EMISSIONS IN THE PLATINUM AGE

3

Key points

Greenhouse gas emissions have grown rapidly in the early 21st century. In the absence of effective mitigation, strong growth is expected to continue for the next two decades and at only somewhat moderated rates beyond.

So far, the biggest deviations from earlier expectations are in China. Economic growth, the energy intensity of that growth, and the emissions intensity of energy use are all above projections embodied in earlier expectations. China has recently overtaken the United States as the world's largest emitter and, in an unmitigated future, would account for about 35 per cent of global emissions in 2030.

Other developing countries are also becoming major contributors to global emissions growth, and will take over from China as the main growing sources a few decades from now. Without mitigation, developing countries would account for about 90 per cent of emissions growth over the next two decades, and beyond.

High petroleum prices will not necessarily slow emissions growth for many decades because of the ample availability of large resources of high-emissions fossil fuel alternatives, notably coal.

3.1 Greenhouse gas emissions by source and country

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2007) estimates that in 2004 greenhouse gas emissions from human activity were about 50 Gt CO_2-e.

Almost 60 per cent of this total was emissions of carbon dioxide from fossil fuel combustion and other carbon dioxide-emitting industrial processes (such as cement production and natural gas flaring).

Other greenhouse gas emissions are measured less accurately. The IPCC (2007) reports that carbon dioxide emissions from land-use change and forestry make up 17 per cent of total emissions. Slightly less than one-quarter of emissions are other gases (which are converted to CO_2-e using their global warming potential—see Chapter 2). Methane is responsible for 14 per cent of the total; nitrous oxide for 7 per cent; and a range of industrial gases for the remaining 1 per cent.

The bulk of greenhouse gas emissions arise from the countries at the centre of global economic activity. The largest emitters are China, the United States and the European Union, which between them are responsible for more than 40 per cent of global emissions. The 20 largest emitters (including emissions from land-use change and forestry) are responsible for more than 80 per cent of global emissions. (See Figure 3.1.)

Richer countries tend to have much higher per capita emissions than poorer countries. The exceptions are poorer countries with high emissions from land-use change and forestry. (See Figure 3.2.)

Developed and transition[1] countries produce about half of current global emissions. However, the growth of emissions is much faster in developing countries, and their share of global emissions will grow over time.

Figure 3.1   The 20 largest greenhouse gas emitters: total emissions and cumulative share (%) of global emissions, c. 2004
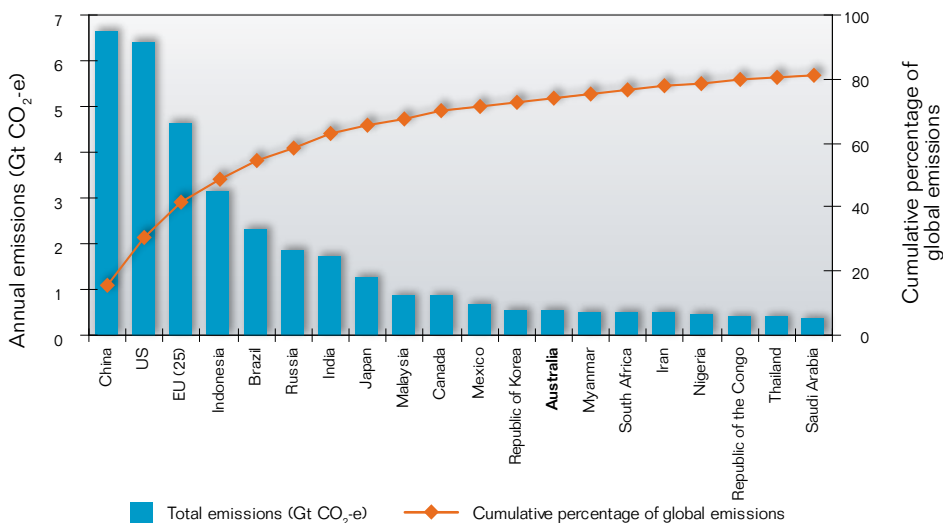
Sources: UNFCCC (2007) 2004 data for US, EU (25), Russia, Japan and Canada; Department of Climate Change (2008) 2004 data for Australia (using UNFCCC accounting); and World Resources Institute (2008) for other countries (2000 data except for CO_2 emissions from fossil fuels, which are for 2004).

Figure 3.2   The 20 largest greenhouse gas emitters: per capita emissions including and excluding emissions from land-use change and forestry, c. 2004
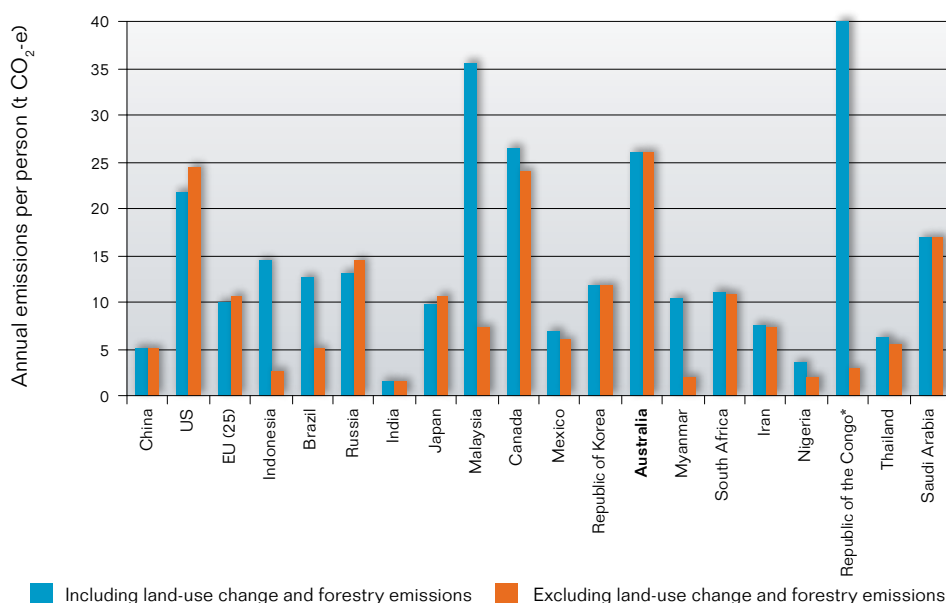
Note: Estimates of forestry-related emissions are subject to large uncertainties in many of the main emitting countries.

* Dark blue bar is truncated; per capita emissions including land-use change and forestry emissions are 105 t.

Sources: UNFCCC (2007) 2004 data for US, EU (25), Russia, Japan and Canada; Department of Climate Change (2008) 2004 data for Australia (using UNFCCC accounting); and World Resources Institute (2008) for other countries (2000 data except for CO_2 emissions from fossil fuels, which are for 2004) and for population (2004).

3.2   Recent trends in carbon dioxide emissions from fossil fuels[2]

Carbon dioxide emissions from fossil fuels are the largest and fastest-growing source of greenhouse gases.

