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ANALYSIS OF THE CONVERGE & CONTRACT FRAMEWORK FOR SETTING FUTURE CO_2 EMISSION TARGETS.

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Abstract

A possible approach for setting future CO_2 emission targets is a proposal commonly referred to as 'Converge & Contract'. Under the Converge & Contract approach, a uniform per-capita emission target would be set for an agreed convergence year, such as 2050 or 2100. Targets for intervening years would be calculated by linear interpolation between initial per-capita emissions of individual countries and the target at the convergence year. Total allowable emissions for a country would then be calculated as the product of its allowable per-capita emission and its population size. Carbon trading could be used between countries with excess emissions and others that have unused emission entitlements. It is analysed here whether that approach could be used to achieve global emission reductions, and what targets would have to be adopted to avoid dangerous interference with the global climate system.

In 2000, globally averaged per-capita fossil-fuel CO_2 emissions were about 1 tonne carbon (tC) per person per year. With a convergence year of 2100, emission targets would have to be set below 3 tC per person per year to bring global emissions below those of the SRES A2 scenario. An emissions target of 1 tC per person per year would be needed to restrict the atmospheric CO_2 concentration by the end of the 21st century to a concentration similar to that under the SRES B1 scenario. These targets could be achieved by all countries without requiring sharp annual decreases in CO_2 emissions.

It is concluded that the Converge & Contract approach provides a feasible approach for setting international emission targets. It would be fair, flexible, simple and universal in its basic principles and could be easily adjusted to achieve required emission reductions. It would also facilitate the inclusion of developing countries and thereby share the task of global emission reduction.

Key words: Commitments; CO_2 emissions; fossil fuels; Kyoto Protocol; per capita emissions; UNFCCC.

Introduction

The Kyoto Protocol represnted a first step in the overall goal of controlling the atmospheric concentrations of greenhouse gases. The significant advance of the Kyoto Protocol was that it set the first legally binding emission targets for a range of nations listed in Annex B of the Protocol (UNFCCC, 1997).

At the same time, the main short-coming of the Protocol is also apparent: the targeted emission reduction is insufficient to achieve the ultimate goal of stabilisation of atmospheric concentrations. Much deeper cuts would be needed to achieve that aim. The targets are even further diluted through the availability of excess emission entitlements of many countries in which inefficient and highly polluting industries have now been shut down for economic reasons. Nonetheless, the Kyoto Protocol represents the first tentative step towards global emissions control, and it has now come into force with the ratification by more than 55 countries and countries that together were responsible for more than 55% of emissions by Annex B countries (UNFCCC, 1997). The USA (Christiansen, 2003) and Australia are the only countries amongst the major emitters that have so far refused to ratify the Protocol.

The USA's position became hardened through the 1997 Byrd-Hagel resolution of the US Senate which states that the USA should not be party to any agreement which would "*mandate new commitments to limit or reduce greenhouse-gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse-gas emissions for Developing Country Parties within the same compliance period.*"

The Kyoto Protocol did not yet include the developing countries in any attempts at emission reduction other than through the Clean Development Mechanism (Najam et al., 2003). Yet, it is recognised that future emissions growth will come predominantly from the expanding economies in developing countries. The problem with inclusion of developing countries is that it would obviously be inequitable to try and force countries to limit their emissions when those emissions on a per capita basis are only a fraction of those in the richer developed countries (Najam et al., 2003; Tonn, 2003; Sugiyama and Deshun, 2004). More generally, it is clearly also inequitable that the emission targets of individual countries should be linked to their past emissions. Hence, countries that were heavy polluters in the past are effectively rewarded for that pollution by being allowed to continue to pollute at those heavier rates into the future.

The Kyoto Protocol mandated that negotiations for future emission reduction targets should begin in 2005 so that new commitments could be agreed to in time to replace the current commitments that cover the period from 2008 to 2012. One possible framework for setting future emission targets is the 'Converge & Contract' approach (Byrne et al., 1998; Meyer, 1999, 2004). It has been chiefly advocated by the Global Commons Institute, and has received support from many individuals and organisations (http://www.gci.org.uk/contconv/cc.html). Is has been advocated as being simple, practical, fair to all parties and allows an equitable inclusion of developing countries.

In the following, implementation of the approach is tested in terms of its ability to achieve stabilisation of atmospheric CO_2 concentrations, the distribution of emissions amongst the main emitting countries and its practicality of implementation as assessed by calculating the required annual changes to emissions that would be needed for countries to meet their commitments.

Converge & Contract

The Converge & Contract approach is based on the underlying notion that future emission targets can only be set fairly if they are defined on per-capita basis (Byrne et al., 1998; Meyer, 1999, 2004; Tonn, 2003; Pandey, 2004). The following gives a brief outline of the approach. In its details, it uses a somewhat simpler approach than the original proposal advocated by Meyer (1999).

