CENTRE FOR POLICY STUDIES

CLIMATE CHANGE

A GUIDE TO THE SCIENTIFIC UNCERTAINTIES

Martin Livermore

THE AUTHOR

Martin Livermore is director of the Scientific Alliance, a membership-based organisation which promotes informed debate on environmental issues. He is a chemist by training and has spent a large part of his professional life working in R&D and technical management for Unilever, Dalgety and DuPont. He has been actively involved in the debates on climate change, energy policy and agricultural biotechnology for a number of years.

ISBN No: 1 905389 46 9

Centre for Policy Studies
57 Tufton Street, London SW1P 3QL
Tel: 020 7222 4488 Fax: 020 7222 4388
e-mail: mail@cps.org.uk website: www.cps.org.uk

Printed by The Centre for Policy Studies, 57 Tufton Street, SW1.

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SUMMARY

- The scientific understanding of climate change is far from complete (despite claims to the contrary).
- It is clear from the evidence that the climate is always changing (but not consistently: the trends and patterns depend upon the timescale chosen); that the average CO_2 content of the atmosphere has increased relatively steadily over the last century; and that increased CO_2 in the atmosphere leads to some increase in temperature (other things being equal).
- However, it is by no means certain that increases in $C0_2$ concentration and emissions are the **dominant** driver of climate change.
- Computer models which seek to predict the effect of $C0_2$ on climate are based on an incomplete understanding of a complex and chaotic system.
- Even measuring climate change meaningfully is itself an uncertain science.
- Current energy policy is driven by the reduction of carbon emissions. However, in light of the uncertain science on which this is based, more effective policies, focussed on long-term energy security, should be pursued (each of these policies which will also, incidentally, reduce carbon emissions).

- These policies include building a new generation of efficient and safe nuclear power stations; promoting greater energy efficiency; and encouraging research into new energy technology.

CHAPTER ONE
A DEFINING ISSUE FOR OUR TIMES?

The words "climate change" have taken on a specific meaning. Constant repetition in the media means that the general public now generally believes that recent climate changes have been unprecedented, are due primarily to mankind's activities and are likely to end in overall harm or, at worst, disaster for both us and the planet.

Climate change has become synonymous with global warming, but the gradual change in terminology now suggests that *any* significant differences in weather pattern should be ascribed to human influence. We are guilty, and we must be punished. The first stage in this punishment was the Kyoto protocol, which sets targets for emissions reductions by industrialised countries in the period to 2012. To follow this, the EU is in the process of adopting a binding target of a 20% reduction by 2020, and the UK Government has floated ideas such as personal carbon allowances.

In some cases, we are told that this merely means paying for the right to emit carbon dioxide (CO_2) already saved elsewhere. But to have any chance of controlling climate, so we are told, the global economy must be decarbonised.

The stringent policies proposed to achieve this are deemed to be necessary because, as for example the Stern Review claimed, "The scientific evidence is now overwhelming".

But this is far from the truth. The science is not settled.

CHAPTER TWO
SOME CERTAINTIES

The first certainty is that the climate is in a continual state of flux, both globally and regionally. It is a constant, unchanging climate which would be remarkable.

Climate is generally defined as the pattern of weather over a long period of time. Normally, 30 years is taken as the timescale for comparison. That is to say, in a period where climate is relatively stable, the maximum and minimum temperatures, rainfall and so on during each season will nearly always fall within certain bounds. But not always; weather records are broken in particular localities round the world on a frequent basis. On the other hand, some records can be remarkably long-lasting. The UK has, this year, had its warmest recorded January since 1916, for example. Weather patterns are notoriously unpredictable.

Climate change becomes noticeable to us if there are significant shifts in weather patterns in our lifetimes. Our memories are not necessarily reliable – our schooldays were not really a happy mixture of long, hot summer days and cold snowy winters – but there have been trends apparent to most of us over the last 30 years. We are tending to get earlier springs and milder winters and, in recent years, many of us have experienced more frequent heat waves. This trend in Western Europe seems certain, but the cause of it is not. And the trends have not been the same everywhere: many places in the Southern hemisphere have had weather which is cooler than expected.