Carbon dioxide emissions from fossil fuel combustion increased by about 2 per cent a year in the 1970s and 1980s, and by only 1 per cent a year in the 1990s. They have expanded by 3 per cent a year in the early 21st century (Table 3.1). While comprehensive national data are only available up to 2005, global estimates show a continuation of rapid emissions growth. The Netherlands Environmental Agency (2008) reports that global emissions of carbon dioxide from fossil fuel use and cement production increased by 3.5 per cent in 2006 and 3.1 per cent in 2007.

A comparison of OECD (developed) and non-OECD (developing including transition) countries shows that the latter group is driving global trends (Table 3.1). In the early 1970s, non-OECD countries were responsible for roughly one-third of global emissions, energy use and output. Since 2000, non-OECD emissions

have been growing almost eight times faster than OECD emissions, accounting for 85 per cent of the growth in global emissions. In 2005 non-OECD countries were responsible for just over half of global energy use and emissions, and 45 per cent of global output.

The OECD countries show a slowdown in growth in emissions, GDP and energy in this decade compared to the last. In the non-OECD countries, the rate of growth in all three has increased significantly in this decade. The high rate of global economic growth seen this decade, at times even above that seen in the 'Golden Age' of the 1950s and 1960s, defines the new 'Platinum Age' that the world has entered (Garnaut & Huang 2007).

Table 3.1   Growth in CO_2 emissions from fuel combustion, GDP and energy

|	Average annual growth rates (%)		
	1971–90	1990–2000	2000–05
World			
Emissions growth	2.1	1.1	2.9
GDP growth	3.4	3.2	3.8
Energy growth	2.4	1.4	2.7
OECD			
Emissions growth	0.9	1.2	0.7
GDP growth	3.2	2.7	2.1
Energy growth	1.5	1.6	0.8
Non-OECD			
Emissions growth	4.2	0.9	5.5
GDP growth	3.8	4.0	6.2
Energy growth	3.8	1.0	4.6

Notes: Emissions growth is CO_2 from fossil fuel combustion. Energy growth is total primary energy supply measured in millions of tonnes of oil equivalent. GDP growth is measured using 2000 US$ purchasing power parities.

Source: IEA (2007a).

There have also been significant changes among non-OECD countries in the energy intensity of economic activity (the energy to GDP ratio) and the carbon intensity of energy use (the emissions to energy ratio). The 1990s saw a rapid decline in energy intensity in the non-OECD group. Energy use grew at only a quarter of the rate of GDP, and emissions at below the rate of energy. This decade has seen the resumption of energy-intensive and carbon-intensive growth in the developing and transition world: energy use has grown at three-quarters the rate of GDP, and carbon emissions 20 per cent faster than energy use.

Figure 3.3 shows just how differently energy intensity has behaved in OECD and non-OECD countries. In the developed world, the energy/GDP curve has declined smoothly and continuously. In the developing world, energy intensity fell only slowly over the 1970s and 1980s, plunged in the 1990s, and has now flattened out, at around 70 per cent of its 1971 level.

Figure 3.3   CO$_2$ emissions/GDP, energy/GDP and CO$_2$ emissions/energy for the world, OECD and non-OECD, 1971–2005 (1971 = 1)
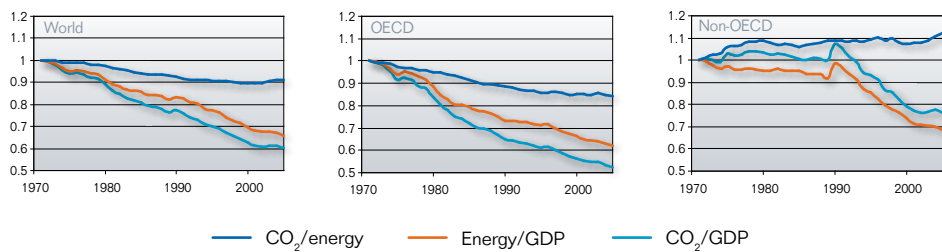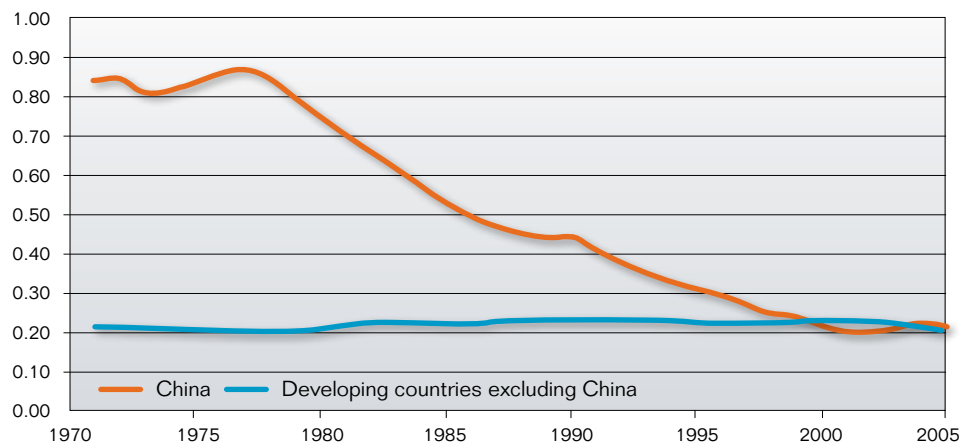

Notes: Emissions are CO$_2$ from fossil fuels. Energy is total primary energy supply measured in millions of tonnes of oil equivalent. GDP is measured using 2000 US$ purchasing power parities.

Source: IEA (2007a).

Figure 3.4 shows energy intensity separately for China and other developing countries. Energy intensities are remarkably steady for developing countries once China is excluded. China started out with an enormously high energy intensity in the 1970s. The ratio declined through the 1980s and 1990s, due to a shift away from subsidised prices and central planning. It flattened only at the turn of the century.

Figure 3.4   Energy intensities of GDP for China and other developing countries, 1970–2005

Note: The ratio is of energy (total primary energy supply measured in millions of tonnes of oil equivalent) over GDP (in 2000 US$ purchasing power parities).

Source: IEA (2007a).

Globally, increasing reliance on coal, which is more carbon intensive than oil and natural gas,[3] has raised the carbon intensity of energy above what it would otherwise have been, keeping it roughly constant, with a slight upward trend in recent years. In the 1980s and 1990s, a reduction in the share of oil in total energy

demand was associated with an increase in the share of gas. Since 2000, the share of gas has remained constant, and the share of coal has increased.

For coal, the same trends are evident in both developed and developing regions, though in much more dramatic terms in the latter. Between 2000 and 2005, coal use increased in developing countries on average by 9.5 per cent annually, and by 11.7 per cent in China.[4] In 2005, 61 per cent of the world's coal was consumed in developing countries, up from 51 per cent just five years earlier. In 2005, coal provided 63 per cent of China's energy, 39 per cent of India's, and only 17 per cent of the rest of the world's (IEA 2007b).

