exceeds 30 billion tonnes by 2100.

6. Climate Outcomes

The climate-related risks associated with the reference path are explored using the most recent version of the simple climate model, MAGICC (Wigley 2000) (see also www.cgd.ucar.edu) and a small set of damage functions. MAGICC consists of a suite of coupled gas-cycle, climate and ice-melt models and has been used extensively to compare the global climate implications of different emissions scenarios and to explore the sensitivity of results to different model parameters.

One crucial input is the climate sensitivity parameter: the equilibrium global mean temperature consequent to a doubling of the atmospheric CO_2 concentration relative to pre-industrial levels. Recent work describes the systematic accounting of uncertainties in model inputs to derive a probability density function for its value (Andronova and Schlesinger 2001; Mastrandrea 2004; Forest et al. 2002; (Murphy et al. 2004; Stainforth et al. 2005). We use the results of Murphy et al. (2004), who found that the 5/95% range for this parameter was 2.4–5.4°C, with a median of 3.5°C. Non-CO_2 greenhouse gas emissions were scaled from the P50 scenario in MAGICC 4.1 (an average of the six SRES marker scenarios) according to the CO_2 emissions in Table 11. Sulphate aerosols from the A1B marker scenario were scaled in a similar manner. All parameters in the model, other than climate sensitivity, are at the mid range.

Table 12. Climate outcomes (atmospheric CO_2 concentration and global mean temperature) for reference path, MAGICC model

Climate sensitivity (°C)	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
	Atmospheric CO_2 concentration (ppm)									
3.5	390	420	461	511	568	629	688	736	769	784
	Atmospheric CO_2 equivalent (All GHG) concentration (ppm)									
3.5	357	404	507	639	737	864	966	1022	1039	1024
	Increase in global mean surface temperature, relative to 1990 levels (°C)									
2.4	0.26	0.44	0.78	1.26	1.70	2.20	2.65	2.95	3.12	3.18
3.5	0.33	0.55	0.97	1.57	2.13	2.78	3.37	3.80	4.06	4.18
5.4	0.41	0.69	1.20	1.94	2.66	3.48	4.25	4.84	5.23	5.46

Note: This figures may be slightly revised for the final document.
Source: Estimates prepared based on MAGICC model runs, as described in the text.

The key results are summarised in Table 12. Given rapid growth in emissions in the near-term, the atmospheric CO_2 concentration level rises at similar rates to the highest of the SRES scenarios, A1FI, through to 2050 when 550 ppm is exceeded. Decelerating emissions growth after 2050 produce levels approaching 800 ppm by 2100. The increase in global mean temperature by 2100, relative to 1990 levels, ranges from 3.2°C to 5.5°C, with an increase of 4.2°C for the median value of climate sensitivity. If CO_2 emissions follow the unchanged policy projection to 2030 and, over 2030–2100 are assumed to be lower bound estimates, then rapid increases in global temperatures to 2100 are anticipated.

7. Potential Damage from Climate Outcomes

Such changes, if unchecked, may have serious consequences, in terms of both market and non-market damages. For economic damage mediated through the market, the damage function is non-linear in temperature (Nordhaus and Boyer 2000). Recent estimates by Nordhaus suggest that market damage may be much greater than previously estimated, with a 3% reduction in global output (using population weights) for a 3° rise in temperature. Here we concentrate on non-market damages, including the risk of setting in train large scale physical processes, such as the shutdown of the thermohaline circulation or disintegration of the West Antarctic and Greenland ice sheets, which would be irreversible and would have major consequences for ecosystems and for economic and social life (National Research Council 2003; Alley et al. 2003; Jones 2003).