Another certainty is that patterns depend upon the timescale chosen. There has been an upward trend in temperature from 1976 to 2006, and equally from 1906 to 2006. However, this masks a warming period through to the late 1930s, a cooling trend through the next three decades, and a jump in average temperatures in the mid-1970s, heralding the start of a warming period. Although it is difficult to ascribe a clear trend to shorter term observations, 1998 remains the warmest year on record for now. Global records from the Hadley Centre for Climate Change (part of the UK Met Office) show there has been no warming trend for the last eight years. How long might such a pattern last before we decide that the period of warming has ended?

Another certainty is that climate change patterns depend on the timescale chosen. There was an upward trend in temperature from 1976 to 2006, and from 1906 to 2006. However, this masks a warming period through to the late 1930s, a cooling trend through the next three decades, and a jump in average temperatures in the mid-1970s, heralding the start of a warming period.

The final certainty to mention is that the average CO_2 content of the atmosphere has increased relatively steadily over the last century. Physics tells us that this should result in some increase in temperature, other things being equal. However, the key argument – the one on which the conclusions of the UN Convention on Climate Change, the Kyoto protocol, the work of the Intergovernmental Panel on Climate Change (IPCC) and the European Emissions Trading System are based – is that this increase in CO_2 is the dominant driver of climate change. That contention is less certain.

CHAPTER THREE
SOME UNCERTAINTIES

Science is rarely completely settled. The scientific method is to propose a hypothesis – a plausible causal relationship – and then design experiments to test it. But these are not designed to *prove* the hypothesis; rather, the intention is to *falsify* it. If no evidence is found which contradicts the hypothesis then, over time, it comes to be regarded as fact, and is generally then described as a theory (as, for example, the theory of evolution).

The apparent certainties of mainstream climate science rely on just four key assumptions, namely that:

1. CO_2 (and a few other gases such as methane) has a warming effect on the atmosphere and the earth's surface;

2. increasing levels of these so-called greenhouse gases are the primary driver of climate change, particularly global warming;

3. in addition to the direct effect, positive feedback mechanisms (particularly evaporation of water) increase the temperature still further;

4. all other drivers are known and have been properly taken account of.

Beyond these basic building blocks – put forward to account for the recent warming trend – lies a complex system of computer models supplied with a range of assumptions about the way human societies will develop. Their output forms the projections for the way the world's climate will change over the next 50, 100 or even 200 years.

But the currently received wisdom of climate change has been only partially tested and, to date, there are a number of key pieces of evidence which do not support it. The only thing which seems to be unequivocally true is the first of the four assumptions. All other things being equal, increasing the amount of CO_2 in the atmosphere does create a warming effect on the surface of the Earth. Beyond that, the science is by no means settled.

UNCERTAINTIES WITHIN THE CLIMATE CHANGE HYPOTHESIS

The current hypothesis of climate change is built on a known fact: that certain gases – including CO_2 – absorb infra-red radiation (of specific wavelengths for each gas) from the Sun and then re-emit these in all directions. The net effect of this is that some of the radiation which would otherwise be lost directly to space is trapped in the form of additional heat. This is what has been popularly termed the "greenhouse effect", although the principle is different from a real greenhouse, which works by blocking outgoing radiation and preventing the escape of warm air via convection.

This heat-trapping effect (so-called "radiative forcing") in itself would produce a relatively small increase in average temperature, which can be calculated from basic physical laws. But CO_2 alone will not lead to ever-increasing temperatures as its concentration in the atmosphere rises. As more CO_2 is added, the infra-red absorption band becomes saturated: no more incoming radiation can be absorbed once a certain concentration of gas has been reached. The consequence is that each additional increment of CO_2 absorbs less radiation than the previous amount. Going from 280ppm (parts per million) to 380ppm will lead to a certain temperature increase; raising the level to 480ppm will have a smaller effect.

CO_2 will not by itself lead to ever-increasing temperatures as its concentration in the atmosphere rises. Each additional increment of CO_2 absorbs less radiation than the previous amount. Going from 280ppm to 380ppm will lead to a certain temperature increase; raising the level to 480ppm will have a smaller effect.