In summary, the acceleration of emissions growth this decade has been caused by three factors: the rapid acceleration of growth in developing countries; the ending of the period of rapid decline in energy intensity in China, which lasted from the 1970s to the 1990s; and the end to the decarbonisation of energy supply in both the developed and (especially) the developing world.

3.3   Existing emissions projections

The most influential projections used in climate change analysis are still those set out in the *Special Report on Emissions Scenarios* (SRES) of the IPCC (2000). These provide a range of future emissions paths out to 2100 under four different 'storylines' about growth and technology.

The SRES authors did not assign likelihoods to particular scenarios, but rather argued that they were all equally plausible. In practice, most attention has been given to low- and mid-range emissions growth scenarios, with high-end scenarios often dismissed as extreme or unrealistic. Other analyses give all SRES scenarios equal weight, rather than asking which ones are more soundly based. Reliance on only the more pessimistic SRES scenarios is seen as unbalanced. One of the criticisms of the Stern Review has been that the SRES scenario it relied on showed 'high range greenhouse gas emissions' (Baker et al. 2008: xi). Stern himself, however, in his Ely lecture (2008), following interaction with the Garnaut Climate Change Review, noted that his review underestimated the likely growth of emissions.

Post-SRES scenarios do not show very different results to those of SRES. GDP growth, total energy use and carbon dioxide emissions are all lower in the median post-SRES no-mitigation scenario than in the median pre-SRES/SRES scenario (IPCC 2007). Energy forecasting agencies have not significantly adjusted emissions forecasts upwards despite the acceleration of growth seen so far this decade. The US Energy Information Administration reference scenarios for emissions and energy consumption growth over the period 2000 to 2020 were no higher in 2007 than in 2000, despite the higher levels in both variables seen so far this decade.[5]

Results from a range of existing projections are shown in figures 3.8, 3.9 and 3.10 along with the results from the updated projections carried out for the Review.

## 3.4   The Review's no-mitigation projections: methodology and assumptions

Two new sets of projections were developed for the Review. Both are constant policy scenarios where no further policies are put in place to mitigate climate change, and no additional impacts of climate change are felt.

The Review's 'Platinum Age' projections cover the period out to 2030, and are based on work by Garnaut et al. (2008). These projections use the most recent International Energy Agency projections (IEA 2007b), which make use of extensive information on energy systems in a partial equilibrium framework. Using an emissions growth decomposition framework, adjustments are made to selected macroeconomic assumptions. The strength of this approach is that it builds on the specialist knowledge of the IEA, and identifies the assumptions that need rethinking. Its limitation is that it does not capture the general equilibrium effects that would derive from the changes in assumptions.

The Review's reference case runs to 2100, and was developed by the Australian Treasury and the Garnaut Review in consultation with other experts. This scenario was implemented in the Global Trade and Environment Model (GTEM), a computable general equilibrium model of the world economy used in the joint modelling exercise by the Review and the Treasury. The top–down modelling of GTEM is complemented by a series of bottom–up models of electricity generation, transport, and land-use change and forestry.

Key GDP and population assumptions up to 2030 are broadly consistent for the two projections.[6] Population projections (figures 3.5 and 3.6) are the United Nations 'medium variant' population projections to 2050, and UN long-term

Figure 3.5   The reference case: global population, GDP and GDP per capita, 2001 to 2100
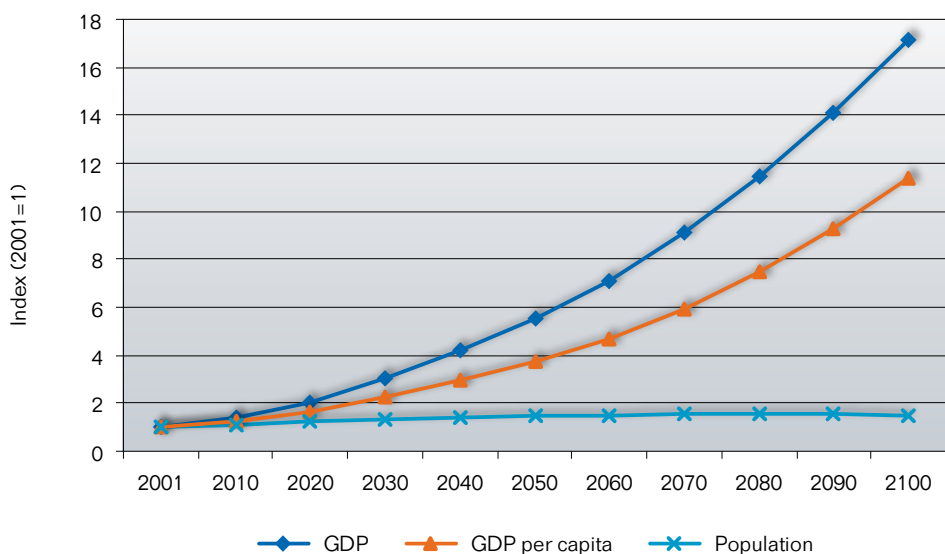
population projections to 2100. Population projections for Australia, however, are based on Australian Treasury (2007) projections, revised in the light of Treasury's most recent analysis of immigration trends. These are higher than UN projections, significantly so in the second half of the century.

By the end of the century the world's population is over 40 per cent larger than at the start. Population growth is above 1 per cent per year in the current decade, then steadily falls to zero annual growth around 2080, when global population peaks. After 2080, population falls by 0.1 per cent a year on average, with nearly all regions showing zero or negative growth. Many developing countries including India gain in population share over the century; Australia, Canada and the United States hold a broadly constant share as a result of immigration; and the shares of China, Europe, Russia and Japan drop.

Assumptions on nearer-term GDP per capita growth rates are based on growth accounting and judgments informed by recent experience, both of which suggest the continuation of high growth, albeit falling over time, in the developing world. Longer term, GDP per capita is assumed to converge over time towards that of the United States, which is assumed in the long term to grow at 1.5 per cent a year. Growth slows in developing countries as the income gap with the United States diminishes. Countries are assumed not to close the gap completely by the end of the century, with average world per capita incomes around half US levels at 2100. The global annual per capita GDP growth peaks at just over 3 per cent in the middle of the 2020s, then falls to 2 per cent by the end of the century. Global annual GDP growth peaks around 4 per cent in the early 2020s, then falls to just below 2 per cent by the end of the century (Figure 3.6).

