On development, demography and climate change: The end of the world as we know it?

Tim Dyson
London School of Economics

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Abstract

Adopting a holistic stance, the present paper attempts to provide fresh perspective on global warming and climate change. It does so by considering most major sides of the issue, and, quite consciously, it does so from a distance. Essentially, five main points are made. First, that since about 1800 economic development has been based on the burning of fossil fuels, and this will continue to apply for the foreseeable future. Of course, there will be increases in the efficiency with which they are used, but there is no real alternative to the continued - indeed increasing - use of these fuels for purposes of economic development. Second, due to momentum in economic, demographic, and climate processes, it is inevitable that there will be a major rise in the level of atmospheric CO_2 during the twenty-first century. Demographic and CO_2 emissions data are presented to substantiate this. Third, available data on global temperatures, which are also presented, suggest strongly that the coming warming of the Earth will be appreciably faster than anything that human populations have experienced in historical times. The paper shows that a rise in world surface temperature of anywhere between 1.6 and 6.6 degrees Celsius by the year 2100 is quite conceivable - and this is a conclusion that does not require much complex science to appreciate. Furthermore, particularly in a system that is being forced, the chances of an abrupt change in climate happening must be rated as fair. Fourth, while it is impossible to attach precise probabilities to different scenarios, the range of plausible unpleasant climate outcomes seems at least as great as the range of more manageable ones. The agricultural, political, economic, demographic, social and other consequences of future climate change are likely to be considerable - indeed, they could be almost inconceivable. In a world of perhaps nine billion people, adverse changes could well occur on several fronts simultaneously and to cumulative adverse effect. There is a pressing need to improve ways of thinking about what could happen - because current prognostications by environmental and social scientists are often rather restricted and predictable. Finally, the paper argues that human experience of other difficult 'long wave' threats (e.g. HIV/AIDS) reveals a broadly analogous sequence of reactions. In short: (i) scientific understanding advances rapidly, but (ii) avoidance, denial, and reproach characterize the overall societal response, therefore, (iii) there is relatively little behavioral change, until (iv) evidence of damage becomes plain. Apropos carbon emissions and climate change, however, it is argued here that not only is major behavioral change unlikely in the foreseeable future, but it probably wouldn't make much difference even were it to occur. In all likelihood, events are now set to run their course.

Introduction

Global warming and climate change receive a huge amount of attention. Whether the world is heating up, the implications for the climate, and the possible long run consequences for humanity are all topics that are never far from the newspaper headlines. It is clear that the issues involved are uncertain, complex, and often the object of controversy. Therefore it might be thought that little can be gained from a general social scientific consideration of the subject - one that starts from a concern with development and demography.

The view taken here, however, is that looking at global warming and climate change in historical perspective, examining the subject in the round (i.e. drawing on material from both the social and the environmental sciences), treating scientific study of it as a form of social activity, comparing human responses to it with those evidenced in relation to broadly analogous issues, and, above all, standing back from the subject - so as not to miss the wood for the trees - can yield fresh insights both about what is happening and about what may happen. Moreover, even the most complex computer models of the world's climate must ultimately be calibrated with reference to direct measurements of atmospheric gas concentrations and temperature that are actually fairly easy to understand.

Accordingly, the present paper attempts to provide new perspective on global warming and climate change by adopting an holistic approach. Essentially, it addresses five main points. First, that since about 1800 economic development has been based on the burning of fossil fuels, and this will continue to apply for the foreseeable future. Although there will doubtless be rises in the efficiency with which energy is used, there is no real alternative to the continued use of coal, oil and natural gas for the purpose of economic development. Second, due to momentum in economic, demographic and climate processes, it is inevitable that there will be a major rise in atmospheric CO_2 during the twenty-first century. Demographic and CO_2 emissions data will be presented to substantiate this point. Third, the available data suggest strongly that the coming rise in global temperatures will be appreciably faster than anything that human populations have experienced during historical times. The paper will show that a rise in temperature of between 1.6 and 6.6 degrees Celsius (deg/C) by the year 2100 is likely. Moreover, particularly in a system that is being forced, the chances of an abrupt change in climate occurring must be rated as fair. Fourth, while it is impossible to attach precise probabilities to different scenarios, it will be argued that the chance of an unpleasant climate outcome is at least as great as the chance of a more manageable one. The agricultural, political, economic, demographic, social and other consequences of future climate change could be very considerable. In a world of eight or nine billion people, adverse developments could well occur on several fronts simultaneously, and to cumulative adverse effect. Related to this, it will be argued here that there is a pressing need to improve our ways of thinking about what may happen - because current prognostications tend to be routine, predictable and restricted. Finally, the paper notes that humanity's experience of another difficult 'long wave' threat - HIV/AIDS - reveals a broadly analogous sequence of human reactions. In short: (i) scientific understanding advances rapidly, but (ii) avoidance, denial, and recrimination characterize the overall societal response, therefore (iii) there is relatively little behavioral change, until (iv) evidence of damage becomes plain. Apropos carbon emissions and climate change, however, it is argued here that not only is major behavioral change unlikely in the foreseeable future, but it probably wouldn't make much difference even if it were to occur.

There certainly is uncertainty about what will happen. But the basic data on trends in atmospheric CO_2 and world temperature - presented here - are straightforward and not in serious dispute. Moreover, despite impressions to the contrary, there is a scientific consensus on the reality of human induced climate change. It seems probable that events are now largely set to run their course.

Development, demography and energy use

The modern processes of economic and demographic development both have their origins in the European Enlightenment. It was in the second half of the eighteenth century that the first glimmerings of the demographic transition occurred in countries like France, Germany and Holland. And this period also saw the birth of the so-called ‘Industrial Revolution’ in Britain - with the associated, momentous new phenomenon of ‘modern economic growth’ (Kuznets 1966).

Before the Industrial Revolution all economies everywhere were extremely constrained in what they could produce. Borrowing a term from Wrigley (1988), pre-industrial economies were 'organic' - in that virtually all of their products were ultimately dependent upon capturing solar energy through the exploitation of wood and other vegetative matter that grew on the land.

The Industrial Revolution transformed this situation through the mass exploitation of coal, which in turn spurred a host of cumulative economic interactions. Britain's annual production of coal in 1800 was about 15 million tons - when the combined output for the rest of Europe was under 3 million. Burning 15 million tons of coal provided the economy with roughly the same amount of heat as the wood that could have been harvested, on a sustainable basis, from about 6 million hectares of land (Wrigley 1988:54-55). This revolution in production, however, could not be constrained to one country, and by the middle of the nineteenth century the use of coal was rising steeply elsewhere in Europe. The United States came to coal a little later - mainly because it had plentiful supplies of timber to burn. But by the mid-1880s coal had become the main source of energy in the US. And, as a result of these developments, it is estimated that world coal production reached about 701 million tons in 1900 and 1,454 million tons by 1950 (Cipolla 1967:55). Today the annual production figure is around 2.5 billion tons of oil equivalent and rising.

With the United States in the vanguard, the twentieth century saw rapid rises in the exploitation of oil and natural gas. The US had large reserves of oil. And from early in the twentieth century its oil industry expanded quickly - spurred by the development of oil-burning furnaces, the spread of car ownership, the rise of aviation, and growth in the production of petrochemicals. The mass exploitation of natural gas (e.g. in electricity generation, and for household heating and cooking) had to await the development of high pressure pipeline technologies in the US during the 1930s. In both Europe and Japan the diversification away from coal, towards oil and gas, occurred several decades later (Ponting 1993).