Table 13 summarises recent findings about the critical thresholds for major impacts in key areas of vulnerability, where a critical threshold is defined as the point at which the relationship between a change variable and an outcome becomes highly negative or non-linear. Critical thresholds for most activities remain highly uncertain. However, the outcomes shown in Table 12 from the reference path on the median value of the climate sensitivity parameter (a CO_2 concentration of 784 ppm (1,024 ppm CO_2-equivalent concentration) and warming of 4.2°C by 2100) exceed the lower published estimates of critical thresholds listed in Table 13 other than for the shutdown of the thermohaline circulation.[2]

Table 13. Potential critical thresholds for nine non-market vulnerabilities

Vulnerability	Global mean limit
Shutdown of thermohaline circulation	5-25°C[1]
Disintegration of West Antarctic ice sheet	2–4°C; <550 ppm CO_2[2,3]
Disintegration of the Greenland ice sheet	1-3°C[4,5]
Widespread bleaching of coral reefs	1-2°C[6,7]
Broad ecosystem impacts with limited adaptive capacity	1–2°C[8,9]
Reversal of net global terrestrial carbon uptake	2–3°C[10]
Large increase of persons at risk of water shortage in vulnerable regions	450–650 ppm CO_2[11]
Rising real food prices; food security issues for developing countries	>2.5°C[12]

Source: Adapted from Oppenheimer and Petsonk (2005); for a review of these and other vulnerabilities, see Pittock (2005).
Notes: [1]Cubasch (2001). [2]Oppenheimer and Alley (2005). [3]Oppenheimer and Alley (2004). [4] Hansen (2005). [5]Greve (2000). [6]Hoegh-Guldberg (1999). [7]Sheppard (2003). [8]Leemans and Eickhout (2004). [9]Hare (2003). [10]Jones et al. (2003). [11]Parry (2001). [12]Easterling and Apps (2005).