So, by itself, CO_2 should give a small increase in average temperatures and, as the concentration rises, so the additional effect on temperature becomes smaller. However, the IPCC hypothesis is that CO_2 leads to significantly greater warming via two important feedback mechanisms. First, in a warming world, there is greater evaporation from the oceans. This is assumed to give a higher average water vapour content in the air (a higher relative humidity), which in turn increases the greenhouse effect because water vapour is also a greenhouse gas. Indeed, the effect of water vapour on temperature is much greater than that of CO_2. The second feedback is that warmer water releases some of the dissolved CO_2, increasing the level of greenhouse gases in the atmosphere still further. The overall result is termed the enhanced greenhouse effect.

Other greenhouse gases are influenced by mankind's activities. Methane, although present at far lower levels, has a much greater influence at a given concentration. It is largely a by-product of farming, but its concentration in the atmosphere seems now to be declining. Ozone can also have an influence. In the lower atmosphere (troposphere) it has a warming effect, whereas higher-level (stratospheric) ozone has a small cooling influence.

It is this high-level ozone which is termed the "ozone layer", and has a beneficial influence by absorbing ultra-violet radiation. We have heard many times about the depletion of this layer (the "hole" over Antarctica), which was believed to have been caused by the release of chlorinated and/or fluorinated hydrocarbon gases, used as refrigerants and aerosol propellants. The low levels of some of these gases also contributes a small amount of positive forcing (warming). The final significant greenhouse gas is nitrous oxide, a product of combustion. However, none of these has as large an effect as water vapour, which has been estimated to account for 88% of the total.

Why, then, is all the focus on CO_2? The important thing to note is that the level of water vapour rises and falls rapidly, but CO_2 levels decline rather slowly. Although there is still debate about the rate, it would seem that it can take several decades for equilibrium to be reached. Because additional amounts of CO_2 stay in the atmosphere for some time, the argument goes, they continue to have a warming effect for many years, as the global climate system slowly moves towards equilibrium.

Vast quantities of CO_2 enter the atmosphere annually from the burning of fossil fuels (coal, oil and gas). The amount is estimated to be equivalent to over seven gigatonnes (Gt) of carbon each year: 7,000,000,000,000 tonnes of pure carbon entering the air annually in the form of CO_2. However, this seemingly enormous figure pales into insignificance beside the estimated annual carbon cycle turnover of around 150 Gt, or the contents of carbon in the air (750 Gt, but that is only 0.04% of the total atmosphere), oceans (36,000 Gt) or biosphere (plants and animals: 1,900 Gt). The current annual increase of atmospheric CO_2 levels is only about half the anthropogenic emissions and, in fact, varies quite significantly from year to year. There is a lot we simply do not know about the carbon cycle.

UNCERTAINTIES OF CLIMATE CHANGE MODELLING

Although there are real uncertainties about the effect of CO_2 on temperatures, this is *the* key driver built in to the sophisticated computer models used by the climate science community.

While there is nothing wrong with models *per se*, they generally represent an incomplete understanding of a complex system. They are normally used to demonstrate the level of effect of a particular variable rather than as a reliable means of projection.

There are also concerns that the models simply do not represent reality. If this is so, then the best inputs in the world (and many dispute that current inputs achieve that) will still give the wrong answers. The modellers claim that all "natural" drivers of climate have been allowed for, that the CO_2 level we now have is unprecedentedly high for the last few millennia, and that similarly high levels reconstructed from ice core and proxy records have always been associated with significantly higher temperatures, sufficient to cause massive sea level rise. However, the evidence is that the peaks in CO_2 levels at times in the last few hundred thousand years was an effect rather than a cause of the higher temperatures. This outgassing of the oceans is exactly what is incorporated in the models as a feedback effect.

Current modelling is based on only one primary set of assumptions about how the climate system works. The test of their relevance should be their ability to reconstruct the Earth's climate during the twentieth century. This does seem to be the case; it is possible to model the climate and see the fluctuations observed in practice. But – and this is a very big but – this is only possible by making additional assumptions and tweaking the models to get the right result. In particular, volcanic activity and the presence of (man-made) aerosols such as sulphates are incorporated in ways which give the right answer.

To construct models based on one particular point of view, and then rely on their output to define policy needs, seems at best blinkered, at worst, perverse.

The use and reliability of modelling then becomes a self-fulfilling prophecy: models are tuned to reproduce the recent climate, based on one set of assumptions, and therefore they are assumed to give an accurate – indeed, the *only* valid view – of the future. To construct models based on one particular point of view, and then rely on their output to define policy needs, seems at best blinkered, at worst, perverse.