The implications of these trends for world energy use are shown in Table 1. Oil has been the most important fuel since the 1960s. By 2003 oil accounted for about 38 percent of global energy use, followed by coal and gas in roughly equal proportion (about 25 percent each). Nuclear and hydro each accounted for around 6 percent. By 2003 global use of fossil fuels was equivalent to the burning of about 8.57 billion tons of oil each year. Notice that growth in the world's consumption of fossil fuels shows little sign of waning. Thus during 1980-90 the combined use of coal, oil and gas rose by an estimated 1,115 million tons of oil equivalent (mtoe); and during 1990-2003 it rose by a further 1,351 mtoe. Besides those countries in eastern Europe and the former Soviet Union (FSU) that experienced economic decline after the collapse of communism, only a handful of countries were burning smaller quantities of fossil fuel energy in 2003 compared to 1993, and then by only small amounts.[1] The overwhelming picture is one of expansion. For example, Brazil, China, India and Indonesia experienced rises in their use of fossil fuels of 42, 52, 59, and 65 percent respectively during 1993-2003. And even in the world's most advanced economies any changes in fuel mix or rises in energy use efficiency were significantly outweighed by increased levels of fossil fuel consumption. Thus during the same period, fossil fuel energy use rose by 12.5, 12.4, and 12.6 percent respectively in the US, the European Union and Japan (British Petroleum 2004).[2]

The huge degree to which differences in levels of per capita fossil fuel energy consumption underpin differences in living standards today is shown by Figure 1. It illustrates the relationship for 63 countries for which recent data are available. Virtually all of the countries which lie far below the fitted line (e.g. Uzbekistan, Kazakhstan, Ukraine, and the Russian Federation) are in the FSU and their use of fossil fuel energy is generally very inefficient. The two points which lie furthest above the line are France and Japan - both of which rely heavily on nuclear energy. Notice that about half (n=32) of all the countries are crammed together in the bottom left hand corner. They have levels of fossil fuel energy consumption of less than one metric ton per person per year. The economies of all these poor countries are severely constrained because they are still predominantly 'organic'. The basic message is extremely clear: countries have been unable to escape from conditions of material poverty in the absence of

[1] In making these statements the figures for coal and gas have been converted to mtoe. Of more than sixty countries for which data are given in British Petroleum (2004), only Colombia (-1.6%), Germany (-1.6%), Qatar (-6.9%) and Sweden (-1.1%) were burning smaller amounts in 1993 compared to 2003.
[2] The European Union figure refers to the fifteen countries which comprised the EU before 2004 i.e. the EU(15).

having access to supplies of fossil fuel energy. As the economic historian Carlo Cipolla succinctly stated (1967:57):

> [H]igh *per capita* consumption of energy not only means more energy for consumption, heating, lighting, household appliances, cars, etc., but [it] also means more energy for production, i.e., more energy available per worker and therefore higher productivity of labour.

In concluding this section it is worth stressing that while the current size of the world's population is certainly an important factor conditioning the total quantity of fossil fuels that is being burnt each year (i.e. around 8.57 billion mtoe in 2003), it is modern economic growth that has been the main engine of growth in humanity's use of fossil fuel energy. Thus between 1950 and 2000 the world's population increased by roughly 140 percent, but the rise in fossil fuel energy consumption during the same period was almost 400 percent (Table 1).

Trends in atmospheric CO_2 and the Earth's surface temperature

The suggestion that the burning of fossil fuels might lead to a build-up of CO_2 in the atmosphere, and so prevent heat escaping from the Earth, stems from the early work of scientists like Joseph Fourier and John Tyndall. But it was the chemist Svante Arrhenius who in 1896 famously published estimates as to how the Earth's surface temperature might be increased by raised levels of atmospheric CO_2.

For most of the twentieth century the idea received little attention. However, by the early 1980s it was becoming apparent that the Earth was probably warming. And concern that this might partly be due to human activities led to the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988.[3] The IPCC has now gone through three assessment rounds (e.g. see IPCC 1990, 1995, 2001a). The fourth assessment is due in 2007. Successive IPCC reports have concluded with growing confidence (i) that the Earth's climate is indeed warming, and (ii) that this is mainly due to anthropogenic (i.e. human-induced) causes - particularly the burning of fossil fuels which releases CO_2. It is important to stress that, contrary to popular impressions, these key conclusions are accepted by virtually all of the world's climate scientists; there is no substantive disagreement on the matter (see Oreskes 2004).

The most recent IPCC assessment concluded that during the final two decades of the twentieth century about three-quarters of the CO_2 released into the atmosphere came from burning fossil fuels, with most of the rest coming from land use changes - especially deforestation. Other greenhouse gases (GHGs) resulting from human activities that have made significant, though lesser, contributions to 'positive radiative forcing', and hence global warming, are halocarbons such as chlorofluorocarbons (CFCs), methane (CH_4), and nitrous oxide (N_2O).[4] It is notable that a sizeable part of the release of both CH_4 and N_2O derives from agriculture - so, again, the current size of the world's population is a pertinent consideration. Some anthropogenic influences have had a cooling effect - notably the release of aerosols (i.e. tiny airborne particles), many of which also come from fossil fuel burning. However, the net effect is very much one of positive forcing (IPCC 2001b:7-9).

Estimates of atmospheric GHG concentrations for most past periods in history have to be imputed from the analysis of materials like ice core samples and tree rings. Nevertheless, the resulting time series suggest that levels of atmospheric CO_2 started to rise from about 1800 i.e. the time of the Industrial Revolution. Moreover, similar trends are evident for CH_4 and N_2O - suggesting that humanity's influence on the global environment entered a distinctly new phase from around that time. Analogous proxy estimates of the world's surface temperature suggest a slight cooling trend in the centuries before about 1910. But the temperature has risen sharply since. The IPCC considers that the rise in the

[3] The mandate of the IPCC, which specifically excludes making policy recommendations for governments, is to assess research on climate change and to provide relevant information to the global community.

[4] Although world CFC production has fallen greatly since the late 1980s, levels in the atmosphere remain high. There remains a thriving black market, and some of the chemicals used as replacements also promote global warming (Sheehan 2002). Among other sources, CH_4 is emitted from fossil fuel burning, coal mining, rice fields, the guts of livestock, and landfill sites; N_2O comes from the use of nitrogen fertilizers, cattle feed lots, and various industrial processes.

twentieth century was about 0.6 deg/C with a 95 percent confidence figure around this estimate of ±0.2 deg/C. The rise was irregular - with comparatively rapid warming before 1940, and again since the mid-1970s (IPCC 2001b:3-9).[5]

Clearly, imputed estimates of atmospheric CO_2 and surface temperature are less satisfactory than those based on direct measurement. Before the twentieth century regular measurements of temperature were only made at a small and unrepresentative number of geographical locations. And, prompted in part by concern among some scientists regarding the calculations of Arrhenius, direct measurement of levels of atmospheric CO_2 date only from 1958-59 with observations made at the Mauna Loa Observatory in Hawaii.

Table 2 gives the Mauna Loa measurements. The level of CO_2 in the Earth's atmosphere has risen from about 317 ppm in 1959-61 to 375 ppm in 2003 and reportedly 378 ppm in 2004 (the level prevailing before 1800 is thought to have been around 280 ppm). Figure 2 shows that although the size of the annual increment in CO_2 fluctuates substantially, it has tended to increase. It is notable that 2002 and 2003 were the first consecutive years with increments exceeding 2 ppm, and the latest increment also seems to have been comparatively high.[6] However in the past some analysts have claimed that there has been no significant trend in the increment since about 1977 (Hansen and Sato 2001). The world's oceans and terrestrial vegetation are major 'sinks' (i.e. absorbers) of CO_2. And there are reasons to believe that, with rising levels of the gas in the atmosphere, and rising temperatures, these sinks may have increased their absorption.[7] Nevertheless according to the observations in Table 2 the average increment for the period 1959-77 was +0.99 ppm, whereas for 1977-2003 it was +1.61ppm. There are certainly no signs that the annual increment is diminishing. And it is certain that the concentration of CO_2 in the atmosphere will rise appreciably more in the present century, although it is uncertain by how much.

Table 2 also gives corresponding annual estimates of the Earth's surface temperature. By convention they are expressed relative to the average temperature holding during 1961-90. The resulting mean temperature 'anomaly' for 1959-61 is zero i.e. the average temperature for these three years is equal to the average for 1961-90. In contrast, the estimate for 2004 is 0.45 deg/C higher than this reference level. The estimated mean anomaly for the five-year period 2000-05 is 0.42 deg/C. The 1990s were the warmest decade since a reasonable quantity of direct records became available (around the middle of the nineteenth century). According to this time series, complied by the Climate Research Unit at the University of East Anglia, the ten warmest years globally have been, in ascending order: 2000, 1990, 1999, 1995, 1997, 2001, 2004, 2002 and 2003 (joint), and then 1998 - the hottest year ever recorded, 0.58 deg/C above the average for 1961-90. Clearly, and unlike the level of atmospheric CO_2, the world's temperature can fall from one year to the next. But Figure 3 shows that the trend has been firmly upwards since the mid-1970s. Notice that the moving average reveals the existence of a fairly regular fluctuation to the rise, linked in part to the El Niño/Southern Oscillation (ENSO) climate phenomenon. There is some suggestion that the next peak in the moving average might occur around 2010.[8]

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[5]The temperature plateau between about 1940 and the mid-1970s is thought have been due to the influence of sulphate aerosols. The fact that global warming was delayed compared to the rise in atmospheric CO_2 may partly reflect the fact that levels of CO_2 (and other GHGs) rose comparatively slowly for much of the nineteenth century. Also, during the initial stages of warming the strength of various buffer mechanisms - such as the ability of the oceans to absorb heat - may have been greater. Recall too that the Earth's temperature seems previously to have been on a slightly declining trend, which may have taken time to turn around.