Figure 3.6   The reference case: global population, GDP, GDP per capita, and CO$_2$-e emissions, 2000 to 2100—average growth rates by decade
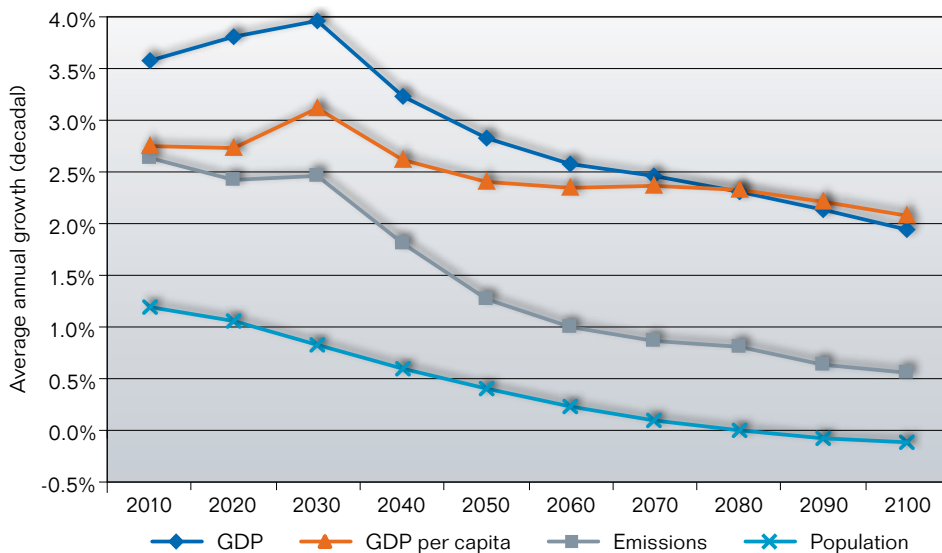
By 2100, total global GDP is 17 times its 2000 level and average per capita GDP increases by 11 times over the century. The distribution of global output is also very different from that seen today (Figure 3.7). The share of China in global output rises sharply until the 2030s, but then declines. The share of India continues to rise and by about 2080 overtakes that of China. The shares of the European Union, North America and the rest of Asia decline. The share of the rest of the world rises over the period, reflecting higher population growth in many low-income developing countries.

Growth in greenhouse gas emissions in the reference case are a function of changes in production and consumption structures in different countries, changes in relative prices including for different sources of energy, and improvements in energy efficiency and the efficiency of intermediate input use. The reference projections also include emissions of methane, nitrous oxide and various industrial gases, as well as a subset of forestry-related emissions and sequestration.

Carbon dioxide emissions from fossil fuel are modelled in the Platinum Age projections as a function of the carbon intensity of energy, and the energy intensity of GDP. Carbon intensity is assumed to remain roughly constant over time, in line with IEA projections: the share of oil decreases, with substitution towards coal as well as low-emissions energy sources. Energy intensity is assumed to decline in both developed and developing countries. This is in contrast to the historical experience in developing countries, where energy intensities have been constant (see Figure 3.4) and is assumed to represent the effect of high energy prices. In particular, in contrast to the experience of the past few years, energy intensity is assumed to fall in China, but not as rapidly as projected by the IEA (see Box 3.1). Platinum Age projections for methane and nitrous oxide update US Environmental Protection Agency projections for higher forecast global growth. Platinum Age

Figure 3.7   Shares in global output of various countries and regions, 2001 to 2100, under the reference case
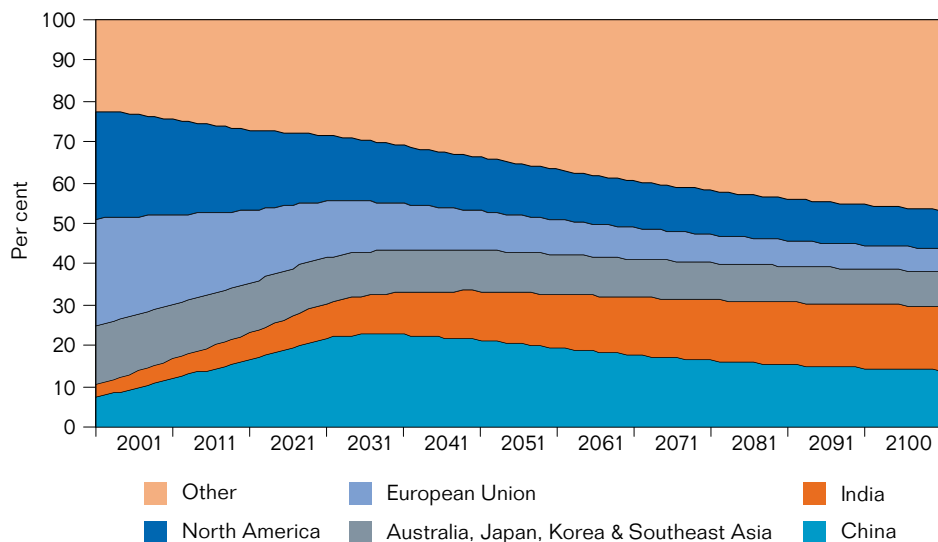
projections for forestry-related carbon dioxide emissions are based on IPCC baselines, and assume a constant value in these emissions out to 2030. Detailed assumptions are available in Garnaut et al. (2008).

3.5 Results from the Review's projections and comparisons with existing projections

Figure 3.8 compares the average growth rates for carbon dioxide emissions from fossil fuels for the Platinum Age and Garnaut–Treasury reference case with a number of SRES (in green) and post-SRES (white) scenarios for the period circa 2005–30. It also shows (in red) average emissions growth in the 1970s and 1980s, the previous decade and so far in this decade (2000 to 2005).

Most carbon dioxide emissions projections for growth out to 2030 forecast annual average growth significantly below the 2.9 per cent annual average growth seen between 2000 and 2005. Even A1FI, the SRES scenario that shows the most rapid emissions growth over the century, often regarded as extreme,