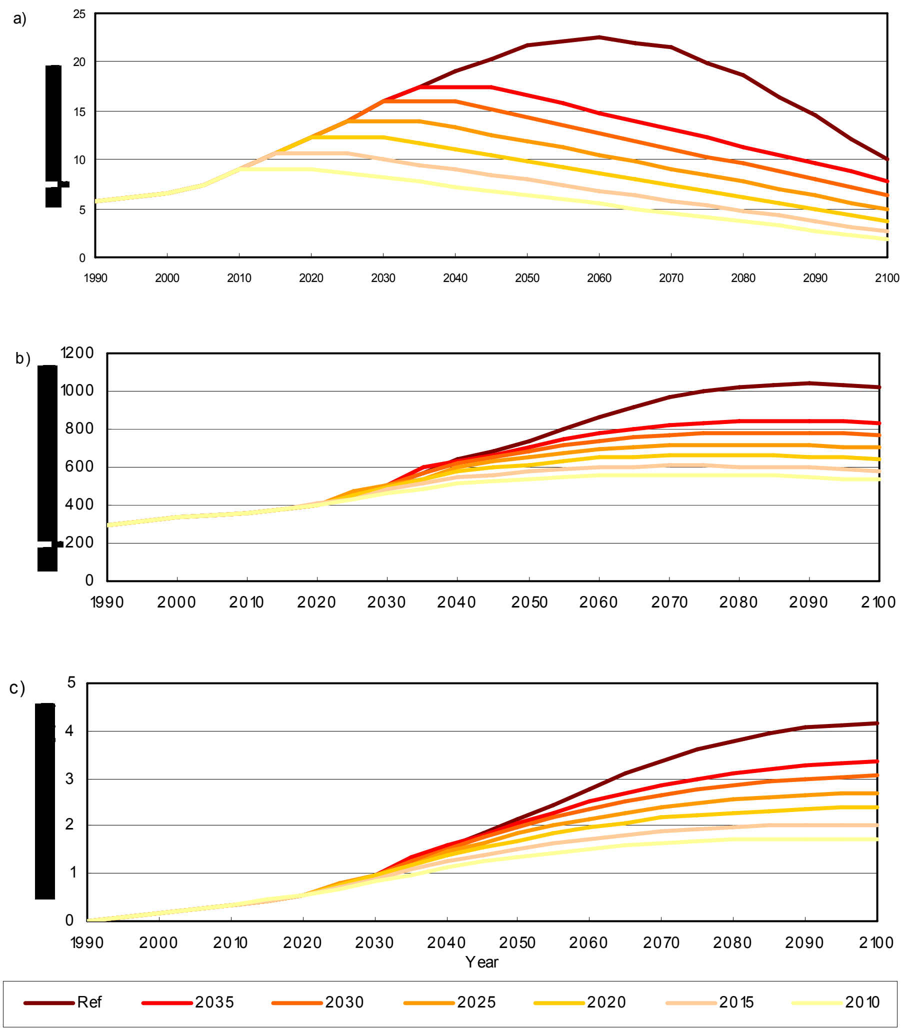
8. Timing and the Policy Window

The most appropriate approach for setting climate policy is to assess both the risks associated with given policy options in tandem with the benefits achieved by taking this policy path. Here, we look at the time scale of opportunities to minimize climate-related damages. We again follow a lower bound approach, and define a series of minimum emissions paths (MEPs) from different points on the reference path over the next three decades. These paths stabilise average global emissions over a decade and

[2] In subsequent unpublished work at the CSIRO Division of Marine and Atmospheric Research, Roger Jones, Benjamin Preston and their colleagues have taken this analysis further. Through an original meta-analysis of the literature on four key vulnerabilities – catastrophic damage to coral reefs, irreversible melting of the Greenland ice-sheet, species extinction and slowdown of the thermohaline circulation – to derive relationships linking global warming to the probability of major damage in these areas. Their results show that projected warming on the reference path exceeds critical thresholds for catastrophic damage to coral reefs and for irreversible melting of the Greenland ice-sheet, and implies heavy species extinction and significant thermohaline circulation slowdown.

then eliminate them over the long term. Specifically, an MEP from year *n* is defined as a path in which the level of emissions over the period from years n_{+1} to n_{+10} is equal to that in year *n* and in which after year n_{+10} emissions are reduced to zero over the next 100 years, in equal absolute annual reductions, implying an accelerating percentage rate of decline. We specify the first path from 2010, and also explore paths from 2015, 2020, 2025, 2030 and 2035. These MEPs for CO_2 emissions are shown, relative to the reference path, in the upper panel of Figure 3. Many alternative paths are possible but, given the long-term nature of adjustment processes in political, economic and energy systems, achieving this stringent specification of emissions reduction from a given starting would require a major effort. Adoption of an MEP by a given date reflects a presumed decision by the international community to contain and reduce CO_2 emissions, and is taken as a quantification of the best that might be achieved in implementing such a decision.

Figure 3. a) CO_2 Emissions, b) Atmospheric CO_2-equivalent Concentration Level and c) Change in Global Mean Temperature Relative to 1990, Reference Case and Minimum Emission Paths, 1995–2100



Source: Estimates prepared based on MAGICC model runs, as described in the text.

In using the MAGICC model, for each MEP non-CO_2 greenhouse gases and sulphate emissions are reduced relative to the reference path by the same percentage as for CO_2. All other specifications and assumptions are as for the modelling of the reference path.

The results are reported in Figure 3 only for the case of the median value of the climate sensitivity parameter (3.5°C).

If an MEP were established by 2010, the atmospheric CO_2 concentration level would rise rapidly to about 460 ppm (540 ppm CO_2-e) by 2050 and stabilise slightly above that level. For the median value for climate sensitivity, the global mean temperature increase would be about 1.3°C by 2050 and would stabilise at about 1.7°C. On this path most of the major impacts from the key vulnerabilities covered in Figure 2 might be avoided, although warming might be much greater than this if a higher than median value of the climate sensitivity parameter applies. On the other hand, if achieving an MEP were delayed to 2035, the CO_2 concentration level rises to 575 ppm by 2050 and to close to 700 ppm by 2100, while the global temperature is 2.3°C by 2050 and 3.4°C by 2100, using the median sensitivity estimate. On the MEP 2035 path there is a very high likelihood of irreversible melting of the Greenland Ice-sheet, virtual elimination of coral reefs, nearly 50% species extinction and a substantial shutdown of the thermohaline circulation.