[6]See the notes to Table 2.

[7]According to the IPCC (2001b:7) about half of all CO_2 currently released into the atmosphere by human activity is absorbed by the oceans and vegetation. There is evidence of increased plant growth because of the fertilizing effect of higher levels of carbon dioxide in the atmosphere (e.g. see Nemani et al 2003).

[8]The annual variation in temperature reflects specific events. Thus the eruption of Mount Pinatubo in 1991 led to a reduction in 1992 and 1993. A major El Niño event - which involves significant oceanic warming - contributed to the record temperatures of 1997 and especially 1998.

As previously intimated, the causal relationships linking levels of atmospheric CO_2 and world surface temperature are extremely complex. A vast amount is unknown about how intermediary mechanisms operate. However it is known that the level of CO_2 at any one moment implies a higher temperature over the longer run - what the IPCC terms a 'commitment' to future warming. Also, while it is generally agreed that increasing levels of atmospheric CO_2 are bringing about a rise in surface temperatures, it is also agreed that in some circumstances the rise in temperature can lead to the release of CO_2 i.e. the direction of causation can work both ways.[9]

In concluding this section it is worth underscoring that the data in Table 2 have the advantages of being comparatively straightforward and reliable. Even the most sophisticated computer climate models have to be calibrated against such basic observations. There is no reasonable doubt that levels of atmospheric CO_2 and surface temperatures are on a distinctly upward path. Accordingly, this is an appropriate place to review the social responses to this growing body of information.

Social reactions to the evidence on global warming

That modern economic growth has raised levels of atmospheric CO_2 - leading to a rise in the Earth's surface temperature and the threat of climate change - is patently unwelcome news. It raises difficult issues about the basis of economic growth. It highlights huge - and morally awkward - disparities in energy use, CO_2 emissions, and living standards between rich and poor. It rears the prospect that some very difficult changes in behavior may be required. Indeed, inasmuch as it suggests the need for big cuts in energy consumption, it strikes at the very heart of the modern conception of 'development'.

Predictably, then, the response to this news has been characterized by a mixture of denial, avoidance and recrimination. The response has been complicated because climate change is commonly seen as a phenomenon which - if indeed it is real - lies far off in the distant future. Most people are preoccupied with the events of their daily lives, they are increasingly distrustful of official sources of information, and they tend to be relatively unconcerned with what may happen over the very long run. Political leaders too have more immediate concerns to occupy their time. They usually avoid difficult issues, being chiefly concerned with the short run - often the period until the next election.

This section briefly considers some of the social reactions to the consensus on global warming that has emerged among climate scientists. The point is not to be critical of such reactions. Rather, it is to underscore that they are to be expected in the context of the dawning of unwanted news. They are social phenomena that often have little direct bearing on the CO_2 and temperature data to which they supposedly relate.

No one doubts that there have been significant rises in levels of atmospheric CO_2 , but a small, vocal minority still question whether the world is heating up. For example, in a paper used in the United States to petition the government to reject the Kyoto Protocol, Robinson and others state:

> The empirical evidence - actual measurements of Earth's temperature - shows no man-made warming trend. Indeed, over the past two decades, when CO_2 levels have been at their highest, global average temperatures have actually cooled slightly. (Robinson et al 1998:1)

A key part of this position - replicated by a host of internet websites - is that the indicated recent rise in surface temperature is spurious. It is contended that, instead, the rise reflects urbanization. That is, it is claimed that direct temperature measurements are being increasingly biased upward over time by the so-called 'urban heat island effect' - as more and more of the measurements take place in urban areas or areas close by. Also important to this position are satellite-based estimates of the temperatures prevailing in the lower troposphere (at altitudes of about 2 to 4 kilometers) which are interpreted as suggesting that there has been little change in the Earth's temperature.

However, both these points have been considered and largely rejected by climate scientists. The research teams that compile the estimates of surface temperature are well aware of the potential bias

[9] The process whereby decaying plant matter and forest soils release CO_2 into the atmosphere is known as 'respiration' and, particularly from soils, it tends to increase with higher temperatures. CO_2 respiration can also occur through forest fires (e.g. see Pearce 1999).

coming from urbanization, and much work has gone into gauging it.[10] The conclusion is that any distortion is small - probably no more than 0.05 deg/C for the entire period before 1990 (IPCC 2001 Box 2.1). Time series, such as that in Table 2, are adjusted downwards to allow for it. The temperature estimates for the lower troposphere are also open to question. Satellites do not gauge temperature directly. Rather, they measure molecular microwave emissions which are then converted into temperatures - a process that involves making many assumptions. Furthermore, the satellite data are only available from the late 1970s - a fairly short length of time that makes trend estimation tricky. Recent work on the microwave data concludes that the temperature of the lower troposphere has probably risen by more than was previously thought. And, when the revised estimates are combined with radiosonde (i.e. balloon-borne) temperature measurements, differences in trend between them and the surface temperatures largely disappear (World Meteorological Organization 2003:198; see also National Research Council 2000). In short, significant progress has been made in reconciling temperature estimates for the surface and the lower troposphere. And in both locations the evidence is that the Earth is heating up.

Of course, questioning and skepticism are integral to science. But statements such as that shown above border on denial. That such statements are made by a minority of non-climate scientists tends to be diminished by the media - which in the interest of providing 'balance' strives to provide equal space to opposing views. Beyond these concerns lie issues of interest on both sides. Some of the work of the IPCC has involved specialists who could have potential conflicts of interest with their commercial work (see Lohmann 2001:22-3). Scientific research on climate change is certainly affected by political and economic considerations (Demeritt 2001). And the provision of advice on how to adapt to, or help mitigate, the effects of climate change is big business. On the other hand, many industries (e.g. in power generation, manufacturing, transport, etc) have considerable commercial interest in the continuing exploitation of sources of fossil fuel energy. And prominent skeptics on global warming have received generous funding from the corporate sector (e.g. see Pearce 1997; van den Hove et al 2003). Furthermore, national governments - invariably with close links to industry - have found it extremely hard to confront the issue head on.

This brings us to the international political response - because reducing global CO_2 emissions would certainly require international agreement. The United Nations Framework Convention on Climate Change was initiated in 1992 to start the process towards stabilization of GHGs. But the Convention specifically avoided the issue of the level at which CO_2 (and other GHGs) should be stabilized - a matter which remains largely unresolved.[11] Following publication of the IPCC's second report, world leaders met in Kyoto in 1997. But in many respects the ensuing 'Kyoto process' can itself be seen as one chiefly concerned with ways of avoiding making reductions in CO_2 emissions. Examples of this tendency include the discussion of 'carbon sequestration' i.e. the planting of trees and other vegetation to help 'neutralize' CO_2 emissions. It took considerable time for the limitations of this approach to be appreciated fully - in particular, that over the long run the areas of forest required are incredibly great and that there is no feasible way of stopping the 'respiration' of sequestrated carbon back into the atmosphere (Lohmann 1999). Another approach with a strong element of avoidance - one that has occupied armies of negotiators, lawyers, economists, consultants, etc, the very stuff of Weberian bureaucratization (Prins 2003) - is the construction of 'carbon markets'. The theory is that by enabling 'emissions trading' such markets will allow some countries (usually richer ones, with high emissions) to pay others (usually poorer ones, with low emissions) - essentially as a way of reducing the need to make any reductions at all.[12] The fact is that:

> None of Kyoto's market measures … tackle directly the physical root of global warming: the transfer of fossil fuels from underground, where they are effectively isolated from the atmosphere, to the air. (Lohmann 2001:5).

[10] Research teams which compile such series include those at the Goddard Institute for Space Studies (GISS) in New York (e.g. see Hansen et al 2001) and the Climate Research Unit (CRU) at the University of East Anglia in Britain (e.g. see Jones and Palutikof 2005).

[11] The Global Commons Institute argues for a limit no higher than 450 ppm (see Hillman 2004:119), although much discussion of the issue mentions a figure of 550 ppm i.e. about twice the pre-industrial level.

[12] The vocabulary of the Kyoto process is tellingly rich with smooth terms like 'carbon offset', 'climate mitigation', 'joint implementation', etc.