Figure 3.8 **Global CO$_2$ emissions growth rates from fossil fuels and industrial processes to 2030: a comparison of Garnaut Review no-mitigation projections with SRES and post-SRES scenarios and historical data**
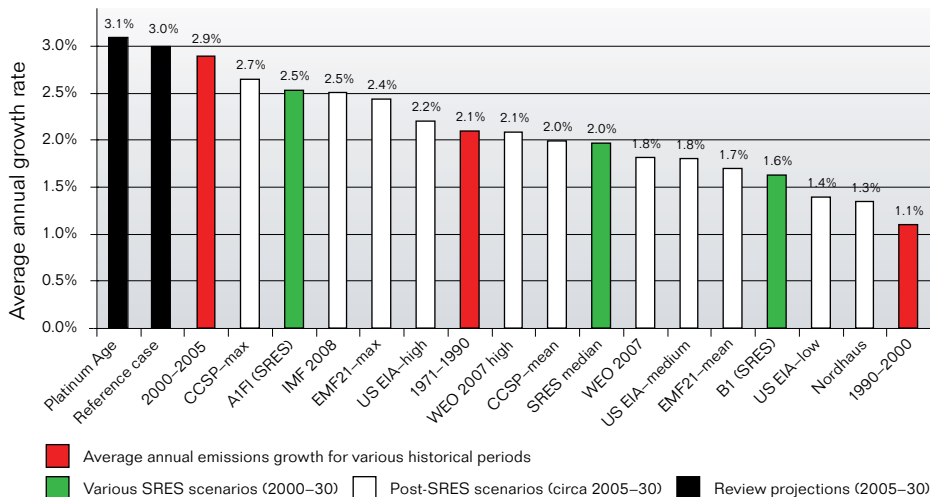
Sources: This figure is modified from Garnaut et al. (2008). Historical data are from Table 1. The SRES scenarios (IPCC 2000) used are A1FI (AIG MINICAM), which shows the most rapid emissions growth, both to 2030 and to 2100; B1 (BI IMAGE), which is at the lower end of the range; and the median SRES scenario (which is defined as the median for each variable and each decade of the four SRES marker scenarios). The SRES scenarios give projections for every 10 years from 1990 to 2100; we report here projections for 2000 to 2030. Post-SRES scenarios included are the mean and maximum emission baselines from the EMF-21 project (Weyant et al. 2006), which included 18 different emissions projection models for 2000 to 2025; the mean and maximum projections from the US Climate Change Science Program (Clarke et al. 2007), which used three models; the base case from the Nordhaus (2007) model for 2005 to 2035; projections for 2005 to 2030 from IEA (2007b) (both the base case and a rapid-growth scenario with higher growth projected for China and India); the high, medium and low projections from the US Energy Information Administration (2007) for 2004 to 2030; and the IMF World Economic Outlook baseline for 2002 to 2030 (IMF 2008).

projects carbon dioxide emissions growth of only 2.5 per cent out to 2030. The SRES median scenario shows growth of 2.0 per cent, and the moderate B1 SRES scenario shows growth of only 1.6 per cent. The post-SRES scenarios lie in a similar range.

The Platinum Age projections and the reference case, however, project growth in carbon dioxide emissions of 3.1 per cent and 3.0 per cent out to 2030. They suggest that the existing range of scenarios underestimates the future growth of emissions in the early 21st century. In the absence of unexpected dislocations in the global economy and in the absence of effective mitigation, emissions growth is unlikely to ease significantly over the next two decades.

Figures 3.9 and 3.10 project greenhouse gas emissions from human activity for the Review's no-mitigation projections and other projection exercises. The Platinum Age projections and the reference case both give annual average growth in greenhouse gas emissions of 2.5 per cent over the period 2005–30, at the top end of existing projections and comparable with the growth rate in emissions seen in the first years of this decade (Figure 3.9).

Emissions levels at 2030 are significantly higher in the Platinum Age than in existing rapid-growth scenarios because of the higher forestry-related emissions built into the base. The Platinum Age projects emissions of 83 Gt CO_2-e by 2030, almost double their 2005 level, 11 per cent higher than the A1FI scenario, and a level of emissions reached only in 2050 in the business-as-usual scenario used by the Stern Review (Stern 2007: 202). Reference case emissions are lower in 2030 at 72 Gt CO_2-e, largely due to lower base-year estimates of forestry-related and non-carbon dioxide emissions.

Figure 3.9   Global greenhouse gas emissions growth rates to 2030: a comparison of Garnaut Review no-mitigation projections, SRES and post-SRES scenarios, and historical data
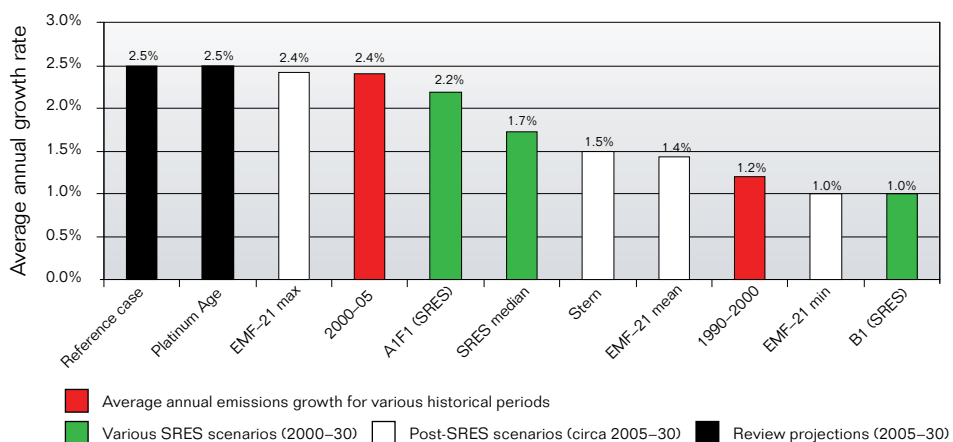
Sources: This figure is modified from Garnaut et al. (2008), which includes detailed notes. See also the notes to Figure 3.8.

Figure 3.10   Global greenhouse gas emissions to 2100: a comparison of Garnaut Review no-mitigation projections and various SRES scenarios
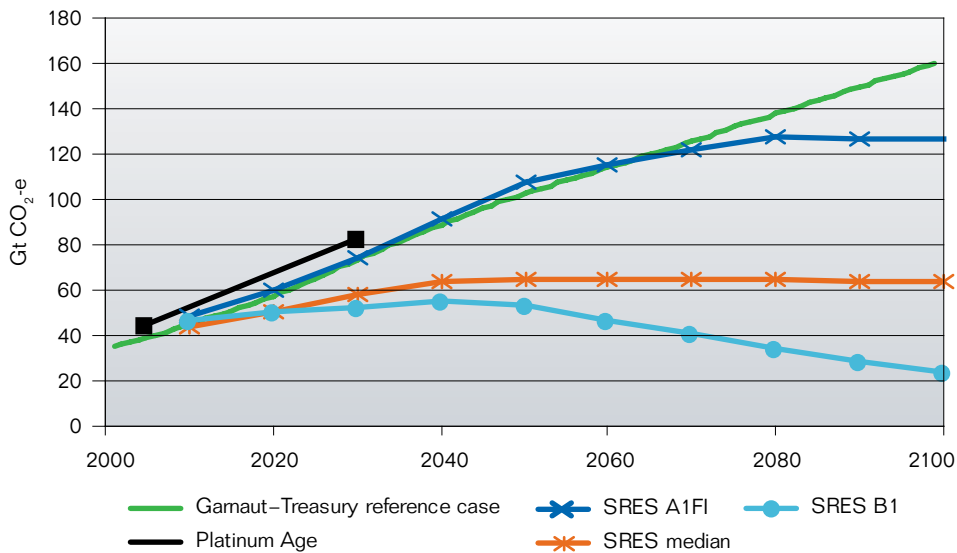
Sources: See notes to Figure 3.8.

Emissions under the reference case continue to rise post-2030 though more slowly (Figure 3.6). Figure 3.10 compares emissions over the century under the two Garnaut Review business-as-usual projections with the three SRES scenarios highlighted in figures 3.8 and 3.9. Although the rise in emissions in the reference case is much slower in the latter decades of the century (the annual growth rate drops to 0.7 per cent at the end of the century), emissions in the reference case are more than twice those in the SRES median scenario by the end of the century. Over the course of the century, emissions in the reference case are comparable with or above those of the 'extreme' A1FI scenario.

