The entry into force of the Kyoto Protocol in February this year is a historic development in international environmental negotiations, and a significant step towards Earth sustainability. The protocol limits the emissions to the atmosphere of six greenhouse gases for the 30 ratifying countries from the developed world.

The Challenge of Stabilising Atmospheric CO_2 Concentrations

There has been much debate as to how much difference the first commitment period of the Kyoto Protocol will make to atmospheric CO_2 concentrations (a[CO_2]), and which subsequent emission reduction targets would be required to stabilise a[CO_2] at a given level. This article attempts to provide a sense of the tremendous challenge of stabilising a[CO_2] at a level thought to avoid dangerous interference in the climate system.

Although there is no consensus as to what a[CO_2] will avoid dangerous climatic interference, it is well understood that this depends upon the sensitivity of the major Earth System processes to climate change, and the vulnerability – that is, sensitivity to, and capacity to adapt – of different economic, environmental and social sectors. Thus, there is no single a[CO_2] we can target, unless we apply a lowest-common-denominator approach.

For example, at the recent International Conference on "Avoiding Dangerous Climate Change" (Exeter (UK), February 2005), experts argued that human societies would be safeguarded from dangerous interference in the climate system by a stabilisation of a[CO_2] equivalent to a global warming of 2°C. This translates to a[CO_2] of less than 550 ppm. Although these figures are contestable, they serve our present purpose, which is to highlight the challenge in stabilising a[CO_2] at 550 ppm – or indeed at any level below 750 ppm. For context, the pre-industrial CO_2 concentration was 280 ppm, and the current concentration is 378 ppm. Notably, the UN Framework Convention on Climate Change, which has gained the commitment of over 160 countries to stabilise a[CO_2], has been very careful to avoid stating a desirable stabilisation level.

A number of normative scenarios covering major possible routes that societies could take in this century, have been developed [1] based on major storylines leading to alternative future emission pathways. These scenarios required assumptions about population and income growth, the cost and availability of current and future energy production and utilisation and many other driving elements. The approach is consistent with the fact that there

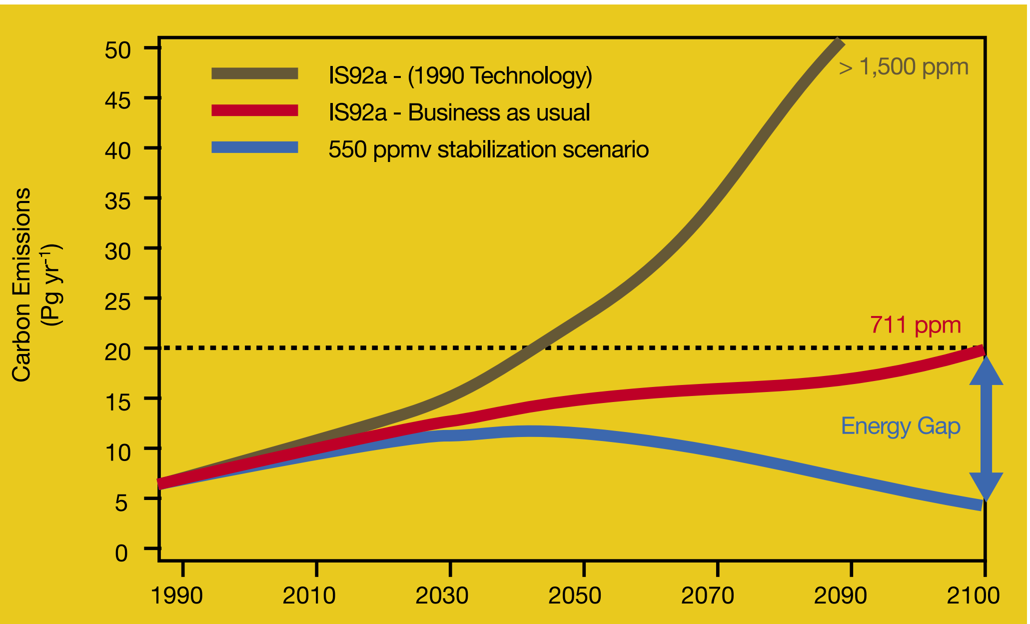

Figure 1. Global carbon emissions 1990–2100 using the IS92a and a 550 ppm stabilisation scenario [3].