It was noted above that in the last decade or so virtually all countries have continued to burn greater amounts of fossil fuel. This also applies to those that have arguably been most prominent in supporting the Kyoto process - notably Canada, Japan and those of the EU. Many of these countries are unlikely to meet their CO_2 reduction targets agreed under the Kyoto treaty (which finally came into force in 2005). Thus comparing 1990 and 2002, it is estimated that Canada's emissions increased by 22 percent and Japan's by 13. While the CO_2 emissions of the EU(15) remained roughly constant, this was mainly due to reductions in Germany and Britain - both of which gained fortuitously from a move away from coal towards natural gas (which emits less CO_2 per unit of energy). Of the remaining countries in the EU(15), only Sweden - which relies heavily on hydro and nuclear - registered a fall in CO_2 emissions. Of the 36 'Annex B' countries of the Kyoto treaty (i.e. the industrialized countries, including former eastern bloc nations), only 12 experienced declines in emissions: the three in the EU(15), plus nine former eastern bloc nations. If one excludes these, then CO_2 emissions among the remaining 24 Annex B countries rose by 13 percent during 1990-2002 (Zittel and Treber 2003). Of course, the United States, the world's largest emitter of CO_2, is not a signatory to the Kyoto treaty. And, to complete the list of predictable social reactions, the 'Kyoto process' has involved no shortage of rather bitter recrimination between representatives of the US and EU countries.

The prospects for an enforceable international agreement to significantly reduce CO_2 emissions are very poor. While it may be in the interest of the world as a whole to restrict the burning of fossil fuels, it is in the interest of individual countries to avoid making such changes. Moreover, the enormous complexities involved - many of them created and informed by matters of interest - will also hinder agreement. Doubtless there will be gains in energy use efficiency, shifts towards less carbon intensive fuels, and greater use of renewable energy sources (e.g. solar, wind and tidal power). But except for a massive shift towards nuclear - which has many serious problems attached, and would in any case take decades to bring about - there are limits to what such changes could possibly achieve in terms of CO_2 reduction. Other technological ideas - like the development of the so-called 'hydrogen economy', or the extraction of CO_2 from coal and its sequestration underground or at sea - are remote, even fanciful ideas as large scale and significant solutions to the problem. Indeed, such notions can themselves be the basis of avoidance inasmuch as they suggest that something is being done. Understandably, poor countries are unlikely to put great effort into constraining their CO_2 emissions - especially in the face of massive discrepancies between them and the rich.

In sum, for the foreseeable future the basic response to global warming will be one of avoidance and, at most, marginal change. That the absolute amount of CO_2 emitted is likely to rise is shown by an examination of basic demographic and emissions data in the next section.

Illustrative calculations on future CO_2 emissions

Demographic growth is a useful place to begin when considering future trends in CO_2 emissions. At the start of the twenty-first century the world's population was about 6.07 billion. The United Nations projects that by 2050 it will be around 8.92 billion (United Nations 2003). This represents growth of about 47 percent in fifty years. Although the projection is approximate, considerable further demographic growth is inevitable - because of population momentum. Moreover it is worth remarking that the UN has a good record of forecasting the world's total population.

By itself an increase in the world's population of roughly one half (i.e. 47 percent) will not lead to a similar proportional rise in CO_2 emissions from the burning of fossil fuels. The reason is that most of the coming demographic growth will occur in poor countries, which - almost by definition - burn relatively small amounts of coal, oil and natural gas. In this context Table 3 summarizes the situation at the start of the twenty-first century and provides a way of exploring the future. Column (i) shows the distribution of the world's population in the year 2000. Columns (ii) and (iii) give the corresponding levels of per capita and total CO_2 emissions by region. Notice that in 2000 the world's population of 6.07 billion was releasing about 23.2 billion tons of CO_2 through the combustion of fossil fuels - implying an average annual per capita emissions figure of about 3.8 metric tons. However, the statistics in column (ii) also underscore the enormous variation that exists around this average. Thus in North America (i.e. the United States and Canada) the average level of emissions was about 19.9 tons of CO_2 per person per year, whereas in sub-Saharan Africa and South-central Asia it was only around 0.9 tons. Column (iii) shows that around the year 2000 the largest absolute regional contribution to total world

CO_2 emissions came from North America, followed closely by Europe. Together these two developed regions contained only about 18 percent of humanity, but they accounted for around 54 percent of all CO_2 emissions from fossil fuel burning.

Turning to the future, column (iv) of Table 3 summarizes UN population projections for the year 2050 by region. During the period 2000-50 the population of sub-Saharan Africa is projected to rise by around 904 million, and that of South-central Asia (which includes India, Pakistan and Bangladesh) by 978 million. Taken together, these two very poor regions are projected to account for about 66 percent of the growth in world population. Note too that the population of North America is projected to rise by about 132 million. Only Europe's population is expected to fall in size. Column (v) shows the total CO_2 emissions that will apply in 2050 if the projected regional populations in column (iv) are combined with the corresponding per capita CO_2 emission figures for the year 2000 given in column (ii). On this simple and unrealistic assumption (i.e. that of holding per capita emissions in each region constant at the level that prevailed around the year 2000), it can be seen that global CO_2 emissions would rise to about 29.6 billion tons i.e. by 27 percent. Also, the average level of per capita emissions for the world as a whole would fall from about 3.8 to around 3.3 metric tons (i.e. 29,548/8,919). The explanation for this fall is that most of the coming demographic growth will occur in poor regions with low emissions - thereby weighting the global per capita emissions figure downwards over time. Precisely the same consideration explains why the projected population increase of 47 percent leads to a rise in global CO_2 emissions of only 27 percent. Note from the sub-totals in columns (iii) and (v) that the projected population growth in the developing regions leads to a 42 percent rise in their total emissions (i.e. from 10.4 to 14.8 billion tons). And for the developed regions too demographic growth produces a 16 percent rise in emissions (i.e. from 12.8 to 14.8 billion tons) - despite the projected decline in Europe's population. This underlines the fact that in North America, especially, immigration could play a significant role in the growth of future CO_2 emissions.

The rise in annual world CO_2 emissions in the next fifty years may well be greater than 27 percent. The huge differentials in current per capita emission levels shown in column (ii) of Table 3 account for this. Although, as comparative newcomers, the developing regions can expect to benefit from rises in the efficiency with which energy is derived from fossil fuel sources, it is nevertheless virtually inevitable that most of these regions will experience significant rises in their per capita emission levels as they develop economically. Consider, for example, that during 1990-99 the level of per capita CO_2 emissions rose appreciably in all the developing regions for which data are available. Thus for Asia (excluding West Asia) the increase was about 19.3 percent; for North Africa/West Asia it was around 19.7 percent; and for South America it was about 22.5 percent (World Resources Institute 2003: 258-9). Conservatively, these figures imply a 20 percent rise in per capita emissions per decade. And, cumulated across five decades, this would translate into an increase in per capita emissions of very roughly 150 percent. That said, no one knows by how much these per capita emission levels will increase. The degree of uncertainty is substantially greater than that regarding the scale of future demographic growth.

However, the figures in column (v) of Table 3 can be adjusted in a straightforward manner to explore the broad implications of different hypothetical trajectories in future per capita emissions. For example, if during 2000-50 per capita emissions in the world's more developed regions were to fall by 40 percent (which many might regard as optimistic) then the total volume of their emissions in 2050 would be about 8.9 billion tons (i.e. 0.6*14,790), and - assuming no change in per capita emissions for the developing regions - then the total volume of world emissions in 2050 would be about 23.6 billion tons (compared to the 23.2 billion that was being emitted around the year 2000). This suggests that a 40 percent reduction in per capita emissions in the developed regions would be outweighed solely by the effects of demographic growth elsewhere in the world. Alternatively, if per capita emissions were to double (i.e. increase by just 100 percent) in the developing regions over the same period then their total emissions in 2050 would be around 29.6 billion tons (i.e. 2.0*14,790), and - assuming no alteration in the per capita emission levels of the developed regions - then the total volume of global emissions in 2050 would be about 44.3 billion tons i.e. a 90 percent rise compared to the 23.2 billion tons being emitted around the year 2000. This calculation underscores the big influence that increased fossil fuel burning to support economic growth in the developing regions may have on the volume of world CO_2 emissions. Finally, consider the case in which per capita emissions in the developed regions fall by 40 percent while those in the developing regions double. This combination would produce global CO_2 emissions in 2050 of 38.5 billion tons (i.e. 8.9 +29.6) - an increase of about 66 percent compared to the year 2000.