OTHER POSSIBLE INFLUENCES ON CLIMATE CHANGE

The high temperatures that are now being projected for the coming century have existed at other times in the past. At such times, they must have been caused by something other than atmospheric CO_2. That cause is, however, another uncertainty.

Fluctuations in the Sun's output, we are assured by many mainstream climate scientists, are not sufficient to have caused the temperature changes seen in the twentieth century. That may be true if we consider only the direct heating effect. However, there may be more complex effects at work: the same sort of feedback mechanisms proposed as part of the enhanced greenhouse effect are equally valid as a way to magnify the impact of relatively small changes in the Sun's output. Certainly, there is clear historical evidence for a link between climate and the solar cycle.

Sunspot cycles have provided a visible way of estimating solar variability for several hundred years. Changes in sunspot numbers have been directly linked to temperature changes, most notably the Maunder minimum of the late 17th and early 18th centuries, which occurred during the coldest part of the Little Ice Age. Looking further back, the Mediaeval Warm Period occurred at a time of maximum sunspot activity (and therefore high solar output). A similarly high level of activity is found at present.

But changes in sunspot activity do not relate just to energy output: there are also major variations in the Sun's magnetic field. A further factor, taken seriously by some but dismissed by many in the mainstream, is the effect of these magnetic field fluctuations on cosmic rays. Recently, a Danish group demonstrated that such high energy rays could in principle provide nuclei for cloud formation and that variations in the Sun's activity control the extent to which they penetrate our atmosphere. Clouds, as we know, have a major but unquantified effect on temperatures, with different types of clouds at different altitudes having either cooling or warming effects.

None of this is certain. However, the lesson surely is that we do not fully understand climate changes, and that the link between CO_2 and temperature is only circumstantial.

LONG-TERM CLIMATE TRENDS

Temperature trends depend on the timescale over which they are viewed. Over a 16,000 year period, there has been clear warming, but most of this had occurred within the first 6,000 years, during the transition from the Pleistocene to the current Holocene era. It was at this time that agriculture developed, communities began to settle and the conditions right for both cultural and economic development became established. Without this emergence from the last Ice Age, civilisation as we know it would not have developed. What should concern us more is that this current interglacial period we are experiencing is not the norm. For the past two million years, the Earth has been in the grip of glacial periods – Ice Ages – for 90% of the time and we do not know when or how the next one will start.

More recently, there has been a slight cooling trend during the Christian era, which started during the Roman Warm Period, but this trend has been punctuated in particular by the Mediaeval Warm Period and the Little Ice Age. The warming of the last century can be seen as a recovery from this. But the recent warming has not been steady, as we noted earlier. The rather complex pattern of temperature change occurred against a backdrop of accelerating emissions of CO_2, and a steady rise of average atmospheric concentration of the gas of about 1.5ppm annually.

Sea levels, we are told, are set to rise faster and cause severe flooding in some parts of the world. Catastrophic rises of several metres have been suggested. In actual fact, even the latest IPCC report gives a range of only 28 to 43 centimetres average rise by the 2090s, down from the figures issued five years ago. About two thirds of any rise would be due to thermal expansion of the oceans, the rest additional melt water from glaciers and icecaps. The average sea level rise over the twentieth century has been around 2mm per year – about 17cm overall. However, this masks a variability which is not understood. Average rises of 1.8mm per year were recorded in the period 1961 to 2003, with the rate increasing to 3.1mm in the decade from 1993, but there have been similar periods of faster rise over short periods at other times during the second half of the twentieth century.

There are no signs of the surface oceans warming to the extent predicted; indeed, recently there appears to have been a slight cooling.

Sea level changes are both complex and difficult to attribute with certainty. Build-up of ice in inland Antarctica and Greenland partly offsets the rise caused by melting of other land-borne ice and a rise in sea temperatures. Various parts of land are rising and falling relative to the sea: for example, the South East of the UK is gradually sinking, at the same time as the North West is rising. But, perhaps most significantly, there are no signs of the surface oceans warming to the extent predicted; recently there appears to have been a slight cooling.