are large uncertainties as to whether our grandchildren – and the governments and institutions they may choose and create – will be highly environmentally conscious, or will become full practitioners of economic globalisation, understanding that the two trends are not necessarily incompatible.

The range of carbon emissions covered by the SRES scenarios [1] is very broad, so that for practical purposes, IPCC leaves us without a best guess at the most likely future carbon emission scenario. Carbon emissions for the end of this century in the SRES scenarios, range from 3–35 Pg yr^{-1} (current carbon emissions from fossil fuel are close to 7 Pg yr^{-1}), leaving an unconstrained set of requirements for the amount of change needed to avoid dangerous interference in the climate system, for whatever target we choose for the purpose of evaluating the challenge.

Part of the uncertainty lies with the difficulty of quantifying the impact of major technological improvements on a[CO_2], and understanding the difference we can make by, for instance, collectively moving into automobile-hybrid technology, improving household energy efficiency by 50% or generating two-thirds of our electricity from renewable energies. None of these major technological changes can be realised any time soon.

As part of a SCOPE-GCP synthesis of the carbon cycle [2] the value of some earlier work on emission scenarios was rediscovered – particularly the IS92a IPCC scenario. This scenario belongs to the family of "business-as-usual" scenarios – those which attempt to highlight what could happen if we do not take specific actions to address the climate change issue, or in other words, what could happen if we let energy markets evolve as they have in the past without specific policies to curb CO_2 emissions.

The IS92a scenario does not include any CO_2 emission reduction targets, nor any broad policy proposals to reduce deforestation rates. What is less widely known, is that this scenario also assumes business-as-usual in technological development, based on the experience of the last century. Thus, IS92a assumes a decrease in energy intensity by 0.8% annually up until 2025, and a 1.0% decrease annually from 2025–2100. More strikingly, IS92a also assumes that by the end of this century 75% of power energy will be carbon free, and that energy generated from bio-fuels will provide more energy than the combined global production of oil and gas in 1990 [3]. These are massive and difficult to appreciate transformations of the energy system, but are probably not beyond what could happen, judging by the impressive advancements of the last century.

Such magnitude of change towards renewable and zero-emission energies might suggest that the CO_2 stabilisation problem would be largely solved by the time we achieve such transformations. But disappointingly, far from it, a[CO_2] by the end of this century would be over 700 ppm under IS92a – about three times the pre-industrial level (Figure 1).

To appreciate the technological challenge involved in limiting a[CO_2] to 700 ppm – which itself may involve unacceptable interference with the climate system – one can project a[CO_2] under a "freezing" of technology at 1990 levels without efficiency improvements (Figure 1). This scenario provides a reference that illustrates the scale of the advancements already expected to occur. Any attempts to stabilise a[CO_2] below 700 ppm will require an even larger effort.

The difference in carbon emissions between a given business-as-usual scenario (for example IS92a with a[CO_2] at about 700 ppm) and a chosen stabilisation level (for instance 550 ppm as argued above) is referred to as the "energy gap". The energy gap between IS92a and a 550 ppm stabilisation level is a staggering 14 Pg C yr^{-1} (Figure 1). This gap can only be closed by implementing emission reduction policies and clear emission cuts, most likely with costs involved. For a number of SRES scenarios, the carbon emission gaps by 2100 range from 1–25 Pg yr^{-1} [4].

Stabilising a[CO_2] will not only require large absolute cuts of greenhouse emissions during this century, but it will ultimately require reducing emissions to close to zero.

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