Table 3.2 shows the projected composition of emissions across countries in the reference case using the regional breakdown which GTEM deploys. The share of most developing countries is growing rapidly. More than 90 per cent of growth in emissions over the century occurs in developing countries.

China emerges as the most important country determining emissions, especially up to 2030. By 2030, its emissions easily exceed those of all developed and transition countries combined. The factors behind the explosive growth in emissions in China are explored in Box 3.1.

Table 3.2   Shares of total greenhouse gas emissions by country/region in the Garnaut–Treasury reference case

	Share of emissions (%)		
	2005	2030	2100
United States	18.3	11.1	5.1
European Union	12.6	7.1	3.6
Former Soviet Union	8.4	6.9	4.5
Japan	3.5	1.8	0.7
Canada	2.0	1.3	1.0
Australia	1.5	1.1	1.0
China	18.3	33.0	21.2
India	4.6	8.0	16.8
Indonesia	2.0	1.8	2.4
Other Southeast Asia and Korea	4.3	2.9	3.3
South Africa	1.3	1.3	1.4
OPEC	4.7	5.4	7.8
Rest of world	18.5	18.2	31.3
World	100	100	100

Box 3.1   Determinants of China's emissions trajectory to 2030

China has the world's largest population, and the highest economic growth rate of any major country. Its energy is unusually carbon intensive: out of 51 countries with a population greater than 20 million, China has the fifth most carbon-intensive energy mix (IEA 2007a). China's energy supply is carbon intensive because coal is the only domestic energy source in which China is even moderately well-endowed per capita on a global basis.

In the coming decades, China will have more impact on global emissions than any other country. Assumptions about future economic growth and energy patterns in China are therefore of critical importance to emissions projections.

China's influence out to 2030 is particularly pronounced. The Garnaut–Treasury reference case projects China's share of global emissions to rise from 18 per cent in 2005 to 33 per cent in 2030. This follows from average annual growth in emissions of 5 per cent. After 2030, China's growth is projected to slow, as its population starts to fall and per capita incomes reach relatively high levels. Emissions growth slows to just 1.3 per cent for 2030 to 2050.

What will drive China's rapid growth in emissions to 2030? First, China's economy will continue to grow rapidly. Using growth accounting, Garnaut et al. (2008) project GDP growth of China of 9.0 per cent from 2005 to 2015 and 6.8 per cent from 2015 to 2025. This rapid GDP growth will take place on the back of continued very high investment levels and total factor productivity growth. This projection is higher than most literature forecasts, but below performance seen in recent years.

Box 3.1   Determinants of China's emissions trajectory to 2030 (continued)

Second, China's economic expansion will continue to be energy intensive. Figure 3.11 shows the acceleration in China's energy consumption in recent years. This reflects rapid growth in China in heavy energy-intensive industry: between 2000 and 2006, crude steel production grew in China by an annual average of 22 per cent, pig iron by 21 per cent, and cement by 13 per cent (National Bureau of Statistics of China 2007a). Analysts differ on the extent to which energy efficiency will improve in China, even without a concern for climate change. The Review expects that, in the absence of deliberate mitigation, and given China's high level of investment and the rapid growth of its heavy industry, the energy intensity of output in China will decline no more rapidly than in other developing countries. The Review's Platinum Age projections adjust the IEA's more rapid energy efficiency improvements downwards to be broadly consistent with the analysis of Sheehan and Sun (2007), who predict elasticities of energy with respect to GDP of 0.8 declining to 0.7.

Third, in the absence of a price on carbon, China is unlikely to move away from its heavy reliance on coal, or make any movement towards sequestration of emissions from coal combustion—the only factors that would reduce the high carbon intensity of its energy system.

While the Review's emissions growth projections for China are substantially higher than those by the IEA, they are supported by other recent studies. Auffhammer and Carson (2008), using Chinese provincial 1985 to 2004 data, project 11–12 per cent annual growth in CO_2 emissions from fossil fuel combustion for the period 2000 to 2010.

Figure 3.11   China total energy consumption, levels and growth, 1978 to 2006
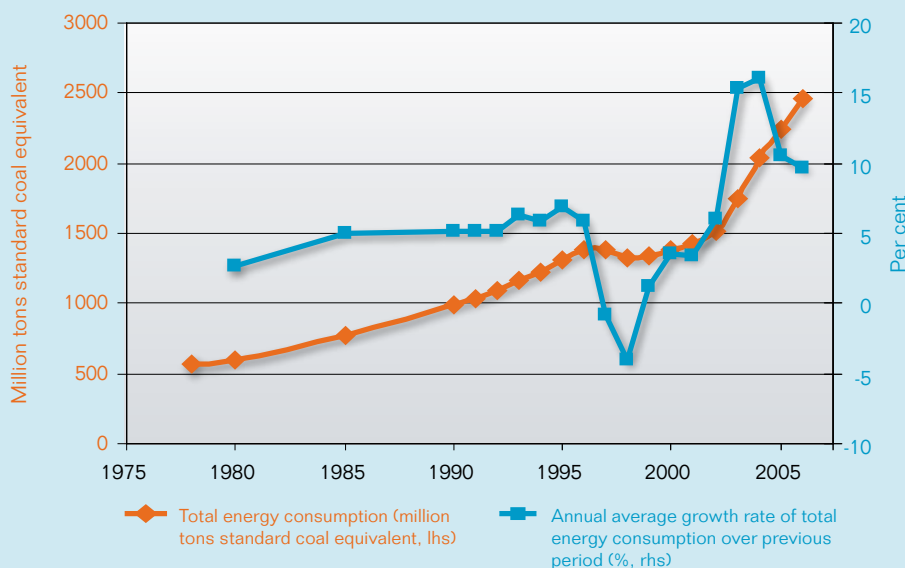

Source: National Bureau of Statistics of China (2007a).

3.6　The impact of high energy prices

Global energy prices have risen dramatically over the last few years. The oil price is now at a historic high, having reached a level in real terms not seen since the early 1980s (Figure 3.12). Natural gas prices are following suit. Most recently, coal prices have also risen sharply. The price rises are driven by increasing demand and limitations on expansion of production. In the case of oil and gas, there is a resource constraint, whereas for coal the supply constraint is purely in terms of mining and transport capacity.

Continued high fossil energy prices, if across the board, will cause reductions in energy consumption and a substitution towards non-fossil-fuel energy sources. These effects by themselves would dampen growth in carbon dioxide emissions. However, substitution away from oil and gas towards coal and synthetic liquid hydrocarbons (derived from coal, tar sands or natural gas) will increase growth in emissions. Making liquid fuels from coal can be cheaper than petroleum at oil prices reached in 2008, and for many countries is attractive as a more secure supply. In the medium term, coal prices are expected to fall as supply capacity is increased in response to excess demand. This in turn will reduce incentives to shift into renewable energy sources and nuclear power, and to reduce energy use. The share of high-carbon fuels in the energy mix, and with it the carbon intensity of energy, will not necessarily fall as a result of high oil prices.