Several conclusions arise from these illustrative calculations. First, the period 2000-50 will see substantial demographic growth - forcing total world CO_2 emissions to rise. Because most of this growth will occur in poor regions, the implied proportional growth in total CO_2 emissions (here 27 percent) is appreciably less than the population increase (47 percent). Second, the influence of population growth on future CO_2 emissions will not be confined to the developing world. North America, and to a lesser extent Oceania (which here effectively means Australia/New Zealand) both have very high per capita emission levels and are expected to experience significant demographic growth. Consider, for example, that in Table 3: the population of South-central Asia increases by 978 million in fifty years, which implies the emission of an additional 900 million tons of CO_2; and the population of North America rises by 132 million, which implies an additional 2,629 million tons of CO_2. Third, even should the developed regions make big cuts in their emissions, these will be more than offset by rises elsewhere. Thus the effect of population growth in the developing regions alone would outweigh a 40 percent reduction in CO_2 emissions in the developed regions. Yet economic development will likely mean that the total emissions of the developing regions will rise by much more. Finally, as a consequence, it is virtually certain that there will be a significant rise in global CO_2 emissions. This will happen due to population growth, but it will happen much more because of the fueling of economic growth.

Even so, there is great uncertainty about how big the coming rise in global CO_2 emissions will be. And, particularly in relation to oil and natural gas, it seems likely that limits to the available supplies may operate to curb future expansion to some degree. It is especially hard to gauge the extent to which per capita emissions will increase with the economic expansion of Eastern Asia (including China) and South-central Asia (including India). There is uncertainty about to what extent, if any, the developed regions will limit their emissions. Such matters can be little more than guesswork. However, given the numbers in Table 3 and some simple assumptions, it seems reasonable to hazard that global CO_2 emissions could rise by somewhere between a quarter and two-thirds during the first half of the twenty-first century.

Prospects for the Earth's temperature and climate

The coming major rise in CO_2 emissions will, of course, occur on top of levels of fossil fuel burning that have already raised the level of CO_2 in the atmosphere by about 33 percent (compared to the pre-industrial era) and brought about an estimated rise in the world's surface temperature of around 0.6 deg/C. There is little doubt that these trends will continue - and that the climate will change as a result.

That said, the interconnections between trends in fossil fuel use, CO_2 emissions, levels of atmospheric CO_2, increases in the world's temperature, and climate change, are unbelievably complex. Even the elaborate computer general circulation models (GCMs), on which the IPCC draws, have massive limitations. These models find the task of simulating the interconnections immensely challenging and inevitably their results have to be grounded on basic observations such as those in Table 2 (Burroughs 2001:239-71). Moreover GCM results are invariably complemented and calibrated using much simpler models that are also grounded in the same basic data (IPCC 2001b:13).

It is certain that the stock of CO_2 in the atmosphere will continue to rise. If future increments were to average 1.61 ppm - as they have since 1977 - then by 2050 the level would be about 451 ppm and by 2100 it would be 532 ppm (see Table 4). These figures, however, could well turn out to be on the low side - partly because of the likely coming rise in anthropogenic emissions, and partly because there are reasons to believe that the net absorptive capacity of the world's oceans and terrestrial vegetation (as 'sinks' for CO_2) may weaken in the future - e.g. due to increased forest fires and changes in seawater chemistry (O'Neill et al 2001:31). The IPCC projections for 2100 produce figures varying from 540 ppm to 970 ppm (IPCC 2001b:14).

Turning to the Earth's surface temperature, the data in Table 2 can be used to gain a rough idea of the likely broad range of the coming temperature rise. Three straightforward approaches to the data have been employed here. The first involves fitting a simple linear regression to all the observations shown i.e. those from 1959 to 2004. Using the resulting equation to extrapolate into the future may understate the quantum of the coming temperature increase - because observations are included from before the mid-1970s when there seems to have been no distinct upward trend. On the other hand, in the future as

in the past, there may well be periods when the world's surface temperature 'plateaus' for some length of time. Nevertheless, this approach suggests that by 2100 the temperature could be about 1.6 degrees deg/C above the average of 1961-90. The second approach employed also involved using a linear regression, but one restricted to the data for 1976-2004 (i.e. the recent period when the trend has generally been upward). Extrapolating on this basis suggests a temperature anomaly for 2100 of about 2.2 deg/C. The final approach used involved fitting a polynomial curve to all the temperature observations in Table 2. Not surprisingly, this provides a slightly better fit to the data; and it reflects the possibility that the rate of temperature increase could be accelerating. This third approach implies a much greater anomaly rise by 2100 of about 6.6 deg/C, a figure that must surely be regarded as constituting an upper bound.

Table 4 summarizes the resulting temperature trajectories, labeled respectively 'low', 'middle' and 'high'. The extreme simplicity of these extrapolations should require no emphasis here. The absolute differences between them are initially relatively modest. But by 2050 the difference between the low and high figures is about 1.6 deg/C. It is noteworthy that the indicated range of temperature rise obtained for the year 2100 in the present exercise (i.e. 1.6 to 6.6 deg/C) is similar to - although at a somewhat higher level than - that arising from the results of the many GCM runs that are summarized in the IPCC report published in 2001 (i.e. 1.4 -5.8 deg/C; see IPCC 2001b:13).[13] This is not surprising since, to reiterate, the computer models must be attuned to the same basic information.

However, the fact that the level of the present range is somewhat higher may be because the temperature anomaly figures for the years 2000-04 were not available to the IPCC at the time of writing their 2001 report. But, as has been noted, the average anomaly for these five years was unusually high at 0.42 deg/C. Thus the thought arises that the IPCC's next assessment report may well adjust the level of the future temperature range upwards. A final comment on the figures in Table 4 is that they envisage a future in which change occurs fairly smoothly (i.e. a 'surprise-free' world) as do the results of the GCM runs used by the IPCC.

In trying to assess the implications of the extrapolated trajectories in Table 4, it is worth recalling that the IPCC considers that the Earth's surface temperature probably rose by about 0.6 deg/C over the twentieth century. On this basis, the 'low' trajectory implies that during the twenty-first century the temperature will increase roughly twice as much as it did during the twentieth; the 'middle' trajectory suggests an increase that is about three times as much; and the 'high' trajectory suggests an increase that is about nine times as much.[14] Also an average temperature anomaly during 2000-04 of 0.42 deg/C implies a rate of temperature rise of roughly +0.4 deg/C every quarter century i.e. between two and three times the rate of the twentieth century. Yet, almost certainly, the twentieth century rise was itself unprecedented in history.[15]

Furthermore, the trajectories in Table 4 raise another possibility - namely that the global climate will not evolve in a comparatively smooth way. For when any system is being forced the chances of a sudden discontinuity occurring are likely to be raised. For example, it is at least conceivable that at some point in the future the rise in temperature could lead to the cumulative, large-scale release of methane (CH_4) from underground deposits of methane hydrate. In turn, this could contribute to further warming - so stimulating the release of still more CH_4. Another conceivable - anticipated - 'surprise'

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[13] It is worth noting that a similar temperature range for 2100 is also implied by an analogous treatment of both the CO_2 and the temperature data shown in Table 2. Thus assuming a level of CO_2 in 2100 of 532 ppm, linear regressions fitted to the data for 1959-2003 and 1976-2003 produce respective temperature anomaly figures of 1.9 and 2.4 deg/C; and if a polynomial curve is fitted to the CO_2 and temperature data for 1959-2003 then the resulting extrapolated temperature figure for 2100 is 6.5 deg/C.

[14] These statements assume that the temperature anomaly figures for 2100 in Table 4 occur over a period of 125 years i.e. since about 1975-76, the center of the reference period 1961-90.

[15] The IPCC conclusion that in the twentieth century the Earth's temperature rose to a higher level than at any time in the previous 1000 years has been challenged, for example on the basis that it ignores the medieval climatic optimum (e.g. see Avery 2003). This is part of the so-called 'hockey stick' controversy. However, evidence of medieval warming is absent from data for many parts of the world and therefore it is not possible to deduce, as some have, that the Earth's temperature in that period exceeded that of the twentieth century. Moreover there is little doubt that the rate of temperature rise in the twentieth century is quite unprecedented in history (e.g. see Burroughs 2001:104).

might involve accelerated ice sheet melting - e.g. of the West Antarctic or Greenland ice sheets, about which there is considerable uncertainty.