The key implication of this analysis is that the rapid increase of emissions to 2030 means that the window for avoiding critical thresholds is closing rapidly, but that immediate action can still substantially reduce the risks of incurring the major damages covered in Table 13. Thus avoiding these so-called ‘catastrophic’ damages is an immediate policy issue, not one for the longer term. If serious and coordinated action is not taken within the next decade, the window will have closed in many cases.

9. Market Failures and Policy Instruments

There is an extensive literature on the cost-benefit assessment of climate change mitigation policies and hence about whether the policies that would be required to avoid the outcomes sketched above, if such policies are available, would be justified in terms of the discounted value of the benefits exceeding the costs incurred. In this report we leave the question of cost-benefit assessment aside for further study, and investigate the implications of the analysis for the nature of the policies that might be necessary.

Most assessments of climate mitigation policies take place within a market economy framework, and start from two points: (i) policies that as far as possible conform with and make use of market forces are likely to be more efficient in achieving an agreed outcome than those that do not, and (ii) market failures are widespread in aspects of the economy relevant to climate outcomes, and hence some policy initiatives are likely to be necessary to achieve optimal outcomes. Four such market failures are of prime importance, and flow in part from the fact that the climate is a public not a private good (being both non-excludable and non-rival), and that the both climate effects and the future actions of agents, including governments, are highly uncertain:

- *Climate costs and benefits are not borne by originating agents*: the costs of climate damaging activities are not fully or even largely borne by those who create the damage, nor do the benefits of climate enhancing activities flow to those undertake these activities.

- *Extensive information failures*: in many areas information failures abound, so that agents make decisions without full realisation of either the private or social costs and benefits of their activities.
- *Sunk costs in energy and environmental technologies*: there are heavy sunk costs involved in power stations and many other forms of energy and environmental investment, so that plant lives are long, diffusion patterns are slower than optimal and many socially desirable clean technologies may not be implemented.
- *Non-appropriability of results of investment in new technologies*: firms that create new technologies are typically unable to prevent extensive spillovers to other firms and to the public, and so capture only a part of the return on their investment. This means that, taken together with uncertainties about future demand and sunk costs in the diffusion process, investment in R&D on technologies for energy use or emissions reduction is likely to be well below the optimal level.

The effects of these various market failures may well be cumulative. For example, each of the first three factors may add to the problems faced by firms considering an investment in R&D directed at a clean power generation technology – the fact that power prices do not reflect true social costs, that future trends are uncertain and that there are heavy sunk costs in power generation may all add to the problems of obtaining reasonable assurance of an adequate return on R&D. But each is a separate market failure, so that in principle a policy initiative is required in each area if an optimum outcome is to be achieved.

Corresponding to these four forms of market failure, there are four sets of potential policy initiatives – measures to ensure that market prices reflect social costs, information provision programs, support for investment in new plant and equipment deemed to have social benefits (e.g. renewable energy) and support for technology development. There has for some time been an extensive literature on the optimum choice of policy instruments for reducing emissions, and more recently studies have appeared that compare a wide range of different instruments to this end (e.g. Fischer and Newell 2005; Gerlagh and van der Zwaan 2006). Fischer and Newell conclude that measures involving a direct price for emissions (such as a carbon tax or a tradeable permit system) provide the most efficient way of reducing emissions, because they provide incentives for fossil fuel energy producers to reduce emissions per unit of output, for consumers to conserve energy and for renewable energy producers to undertake R&D and to expand production. Gerlag and van der Zwaan find that a portfolio standard for the carbon emission intensity of energy (which involves a tax on carbon use with the proceeds recycled to renewable energy sources) is always the most efficient approach, more so than a carbon tax alone. Both studies find that subsidies for technology development or for production of renewables are among the least efficient options. The best option is some direct pricing measure for carbon, with or without the investment of revenue in renewables development.[3]