**Figure 3.12　Oil, gas and coal prices, 1970 to 2008**
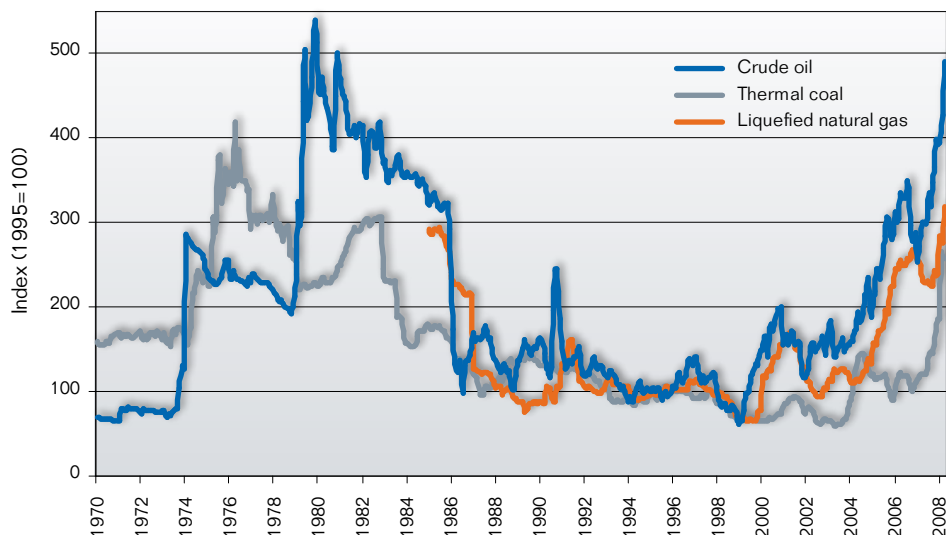
Note: Nominal prices converted to SDRs and deflated by the G7 CPI. Indexed to 1995. Prices are as at January for 1970–2007 and as at April for 2008.

Source: Table compiled by the Centre for International Economics based on IMF IFS Statistics, OECD Main Economic Indicators, *Financial Times*, and CIE estimates.

Recent data suggest that the increase in oil prices is not resulting in lower global emissions (Figure 3.13). Since 2005, growth in global oil use has slowed to around 1 per cent annually, but total energy use has grown by almost 3 per cent annually. Gas use has grown roughly in line with total energy use, while coal consumption has grown at 5 per cent, and use of other energy sources (principally renewables and nuclear) at only around 2 per cent (BP 2008). Energy-related carbon dioxide emissions have grown slightly faster than total energy use. There is strong momentum in growth of liquid fuel production from Canadian tar sands. Looking ahead, investment in coal-fired electricity generation remains strong, particularly in Asia but also other parts of the world. China is investing in coal-to-liquid plants and is expected to start operating the largest such facility outside South Africa later in 2008 (Nakanishi & Shuping 2008). Coal liquefaction is also being considered in the United States.

It is instructive to examine the oil price shocks in the 1970s and especially the 1980s (Figure 3.12). In both episodes coal prices rose later than oil prices, and fell back to or below earlier prices more quickly than oil prices. In both cases, the drop in global oil consumption was more pronounced than for other fuels (Figure 3.13). Electricity generation from renewables and nuclear power in particular grew in the aftermath of the oil price shocks, but by less than energy from coal in absolute terms. The carbon intensity of global energy supply fell markedly in the first half of the 1980s, then stagnated. It fell in the 1990s primarily because of restructuring in the former Soviet Union, and in this century has been on the rise again.

Figure 3.13   Global energy use and CO_2 emissions, 1970 to 2007
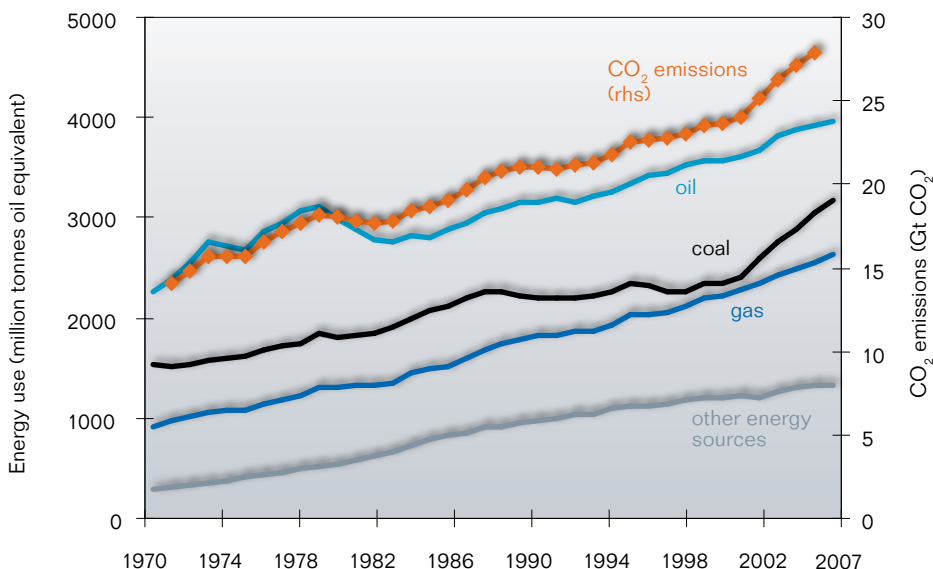
Sources: Energy use from BP (2008); CO_2 emissions from IEA (2007b) and Carbon Dioxide Information and Analysis Centre (2008).

The upshot is that high petroleum prices do not necessarily mean lower greenhouse gas emissions, and may actually lead to higher emissions. On the one hand, high prices accelerate improvements in energy efficiency and promote non-fossil-fuel energy. On the other, high oil prices increase demand for coal. Coal prices will remain high only if investment in new capacity cannot keep up with growth in demand. If coal prices remain high, renewable energy will become more attractive at the margin, but only in a context of rapid growth in demand for coal. Although it is impossible to know which influence will dominate, recent experience suggests that high petroleum prices are as consistent with an acceleration as with a deceleration of emissions growth.

3.7   Resource limits

By 2100, under the Garnaut–Treasury reference case projections, global output will be 17 times its current level. Australia's real per capita income would be US$137 000, compared to US$36 000 in 2005.

By 2100, today's developing countries would achieve higher levels of per capita expenditure than current levels in today's rich countries. India, which only has 5 per cent of Australia's per capita income today, has in the reference case in 2100 a per capita income 2.2 times Australia's current level. Does the world have the resources to support consumption based on today's preferences at these levels of income?