However, perhaps the most likely possible 'surprise' scenario in the present century is that the rise in temperature could lead to a collapse of the thermohaline circulation system in the world's oceans. This would cause a sudden, huge alteration in the global climate. Rapid collapses of the thermohaline system have occurred in the distant past. It seems that a key component of such a collapse would be a shutdown of the Gulf Stream in the North Atlantic, leading to a major cooling of northwestern Europe - although it is important to underline that the climatic ramifications of such an event would almost certainly extend worldwide. Such a shutdown could be triggered by decreases in the salinity of the ocean to the east and south of Greenland itself caused by the melting of Artic ice and increased discharge of fresh water from northern rivers. There is evidence of falls in salinity in these areas of ocean (Calvin 1998; Palmer 2003). However, most climate scientists believe that the thermohaline system will not collapse during this century (IPCC 2001b:16; Osborn 2004), although no one can be sure.

It is impossible to attach probabilities to these four stylized possibilities - the low, middle and high temperature trajectories, and the occurrence of some sort of surprise. However, it seems reasonable to conclude that the chances of humanity facing a very difficult situation sometime in the twenty-first century are considerable. Thus if one considers that the possibilities are equally likely then the chance of such a situation occurring is about fifty percent. The low trajectory would involve a doubling of the rate of temperature rise experienced in the twentieth century, which might well be manageable. But the middle trajectory would be significantly more demanding. The high trajectory - or for that matter any that is significantly warmer than the 'middle' - would almost certainly be catastrophic; and the same applies to any likely 'surprise'. So the range of future outcomes varies from the tractable to the disastrous. The next section considers what could happen, and makes some comments about conventional thinking on the subject.

Thinking on the consequences of climate change

Mainstream thought on the effects of a rise in temperature for the world's climate, and its people, has at one and the same time been valuable, yet restricted. The temperature rises discussed in the previous section may seem small, but their implications could be immense.

So far as the consequences for the climate are concerned, and with reference to its projected range of temperature increase for the year 2100 (i.e. 1.4-5.8 deg/C), the IPCC valuably summarizes the essentials as follows: the land surface temperature rise will probably be greater than the ocean surface temperature rise; there will probably be more hot days and fewer cold days, but with a reduced diurnal temperature range over most land areas; there will be increases in water vapor in the atmosphere, and rainfall will increase in most locations; in many places there will more intense rainfall events; in many places there will be an increased risk of drought (e.g. such as those associated with El Niño events); it is likely that there will be increases in the frequency of extreme weather events - like thunderstorms and tornadoes; it is likely that there will an increase in variability of the rainfall associated with the Asian summer monsoon; glaciers and ice caps will continue to melt; and sea levels will probably continue to rise as the ocean expands due to thermal expansion and the melting of snow and ice - a global mean sea level increase of anywhere between 9 and 88 centimeters over the period 1990-2100 is projected (IPCC 2001b:13-16). In relation to all these effects there will be variation by world region, and the effects will generally vary directly with the extent of the coming temperature rise.

The task of gauging what the numerous consequences of these possible changes in climate might be for humanity is probably even greater than that of determining the nature of the likely climate changes themselves. This is partly because of the existence of both regional and socioeconomic variation, and because of the multitude of dimensions of both the environment and human life. However, key elements of the IPCC's assessment of the implications and consequences of coming changes in climate for human populations include: that natural systems are often limited in the extent to which they can adapt, and that changes in such systems can sometimes be irreversible; that although adverse impacts will probably tend to predominate there will also be beneficial impacts - thus, for example, while the overall effect for world agriculture may be negative, in some locations levels of agricultural production might be raised from some climate changes (e.g. increases in temperature and rainfall); that in most

settings - whether between or within countries - the adverse effects of climate change will fall disproportionately upon the poor - for example, '[t]he effects of climate change are expected to be greatest in developing countries in terms of loss of life and relative effects on investment and the economy' (IPCC 2001c:8), and 'squatter and other informal urban settlements with high population density, poor shelter, little or no access to resources ... and low adaptive capacity are highly vulnerable [to urban flooding]' (IPCC 2001c:13); that there will probably be appreciable increases in the geographical areas and human populations that are subject to water stress, to flooding and to food insecurity as a result of climate change; that disaster losses due to extreme weather events are likely to rise substantially; that the adverse impacts of climate change will be greater with more rapid warming; and, lastly, that adaptation is a necessary strategy to complement efforts at climate change mitigation - thus, '[f]or each anticipated adverse health impact there is a range of social, institutional, technological, and behavioral adaptation options to lessen that impact', and '[a]daptation to climate change presents complex challenges, but also opportunities, to the [insurance and financial services] sector' (IPCC 2001c:12 and 13).

Given the sheer magnitude of the task, the IPCC's exploration of the likely consequences of the coming change in the world's climate is commendable. However it is open to criticism in several key respects. For example, questions arise about the vocabulary that is used. The single most important theme is usually that of ways of adapting to climate change. But 'adaptation', and similar words like 'coping', are not neutral. They presuppose changes to which it will be possible to adjust. Likewise, the analytical perspectives that tend to be employed - for example, that there will be 'winners' as well as 'losers' (echoed in some of the preceding extracts), can be criticized in that they presume an element of symmetry - yet it could be that on the basis of some future trajectories of temperature and climate, conditions might deteriorate for almost everyone.

Again, and as one might expect, studies of the consequences of climate change tend to proceed sector by sector - for example, examining the possible implications for agriculture, industry, the service sector, health, etc. Almost inevitably this means that it is hard to do justice to the manifold possible interactions between different sectors. In fact, in broad terms, the IPCC's assessment of the implications of future climate change starts from a consideration of possible ecological changes - for example, relating to water resources, coastal zones, and marine ecosystems - and then proceeds to discuss the implications for the production of goods and services, human settlements, energy, industry, financial services and health. While this is a reasonable direction in which to proceed, it is not the only possible one. Thus it is arguably less people-centered than, for example, the recent Millennium Ecosystem Assessment - which more specifically considers ecosystems in terms of the benefits that they provide to people (e.g. in terms of timber, clean air, fibers, food etc). Moreover, and predictably, the dominant social science perspective in these studies is that of economics. Input from, for example, sociologists or political scientists is negligible in the published IPCC reports. However this means that some potentially important effects of future climate change receive virtually no consideration at all - for example, as to how people's views of the world might alter (e.g. in terms of religious beliefs) or the ways in which the behavior of states in the international arena might change (e.g. towards positions that are even more dominated by instrumentalism and self-interest).

A common thread behind the issues raised in the preceding paragraph is that study of the possible consequences of future climate change tends to shy away from contemplating circumstances that incline in the direction of the 'high' temperature trajectory or the occurrence of a 'surprise'.[16] It has been argued here, however, that there is a fair chance that such circumstances might arise. Therefore it may not be farfetched to say that most such studies evince more than a hint of avoidance. This is not the place to consider the possible consequences of hotter scenarios or those involving a surprise, but a few observations are relevant by way of conclusion.

First, consider that the world's population later in this century will probably be around nine billion. The addition of an extra three billion people will mostly be those who are poor and relatively vulnerable. Second, the continuing process of urbanization will mean that extremely large numbers of people - probably several billion - will be living in low lying, densely populated, coastal areas of the developing world, and their situation is likely to be particularly exposed. Third, probably the most important

[16] An exception is Stipp's (2004) account of an internal report for the US Department of Defense that considers the possible consequences of rapid climate change. See also National Research Council (2002).

consequence of future climate change for human populations relates to agricultural production in the world's tropical and semi-tropical regions (IPCC 2001c). Food production in such areas is an activity that is unlikely to be able to adapt to a rapid rise in temperature, and it will certainly not be able to cope with any abrupt change in climate. Perhaps no economic generalization is sounder than that small declines in food production can produce big rises in food prices, often with very significant political ramifications. Fourth, more thought needs to be given to circumstances in which several adverse changes occur simultaneously and to cumulative adverse effect. This is the matter of how potential developments might interact. For example, flooding of coastal areas, which might result partly from sea level rise and partly from increased rainfall, could lead to the simultaneous loss of cropland and urban infrastructure, producing food price rises, large scale migration, and possibly significant sociopolitical disruption.

Finally, any abrupt change in the world's climate could well lead to a situation in which virtually everyone loses and nobody wins. This could happen, for example, through the likely severe adverse effects on agriculture everywhere. In such circumstances it would be especially naive to believe that only poor countries would be badly affected. Indeed, it is worth considering the notion that the very interdependent complexity and high degree of specialization that characterize the world's most economically advanced countries could be a potential source of vulnerability for some of them. A sudden change in climate would have consequences that may be almost inconceivable to those of us who have grown up in a generally improving world, one underpinned by massive increases in the use of fossil fuel energy.