By contrast, the policy focus in many countries at the present time remains on technology development – for cleaner forms of energy generation from fossil fuels,

[3]Gerlagh and van der Zwaan (2006) argue that the difference between the two studies on this point can be traced to different assumptions about whether the decrease in costs for non-carbon energy sources from learning by doing as production rises outweighs the cost increase from site scarcity as such forms of energy production become much more widespread.

development of non-carbon technologies and increased energy efficiency – and on increased use of renewables. For example, the key message of the Communiqué from the first Ministerial meeting of the Asia-Pacific Partnership on Clean Development and Climate (2006), whose six member nations[4] account for nearly 60% of global CO_2 emissions was:

> We recognised that renewable energy and nuclear power will represent an increasing share of global energy supply. We recognised that fossil fuels underpin our economies, and will be an enduring reality for our lifetimes and beyond. It is therefore critical that we work together to develop, demonstrate and implement cleaner and lower emission technologies that allow for the continued economic use of fossil fuels while addressing air pollution and greenhouse gas emissions. We undertook through this Partnership to cooperatively promote the deployment of promising technologies that offer greater energy efficiency and lower air pollution and greenhouse gas intensities.

This emphasis on technology development, both for fossil fuel and renewable energy sources, is not only inconsistent with the economic analyses above, but becomes even more problematic on the new growth path. If the central objective of policy becomes to achieve a substantial reduction in emissions over the next twenty years, relative to a rapidly rising reference path, new technologies now in the R&D phase will play only a minor role in meeting that objective, given the well-known phases of technology development and commercialisation (Grubler et al. 2002). For example, an IEA expert study on prospects for CO_2 capture and storage concluded that such technologies are not likely to have a significant commercial impact until after 2030 (IEA 2004b). The studies reported above also have not been deployed to this end. For example, Gerlag and van der Zwaan run their model with a baseline case in which CO_2 emissions increase very gradually, being less than 10 MtC in 2030 and less than 15 MtC in 2030, with the deviation of emissions from baseline mainly emerging after 2025. If such a model was run with the new growth path as a baseline, it is likely that the preference for carbon price or portfolio standard measures would be reinforced, given the delays involved in the commercial availability of new technologies.

10. Conclusion

This project has been directed at analysing the impact of the global knowledge economy on future prospects for climate change. This impact is felt primarily through two potentially conflicting aspects of the knowledge economy: the accelerated growth in several large developing countries, notably China and India, and in the world economy as a whole, and the rapid growth in new technologies and their diffusion around the world. To date, economic analysis of the future impact of human activity on the climate has been primarily based on scenario methods, in which a number of scenarios are developed but none is identified as the most likely outcome. This method focuses on the internal consistency of individual scenarios rather than on what can be learnt from existing knowledge of underlying trends. By contrast with scenario approaches, we have use methods to make maximum use of existing knowledge – of the likely energy path over the next 25-30 years, of the minimum time-scales for new technology diffusion and through a meta-analysis of the literature of the likely impacts for given levels of global warming – and show that robust and relevant conclusions can be obtained by the use of such methods.

[4] The member nations are Australia, China, India, Japan, Republic of Korea and USA.

There are eleven main conclusions to this study, outlined below:

i. *CO_2 Emissions in the Knowledge Economy: Overall Assessment*. It is clear that the net effect of the two relevant aspects of the knowledge economy – rapid growth, especially in the developing countries, and new technology development and diffusion – will have their primary effects in different time frames. Emissions are rising rapidly at the present time, as OECD country emissions continue to rise and key developing countries expand fossil fuel energy sources (particularly coal) to meet the demands of rapid growth, and on current policies this is likely to continue for some decades. The expected effect of structural change towards the service sector on emissions growth is not being strongly felt, largely because of the transport intensity of the knowledge economy and the limited progress being made in reducing the energy intensity of transport. More generally, the major impact of new technologies to reduce energy use substantially and to generate that energy from non-fossil renewable sources is not likely to be felt (on current policies) until after 2020-30 in the developed countries, and after 2030-2050 in the developing countries. It is possible, but by no means assured, that global CO_2 emissions could be largely eliminated within one hundred years, in spite of a threefold to fourfold increase between 2002 and say 2050. But even so the climate implications of emissions during the next few decades could be profound. Detailed empirical study of the likely timing of these trends, and their climate implications, is necessary.