Concerns about natural resource limits to growth were raised by the Club of Rome and others in the period of high resource prices associated with the latter stages of Japanese industrialisation and rapid growth in the early 1970s (Club of Rome 1972). This group included eminent Japanese economist Saburo Okita, Director of Japan's Economic Planning Agency at the high tide of rapid Japanese post-war growth and author of the Ikeda administration's income-doubling plan of 1960. The Club of Rome was not from the fringe of modern development policy. Its central prediction was not for an imminent collapse in economic activity, as is often reported, but for a collapse in the middle of this century due to resource constraints and pollution (Turner 2008). Similar pessimistic expectations about the availability of natural resources to support rising human living standards had been raised by eminent economists from time to time in the first century of modern economic development (Malthus 1798; Jevons 1865).

The last quarter of a century of low resource prices has led economists generally to dismiss such concerns and forecasts on the grounds that they underestimate human ingenuity and the capacity for markets to support far-reaching structural change. The failures immunised the economics profession against acknowledgment of the possibility of resource supplies being a fundamentally important constraint on growth. However, the possibility that natural resource constraints might force fundamental changes in consumption patterns has been seeping recently into the professional consciousness, as real commodity prices across a wide front have now been sustained at exceptionally high levels for longer than ever before. High

commodity prices across the board, despite the US economy teetering on the edge of recession, are concentrating many minds.

The prospects of much higher levels of income for high proportions of the world's people later in the 21st century focuses minds even more keenly. Will resource constraints prevent total global output from increasing by 17 times from the levels of the early 21st century that are already stretching supplies of many natural resource–based commodities?

There are many potential limits that could conceivably constrain output, from fuel to food to water. Pressures on global agricultural resources could be particularly problematic, especially if climate change diminishes productivity. They could seriously undermine political stability in some developing countries.

Could limits on minerals and fossil fuels also constrain growth? Table 3.3 looks at the number of years that reserves and the known reserve base can sustain production at current and assumed 2050 levels for several mineral resources and fossil fuels. By 2050, global output is projected in the reference case to be almost five times its current level. For this illustrative exercise, it is assumed that the production of metals and minerals is at three times current levels in 2050. Predicted production of oil and coal in 2050 is based on US Energy Information Administration projections. These rates of production are compared to estimates of reserves and the reserve base. Reserves are that portion of the reserve base which can be economically extracted. For fossil fuels, the reserve base is the total global 'ultimately recoverable' resource base, including an estimate of undiscovered resources. For metals and minerals, the reserve base is that portion of the global resource which has been identified, whether or not it is economic.

Current reserves for several metals will not last long, especially at 2050 levels of production. High prices will push more of the reserve base into reserves. The current reserve base will support current production levels for all the minerals reported for at least 30 years, but will support production at 2050 levels for 20 years or less. This suggests that extreme pressures on supplies of minerals and metals, if they arise, will not do so until towards or after the middle of the century. Whether they do arise then depends on the gap between the reserve base and the total resource base. This can be large. For example, the US Geological Survey estimates the global reserve base for copper to be 940 million tons, but world resources (including deep-sea nodules) to be 3.7 billion tons. Note that any tendency towards exhaustion of reserves would raise prices, which would convert resources into reserves. It would also stimulate exploration, leading to expansion of reserves and the reserve base.

In relation to fossil fuels, Table 3.3 suggests that conventional oil reserves may well come under pressure over the next several decades, but that there are ample supplies of coal. Some argue that conventional oil reserves are exaggerated (Campbell & Laherrère 1998). But unconventional sources, including oil sands in Canada, extra-heavy oil in Venezuela and shale oil in the United States, Australia and several other countries, not included in the table below, are thought to amount to at least 1 trillion barrels, or almost 50 per cent of ultimately recoverable conventional oil resources (IEA 2006).

Table 3.3   Time to exhaustion of current estimates of reserves and reserve base for various metals and minerals, and fossil fuels

	Number of years after which exhaustion will be reached of			
	Reserves		Reserve base	
	At the production rates of			
	2007	2050	2007	2050
Metals and minerals				
Nickel	40	13	90	30
Zinc	17	6	46	15
Copper	31	10	60	20
Bauxite	132	44	168	56
Platinum group metals	154	51	173	58
Lead	22	7	48	16
Tin	20	7	37	12
Tungsten	32	11	70	23
Iron ore	79	26	179	60
Fossil fuels				
Coal	139	66	214	101
Gas	60	32	110	58
Oil	40	23	70	40

Note: For metals and minerals, current production, reserves and reserve base are the latest estimates from the US Geological Survey (http://minerals.usgs.gov/minerals/pubs/commodity). Reserves are defined by the US Geological Survey to be 'that part of the reserve base which could be economically extracted or produced at the time of determination'. The reserve base is 'resources whose location, grade, quality, and quantity are known or estimated from specific geologic evidence'. Production rates for 2050 are simply assumed to be three times current levels.

Fossil fuel figures are the latest estimates from the US Energy Information Administration, the International Energy Agency and the World Energy Council. Coal includes both black and brown coal. Fossil fuel reserves are recoverable reserves: those quantities which geological and engineering information indicates with reasonable certainty can be extracted in the future under existing economic and operating conditions. (US EIA 2007: Table 8, Chapter 5). The reserve base for fossil fuels is the global resource base: all 'ultimately recoverable resources', including an estimate of 'undiscovered conventional resources that are expected to be economically recoverable' (IEA 2006: 91).

Source: Table compiled by the Centre for International Economics.

This analysis suggests that mineral and fossil fuel shortages will not be a constraint on growth in the first half of this century. By that time, if the world were still on a business-as-usual path, the environmental damage would have already been done, as dangerous levels of temperature increase would already have been locked in, if not already realised. Shortages of minerals and fossil fuels will not solve the world's emissions problems.

The recent and projected continued rapid growth in emissions has major implications for the global approach to climate change mitigation. Earlier and more ambitious action than previously thought will be required by all major emitters, if the world is to hold the risks of dangerous climate change to acceptable levels.

Notes

1   Transition countries are countries in central and eastern Europe and the former Soviet Union defined in the United Nations Framework Convention on Climate Change and Kyoto Protocol as 'undergoing the process of transition to a market economy'.

2   This section draws on Garnaut et al. (2008). See also Raupach et al. (2007).

3   The US Energy Information Administration (1998) reports that on average oil emits 40 per cent more carbon dioxide than gas, and coal 27 per cent more than oil per unit of energy input.

4   In 2006, China's coal consumption grew by 11.9 per cent and in 2007, according to preliminary estimates, by 7.8 per cent (see National Bureau of Statistics of China 2007a, 2007b).

5   See annual US Energy Information Administration *International Energy Outlooks*. See IMF (2008) and Sheehan et al. (2008) for two recent projections with more rapid rates of emissions growth.

6   Note that GDP is measured using purchasing power parities rather than market exchange rates in both sets of projections.

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