Conclusions

The essential argument of this paper has been that there is a significant chance of very major climate change occurring at some time during the present century. Of course, it is quite possible that future change in the world's climate will be modest, manageable, and perhaps even beneficial for many. But the chances of some sort of disastrous change occurring - abrupt or otherwise - appear to be just as great.

The paper has presented relevant time series data - particularly on levels of atmospheric CO_2 and the world's surface temperature - so that, to some extent at least, the reader can make up his or her own mind about past and future trends. It can be predicted with near certainty that the level of CO_2 in the atmosphere will continue to increase monotonically in the coming decades. It is likely that the Earth's surface temperature will continue to rise at an unprecedentedly rapid rate. There seems to be a fair chance that the next secondary peak in the temperature cycle will occur around the year 2010. It seems probable that the IPCC will revise its future range of temperature trajectories upwards in its next report that is expected in 2007. Anyhow, the time series presented here can be updated - since how these measures change in the coming years should be extremely interesting, and help us to determine just where the world is heading.

Denial and avoidance have also been significant themes here. Understandably, people don't like to confront difficult issues, nor do they like to change their behavior. As was intimated at the start, there is a broad parallel here with HIV/AIDS. Within five years of its identification, all the main transmission routes were known, the virus was isolated, tests had been developed, and the first antiretroviral drug was available. Yet denial and avoidance were rife - they still are - and, partly as a result, some 60 million people have either died of the disease or are currently infected. There is much evidence that people only really change their sexual behavior when evidence of damage becomes plain. And, similarly, the thrust here has been that people will only really alter their behavior when they experience very damaging weather phenomena themselves. That said, the purpose of this piece is to try to comment objectively on the subject, rather than to try to alter behavior.

That modern economic growth and the demographic transition both began at around the same time in history is hardly coincidental. Population growth, migration, and urbanization all play significant roles in the subject of global warming and climate change. However, the most important part, by far, is that played by fossil energy - coal, oil and natural gas - in fuelling economic development. It is important to remember that what still locks so many people in conditions of material poverty is their reliance upon economies that remain overwhelmingly 'organic' i.e. they have no real access to the energy supplied by fossil fuels. If there are major changes to the world's climate in the coming century then the

agricultural, economic, political and wider social repercussions could be so great that they impact on the future growth trajectory of the human population. While our children or grandchildren may not face the end of the world, they could well face the end of the world, at least as we have known it.

Table 1 World energy supplies, 1950-2003

Year	Coal production (mtoe)	Oil production (mill. tons)	Natural gas production (mtoe)	Total fossil fuels (mtoe)	Nuclear energy consumption (mtoe)	Hydro consumption (mtoe)	Total (mtoe)
1950	884	518	187	1589	-	-	1589
1960	1271	1049	458	2778	-	-	2778
1970	1359	2355	919	4633	17	269	4919
1980	1708	3088	1311	6107	161	387	6655
1990	2254	3168	1800	7222	453	494	8169
2000	2112	3604	2190	7906	584	614	9104
2003	2519	3697	2357	8573	599	595	9767

Notes: All figures are in million tons of oil equivalent (mtoe) and should be regarded as only broadly indicative. World nuclear generating capacity was insignificant in 1960, but the total figures given above for 1950 and 1960 are slight underestimates because they contain no allowance for hydro. There were minor discrepancies between the some of the time series used above, but they can safely be ignored for present purposes

Principal data sources: Coal 1950-80 (Kane 1996), 1990-2003 (British Petroleum 2004); Oil 1950-60 (Flavin 1996a), 1970-2004 (British Petroleum 2004); Natural gas 1950-60 (Flavin 1996b), 1970-2004 (British Petroleum 2004); Nuclear (British Petroleum 2004); Hydro (British Petroleum 2004)

Table 2 Global atmospheric CO_2 concentrations and surface temperature anomaly estimates, 1959-2004

Year	CO_2 (ppm)	Annual increment (ppm)	Temp. anomaly (deg/C)	Year	CO_2 (ppm)	Annual increment (ppm)	Temp. anomaly (deg/C)
1959	316.00	-	0.01	1982	341.09	1.14	0.02
1960	316.91	0.91	-0.03	1983	342.75	1.66	0.23
1961	317.63	0.72	0.02	1984	344.44	1.69	0.03
1962	318.46	0.83	0.01	1985	345.86	1.42	0.01
1963	319.02	0.56	0.04	1986	347.14	1.28	0.10
1964	319.52	0.50	-0.23	1987	348.99	1.85	0.25
1965	320.09	0.57	-0.17	1988	351.44	2.45	0.24
1966	321.34	1.25	-0.08	1989	352.94	1.50	0.16
1967	322.13	0.79	-0.09	1990	354.19	1.25	0.31
1968	323.11	0.98	-0.11	1991	355.62	1.43	0.25
1969	324.60	1.49	0.04	1992	356.36	0.74	0.12
1970	325.65	1.05	-0.03	1993	357.10	0.74	0.18
1971	326.32	0.67	-0.19	1994	358.86	1.76	0.23
1972	327.52	1.20	-0.04	1995	360.90	2.04	0.37
1973	329.61	2.09	0.09	1996	362.58	1.68	0.23
1974	330.29	0.68	-0.17	1997	363.84	1.26	0.41
1975	331.16	0.87	-0.12	1998	366.58	2.74	0.58
1976	332.18	1.02	-0.20	1999	368.30	1.72	0.34
1977	333.88	1.70	0.06	2000	369.47	1.17	0.29
1978	335.52	1.64	-0.04	2001	371.03	1.56	0.42
1979	336.89	1.37	0.07	2002	373.07	2.04	0.47
1980	338.67	1.78	0.10	2003	375.61	2.54	0.47
1981	339.95	1.28	0.13	2004	378	-	0.45

Notes: The CO_2 concentrations are derived from air samples collected at the Mauna Loa Observatory. The CO_2 figure given for 2004 is approximate and comes from a news report by Shukman (2005). The temperature series are combined global land and marine surface temperatures relative to the average temperature recorded for the period 1961-90. They are taken from the 'Global average temp 1856 to 2005' dataset (TavGL2) of the Climate Research Unit at the University of East Anglia, UK.

Principal data sources: CO_2 (Keeling et al 2004); Temperature anomaly data (Palutikof 2004; Jones and Palutikof 2005) and <<http://www.uea.ac.uk/cru/data/temperature/>>.

Table 3 Estimates of regional and global emissions of CO_2 produced by the combustion of fossil fuels for around the year 2000, with illustrative calculations for 2050

Region	Population (millions)	Per capita CO_2 emissions (metric tons)	Total CO_2 emissions (million metric tons)	Projected population (millions)	Total CO_2 emissions (million metric tons)
	2000	2000	2000	2050	2050
	(i)	(ii)	(iii)	(iv)	(v)
Developing regions					
Sub-Saharan Africa	653	0.9	613.8	1557	1463.5
North Africa/West Asia	335	4.3	1430.8	647	2763.4
Eastern Asia	1481	3.4	5044.6	1590	5415.8
South-central Asia	1486	0.9	1368.2	2464	2268.7
South-eastern Asia	520	1.3	696.1	767	1026.8
Central America and Caribbean	173	2.8	481.2	258	717.6
South America	347	2.2	771.9	510	1134.5
Subtotal	4996	2.1	10406.6	7794	14790.3
Developed regions					
Europe	728	8.4	6106.2	631	5292.6
North America	316	19.9	6294.5	448	8923.8
Oceania	31	11.8	365.0	46	541.6
Subtotal	1075	11.9	12765.7	1125	14758.0
World	6071	3.8	23172.2	8919	29548.3

Notes: All the figures given above are approximate - especially those relating to CO_2 emissions. The per capita and total emissions statistics shown for 2000 actually pertain to 1999. The regional groupings of countries used are those employed by the World Resources Institute, but with Asia (excluding West Asia) being broken down according to the standard groupings of the United Nations. Here Sudan forms part of sub-Saharan Africa. The regions are designated as either 'developing' or 'developed' - perhaps the main qualifications being that Japan falls in Eastern Asia, and that Melanesia is part of Oceania. The World Resources Institute provides no regional statistics on CO_2 emissions for sub-Saharan Africa. In 1999, however, South Africa had estimated per capita and total CO_2 emissions of 8.1 tons and 346 million tons respectively. To get the figures shown above for sub-Saharan Africa for the year 2000 it was arbitrarily assumed that per capita emissions for the remainder of the region averaged 0.4 tons (about the levels indicated for Angola and Senegal). Several modest adjustments were required to produce the relatively consistent regional and global picture given above, and therefore some of the figures on CO_2 emissions differ slightly from those of the World Resources Institute on which they are based. The figures in column (v) are the product of those in (ii) and (iv).