Whatever the reality and the future trend, many low-lying areas are always vulnerable to flooding and need appropriate protection. Sea levels are, in any case, on a long-term upward trend. This, together with the tendency to build on the coast and near tidal rivers, means an increasing need for flood protection in many areas. Any acceleration in sea level rise may change the exact requirements, but does not create a need where none previously existed.

Some people have predicted an increase in the number of tropical storms, although the IPCC's current view is that these storms will become fewer in number but increase in intensity because of higher sea temperatures. Certainly there have been large variations in the number of hurricanes and typhoons during the last century, but the scale of the disasters we hear about in the media, when such storms hit land, are to a large degree related to the vastly increased infrastructure there to be damaged. People continue to move to hurricane-prone Florida, for example, despite the rather obvious risks.

MEASUREMENT UNCERTAINTIES

Although we are well aware of changes in weather patterns in our lifetimes, quantifying the change is more difficult. The concept of average global temperature is itself more complex than it first seems. Should we take average readings for individual stations over a 24-hour period and combine them? How do we assure an even coverage of stations to ensure the average is not weighted too much in one direction? Does averaging temperatures over 24 hours properly account for maxima and minima? In practice, there are fewer measurements of sea than land temperature, and land-based stations are not always found in areas where they are free of external influences. In particular, stations at one time in rural areas may now be surrounded by built-up areas and be subject to the well-known Urban Heat Island effect. Observing climate is one thing; characterising it neatly in a quantitative form which can be analysed and correlated with other factors is much more difficult.

Equally, measuring CO_2 levels is not as easy as it seems. We hear that levels have gone up from a pre-industrial 280ppm to a current (2005) level of 379ppm. These figures mask significant seasonal and regional variability. Records of past CO_2 levels are generally measured from ice cores. Cores taken from the Greenland ice cap take us back 600,000 years – itself perhaps a sign of how resilient this ice sheet is, having survived a wide range of average temperatures over such a long period of time. There is, however, debate about the reliability of this data. Air bubbles do not get finally sealed into the ice for around 80 years, as fresh snowfall compresses it. During this time, there is opportunity for exchange of gases with the atmosphere and surrounding ice. The other issue is that, even at very low temperatures, there is some liquid water present, and CO_2 and the other components of air have a different solubility in this.

CHAPTER FOUR

CLOSING RANKS AGAINST THE SCEPTICS: THE UNSCIENTIFIC METHOD

Climate change is a unique issue, aligning environmentalists, the scientific establishment and politicians in an alliance which is intolerant of dissent. August bodies such as the Royal Society and senior figures like the government Chief Scientific Adviser are not above making dismissive and personalised attacks on individuals and organisations who question the received wisdom.

At all turns, we are told that the science is settled, that anyone who believes otherwise is a "Flat-Earther" or in the pay of Big Oil. Scientists have their motives questioned and their sources of funding looked at in great detail to make sure that they are not tainted by involvement with the private sector. If all else fails, they are dismissed as crackpots and labelled as climate change "deniers", with an implied reference to the Holocaust. At least one commentator has suggested Nuremberg-style trials of climate criminals, and more than one politician has openly asked for sceptics to be denied media space. Fortunately, and despite the almost universal belief in the IPCC among journalists, the media thrives on confrontation, so we can still expect to see, hear or read differing opinions.

The scientific method – the basis of the Enlightenment and the explosion of scientific discovery in recent times – is based on careful observation and interpretation of evidence. In the case of climate change, however, we are witnessing very unscientific behaviour. Evidence is highlighted which supports the mainstream view; conflicting evidence is discredited or not mentioned. There is a real sense that minds are made up and will not be changed by facts alone.

This behaviour is, unfortunately, not unusual. Scientific authorities are like any others: they do not like to have their beliefs and judgements questioned. A classic example is Alfred Wegener's hypothesis of continental drift: the idea that land masses were not fixed, but moved over time. This was fiercely resisted at the time, but the concept of continents moving is now mainstream, as a consequence of plate tectonic theory. In earlier times, scientists believed in phlogiston, a substance which materials lost when burnt. It was only later, with the evidence provided by Lavoisier, that it was accepted that combustion was the result of a combination of oxygen with whatever was burnt.

It is unprecedented to release a summary and to later alter the report on which it is based. And, to make matters worse, it is a politically-orientated document which has not been agreed by the majority of the scientists in the working group.