ii. *CO_2 Emissions to 2030*. On an unchanged policy basis, global CO_2 emissions are projected to rise from 6.7 billon tonnes of carbon in 2002 to 15.9 billion tonnes by 2030, an increase of 137% or 3.1% per annum. Growth in the current decade is particularly strong (3.7% per annum over 2002–10), with growth in the developing countries at 7% per annum. Global emissions growth is projected to continue at 3.7% per annum over 2010-2020, in spite of slowing growth rates in both developed and developing countries, because of the much greater weight of developing countries in the global total, but slows in the next decade. Emissions from the OECD and the transition economy regions both grow at 1% per annum or more over 2002–30, and developing country emissions are projected to grow at a somewhat faster rate (5.1% per annum) over 2002–30 than over 1971–2002 (4.8%). Increased use of coal accounts for 56% of the global increase in CO_2 emissions to 2030; emissions from coal use rise at 5.6% per annum over 2002–10 and 4.0% per annum over 2002–30, continuing the recent trend whereby global consumption of coal rose by 5.6% per annum between 2000 and 2005.

iii. *Lower Bound Emissions Beyond 2030*. Based on our analysis of the minimum time-scales for new technology development and diffusion and on the inherent dynamics of the unchanged policy projection, we have developed a lower bound path for emissions beyond 2030. The claim is that, given the projection to 2030, global emissions are unlikely to be lower through to 2100 than on this lower bound, even with rapid diffusion of new technologies, although they might of course be much higher. On this path global CO_2 emissions from fuel combustion peak at 22.5 Gt C in 2060 but fall to 44% of that level by 2100. Emissions from the OECD and transition economies are virtually eliminated by 2100, and global emissions by 2100 are well below their level in 2030. This is certainly not a projection to 2100, but a lower bound path in the face of potential technological developments.

iv. *Warming Implications of the Unchanged Policy Lower Bound Path*. The MAGICC model has been used to assess the implications of the overall path for CO_2 concentrations and global warming. Given rapid growth in emissions in the near-term, the atmospheric CO_2 concentration level rises through to 2050 when 550 ppm is exceeded. In spite of its lower bound character, this path, produces levels approaching 800 ppm by 2100. The increase in global mean temperature by 2100, relative to 1990 levels, ranges from 3.2°C to 5.5°C, with an increase of 4.2°C for the median value of climate sensitivity. If CO_2 emissions follow the unchanged policy projection to 2030 and, over 2030–2100 are assumed to be lower bound estimates, then rapid increases in global temperatures to 2100 are likely.

v. Climate Implications of the Unchanged Policy Lower Bound Path. The implications of these outcomes for atmospheric CO_2 concentration and for global temperature have been assessed in terms of recent findings in the literature about the critical thresholds for major impacts in key areas of vulnerability. Here a critical threshold is defined as the point at which the relationship between a change variable and an outcome becomes highly negative or non-linear. While critical thresholds for most vulnerabilities remain uncertain, it is evident that the outcomes for the reference path on the median value of the climate sensitivity parameter (a CO_2 concentration of 784 ppm and warming of 4.2°C by 2100) exceed most of the published estimates of critical thresholds for nine key areas of vulnerability. The climate impacts of following this path are likely to be highly adverse.

vi. Central Role of Emissions to 2030 in Driving These Outcomes. Given that we have adopted a lower bound approach for emissions beyond 2030, the central driving force in these outcomes is the rapid growth of emissions to 2030. The lower bound approach beyond 2030 has been chosen to ensure this: given projected emissions to 2030, this is the lowest path of emissions that could reasonably be achieved, given even aggressive development and diffusion of new technologies. The inevitable conclusion is that allowing the reference path to develop to 2030 implies highly adverse climate outcomes, even given the most optimistic assumption for trends after 2030.