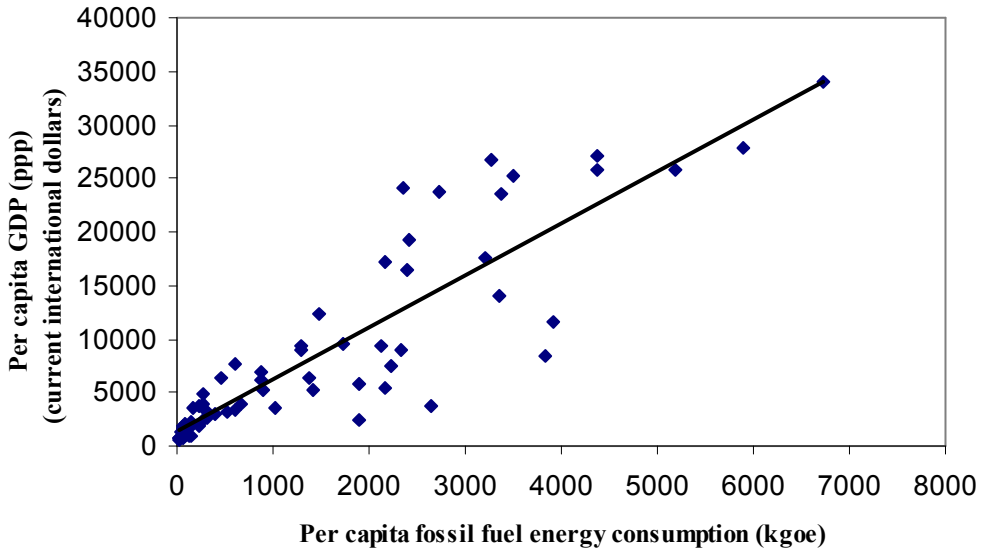
Principal data sources: World Resources Institute (2003: 258-59); United Nations (2003)

Table 4 Simple projections of global atmospheric CO_2 concentrations and surface temperatures, 2004-2100

Year	CO_2 (ppm)	Temperature anomaly (deg/C)		
	(i)	(ii)	(iii)	(iv)
		'Low'	'Middle'	'High'
2004	375.61	0.45	0.45	0.45
2025	411.03	0.67	0.86	1.23
2050	451.28	0.99	1.32	2.56
2075	491.53	1.31	1.77	4.35
2100	531.78	1.64	2.23	6.58

Notes: The CO_2 figure shown for 2004 is actually that recorded for 2003. It must be emphasized that the CO_2 figures shown for later this century assume the continuation of an annual increment of 1.61 ppm and therefore will probably turn out to be on the low side. The temperature figure given for 2004 is that recorded in that year. To get the three temperature trajectories, the equations used and their associated R^2 values were: column (ii) $y = 0.0128419x - 25.3323271$ ($R^2 = 0.71$); column (iii) $y = 0.018307x - 36.213828$ ($R^2 = 0.75$); and column (iv) $y = 0.0003608x^2 - 1.4170634x + 1391.2827463$ ($R^2 = 0.79$). All the temperature projections are relative to 1961-90. The year 1976 was taken as the first year for deriving the second equation because the average temperature anomaly for 1976-80 is zero (i.e. equal to the average temperature holding in 1961-90) while those for all subsequent five-year periods, based on the data in Table 2, are positive.

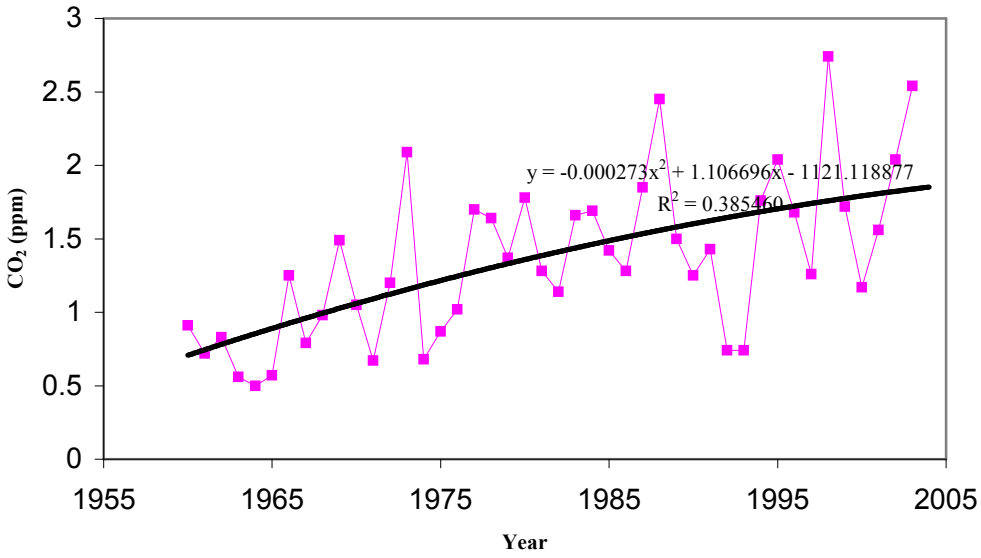
Figure 1 Fossil fuel energy consumption as a determinant of per capita gross domestic product around the year 2000



Notes: Data on both variables were found for 63 countries, all with estimated populations in 2002 of 10 million or more. The trend line shown is a simple linear regression. The GDP data are expressed in purchasing power parity terms, and the energy use data are expressed in kilograms of oil equivalent (kgoe). As well as the various factors discussed in the text, some of the scatter around the trend line undoubtedly reflects inadequacies in the data.

Principal data source: World Resources Institute (2003: Tables 4 and 8).

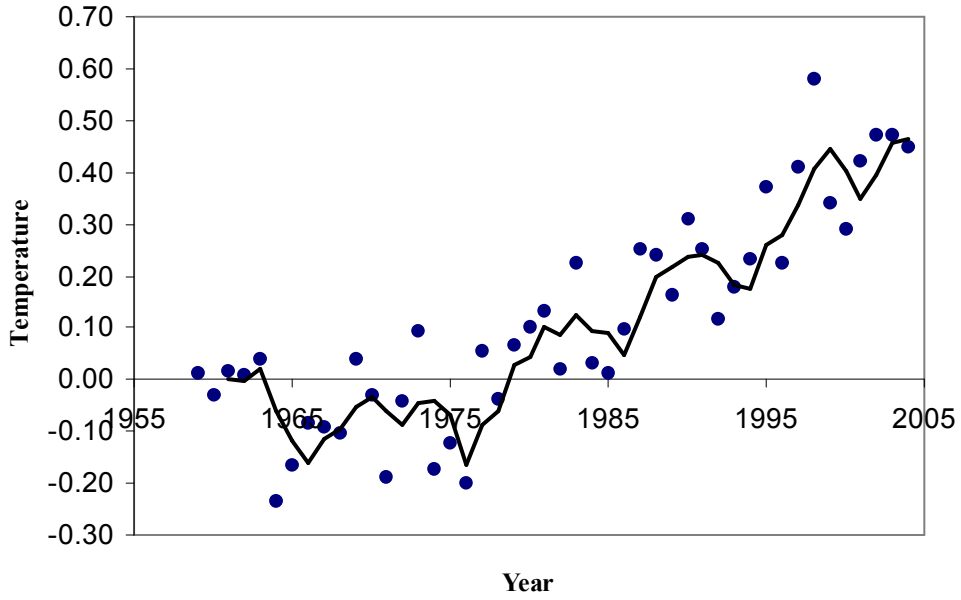
Figure 2 Annual increments in atmospheric CO_2 (ppm) as measured at the Mauna Loa Observatory, 1959-2003



Note: Increments are expressed in parts per million (ppm).

Principal data source: See the notes to Table 2.

Figure 3 World surface temperature anomaly estimates, 1959-2004



Notes: Temperatures are in degrees Celcius (deg/C). The trend line is a three year moving average.

Principal data source: See the notes to Table 2.

Note and acknowledgement

The subtitle of this paper is taken from a television program broadcast on 10 January 2005 as part of UK Channel Four's *War on Terra* season. The paper attempts to examine the subject of global warming and climate change objectively, and is not about advocacy. I thank Tim Forsyth, Brian O'Neill and Chris Wilson for help and advice. The usual disclaimer applies.

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