Is it wrong to ask awkward questions, particularly when scientific understanding of the climate system is still so uncertain? Healthy scepticism should advance our knowledge faster by raising legitimate questions to be tested. True scientists should be sceptical at heart

Unfortunately, not only is the scientific establishment trying to close down debate on this issue, but the very way the IPCC's findings are made public invites distrust. In early February 2007, the first part of the Fourth Assessment Summary was released. Billed as the report of Working Group 1, entitled *The Physical Science Basis*, this was in fact merely the Summary for Policymakers (SPM). The full report – running to many hundreds of pages – will not be published until May. In the meantime, in the IPCC's own words, it will be further revised to "ensure consistency with the SPM". It is unprecedented to release a summary and to later alter the report on which it is based. And, to make matters worse, the SPM is a politically-orientated document which has not been agreed by the majority of scientists in the working group.

Such behaviour inspires neither confidence nor trust.

CHAPTER FIVE
POLICY

If scientific uncertainty over climate change were the only issue, it would be one that scientists could work out for themselves over time. However, the implications are far-reaching for all of us. Politicians – whatever their personal view of the issue – feel the need to use green rhetoric and take it forward into policy making.

In the UK, environmentalist policies are now mainstream, with the major political parties vying for the green high ground by talking about how they would tackle climate change. The problem is that policies designed to meet an unproven challenge are likely to be bad policies; and that they could come back to haunt whoever introduces them.

Fortunately, politicians are canny people who have the will to survive and succeed. Words are one thing, but actions are another. The Blair Government has talked tough but actually done rather little. The Conservative Party has not yet committed itself on climate change policy, although it has raised expectations. Careful analysis of the facts and options could still prevent either party from pursuing expensive and futile policies of decarbonisation.

The UK's apparently good record on emissions reductions is due in no small part to the loss of our coal and steel industries rather than climate change policy: a good example of the principle of unintended consequences. But the measures we are told will now need to be introduced seem not to have the support of the electorate. Doubling air passenger duty is a rather heavy-handed and ineffectual piece of tinkering. There is, as yet, no concerted policy.

A number of questions remain. Will the public accept the alarmist rhetoric and support additional taxes and costs? Will politicians continue to vacillate until the scientific evidence becomes clear one way or the other? Will concerted international action become a reality given America's apparent conversion to the cause, but without any likely enthusiasm from China and India?

SOME ALTERNATIVES

The focus of evolving energy policy is reduction of carbon emissions, on the assumption that, once a global agreement can be reached, CO_2 levels can be controlled and climate change mitigated. But there are policies which are more rational and with a different focus but which would still also result in a gradual decarbonisation of the economy.

There are policies which are more rational than that of attempting to reduce carbon emissions: developing nuclear energy, energy efficiency and innovation will together ensure reliability of energy supply for the years ahead.

Energy security should be the first target of any government. Volatile oil prices and geo-political instability in major oil and gas producing regions should be sufficient to spur on the development of other economic means of power generation. While longer-term alternatives are being sought, we have the opportunity to build a new generation of efficient and safe nuclear power stations, producing far less waste than older designs. Renewables also have their part to play, although the current obsession with inefficient and intermittent wind power is surely misplaced. Combined heat and power schemes should also play a bigger role in urban areas, as they do in some other countries.

The second target should be energy efficiency. Significant amounts of energy could be saved by using more energy-efficient equipment and insulating houses better. Government is already moving in this direction, but more could be done to give appropriate incentives for change. This is certainly win-win: energy bills would be reduced, and generating capacity would not need to rise.

The third area for attention is innovation. Rather than try to back winners, government policy should be set so as to encourage research into a wide range of novel technologies. Who knows whether the future of personal transport lies in hydrogen-powered fuel cells replacing the internal combustion engine? Will developments in nano-technology and materials science finally allow cost-effective solar panels to be made? Whatever the answers, these and other technologies should be allowed to develop and compete with each other.

Future prosperity lies in generating electricity efficiently and reliably, without too much reliance on any one fuel. We should also be using energy as efficiently as possible, without compromising quality of life. These are sensible targets which would continue the long-term trend in reduction of energy intensity of our economy. How much better this would be than setting rigid targets in pursuit of an improbable attempt to control our climate.