vii. Relation of Projection to 2030 to SRES Marker Scenarios. Because the projection path for CO_2 emissions to 2030 is the key determinant of these climate outcomes and lies above all of the SRES indicator scenarios for the projection period, these scenarios no longer provide a reliable basis for studying future trends. A more detailed set of projections than those provided here should be prepared as a matter of urgency, by an international group coordinated by the IEA. These projections are urgently needed to assess the joint impact of development and climate change across regions and sectors.

viii. Analysis of the Time Dimensions of Mitigation Policy. To analyse how rapidly policy needs to adjust to avoid these seriously adverse climate outcomes, we have created a series of Minimum Emissions Paths (MEPs). An MEP can start at any point on the reference path, and assumes that at that point of time effective policy initiatives are put in place that have the effect of stabilising average global emissions over a decade and then eliminating them over the next one hundred years. If an MEP were established by 2010, the atmospheric CO_2 concentration level would rise rapidly to about 460 ppm (540 ppm CO_2-e) by 2050 and stabilise slightly above that level. For the median value for climate sensitivity, the global mean temperature increase would be about 1.3°C by 2050 and would stabilise at about 1.7°C. On this path most of the major impacts from the key vulnerabilities might be avoided, although warming could be much greater than this if a higher than median value of the climate sensitivity parameter applies. On the other hand, if achieving an MEP were delayed to 2035, the CO_2 concentration level rises to 575 ppm by 2050 and to close to 700 ppm by 2100, while the global temperature increase is 2.3°C by 2050 and 3.4°C by 2100, using the median sensitivity estimate. At this level the critical thresholds for all of the nine vulnerabilities other than the breakdown of the thermohaline circulation are breached, and the risk of such a breakdown is increased. Outcomes for MEPs established at points between 2010 and 2035 are intermediate between these two.

ix. *Policy Initiatives with Immediate Effect are Necessary*. It follows from this analysis that policies with immediate effect, in the sense of substantially reducing global emissions relative to the reference path prior to 2020, are urgently needed if large scale damage is to be avoided. In several senses climate change is now an immediate and not a long run issue. Rapid growth in emissions, such as to greatly increase the risks of large scale climate damage, is occurring now, and on present policies emissions will almost double their 2000 level by 2020. This emissions path will in turn lead to rapid global warming over the next two decades. Thus, while the full impacts of increasing greenhouse gases will emerge over centuries and indeed millennia, both the central causes and the immediate effects are immediate realities.

x. *Measures to Reduce Energy Use and to Encourage Renewable Energy Sources are Required.* The reference case projection takes account of existing trends and policies, including the diffusion of various existing technologies throughout the energy system. While many new 'break-through' technologies are under development, our review of an extensive literature shows that it is unlikely that any of these will have a major, commercial impact on energy use and emissions much before 2030. This means that, if emissions growth along the reference path is to be arrested in the near term, policy measures to reduce global energy consumption and to accelerate the diffusion of non-coal technologies are urgently needed. The recent literature suggests that the most efficient option is some direct pricing measure for carbon content (such as a carbon tax), with the revenue invested in the development and diffusion of renewable energy sources.

xi. *Policy Initiatives of the Asia-Pacific Partnership on Clean Development and Climate*. This partnership, which involves six countries including Australia that account for nearly 60% of global CO_2 emissions, provides an important opportunity for dialogue and policy development on climate change. However, to date it has primarily focused on technology development, especially on technologies (such as carbon capture and sequestration) which will only impact on emissions in the longer term. While such technologies are likely to play an important role in the long run process of decarbonisation of the world's energy supply, they will have little impact on emissions over the next two decades. It is therefore important that the partnership also address the immediate issues of reducing sharply the growth of global energy use, and of the carbon-based sources of energy that are generating such rapid growth in CO_2 emissions.

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