1) A uniform global per-capita emission target would be set for a certain year, which could be 2050 or 2100, or any other year agreed to in international negotiations. In principle, a year even earlier year than 2050 could be chosen, but that would make it difficult for targets to be achievable and politically acceptable. In the following, this year is referred to as the 'convergence' year.

Targets for intervening years would be simply calculated by linear interpolation between initial actual per-capita emissions of each country and the target per-capita emissions at the convergence year. Meyer (1999) used a more complex expression to calculate entitlements in intervening years, but a linear approach is preferred here as being simpler and more transparent. Initial emissions could be those reported for 1990, for 2000, or for any agreed later year, or they could be based on emissions calculated on the basis of the commitments that have already been made for the First Commitment Period.

2) After the convergence year, allowable per-capita emissions might be held constant, or they could be further contracted if global environmental concerns warrant that.

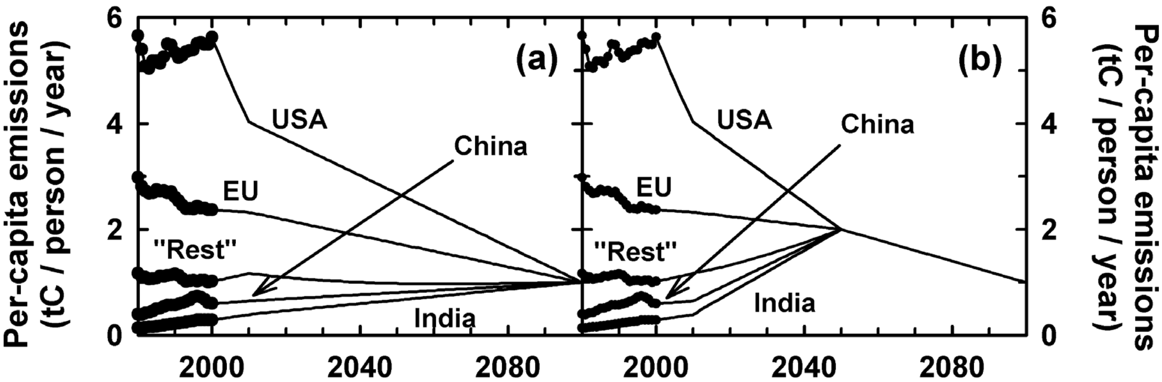
3) Total allowable emission for a country would then be calculated as the product of its allowable per-capita emission and its population size. As a further option, some have argued that it would be warranted to place a cap on countries' acceptable population beyond some date in order to discourage countries from increasing their populations with the aim of increasing their total emission allowance (e.g. Byrne et al., 1998; Meyer, 1999). However, that would seem to be an unnecessary restriction, and the calculations in the following have been done without use of a population cap.

4) Some countries might find it too difficult or costly to meet their assigned targets through domestic activities while others might have actual emissions that are below their allowable targets. An active global trade between countries with unused emission entitlements and others with on-going excess emissions would ensure broad participation in global emission reduction efforts and help to ensure that abatement is carried out by those emitters where emission reductions can be achieved at lowest marginal cost.

The analysis done here considered only fossil-fuel based CO_2 emissions because they constitute the bulk of relevant emissions. However, the basic principles could be easily adapted to also include other greenhouse gases as well as net emissions from biospheric carbon exchange. Issues around inclusion of biospheric emissions are addressed in the Discussion.

Hence, international negotiations might set 2100 as the convergence year and 1 tC per person per year as the allowable emission rate. This is illustrated in Figure 1a for the European Union and a number of selected countries. Current average global per-capita emissions from fossil fuels are about 1 tC per person per year. As targets under the Kyoto Protocol have already been set for a number of countries up to the 2008-2012 First Commitment Period, calculations were done from 2010 onwards and used the agreed emission reduction commitments as the starting point. Targets for years between 2010 and the convergence year were calculated by linear interpolation of per-capita emissions in 2010 and the convergence amount at the convergence year.

Figure 1. Per-capita fossil-fuel based CO_2 emissions for selected countries and regions, and their future emission entitlements with (a) setting the convergence target as 1 tC per person per year and 2100 as the convergence year or (b) a convergence target of 2 tC per person per year by 2050, followed by a common contraction to 1 tC by 2100. The European Union (EU) is taken to be the enlarged group of 25 countries. 'Rest' includes all countries other than the EU, USA, India and China. Per-capita emissions from 1980 to 2000 (shown as symbols) are actual reported emissions. Emissions from 2000-2010 have been calculated based on countries' commitments under the Kyoto Protocol, assuming the same annual percentage change from 2000 to the committed target emission in 2010. For countries without emission targets, the same emissions growth rate as observed between 1990 to 2000 was assumed to also pertain to 2010, with assumed limits between 1 and 5% per year. Thereafter, allowable emissions were calculated based on the Converge & Contract approach.



Allowable per-capita emissions would have to decrease substantially for countries such as the USA, but meeting the commitments already undertaken under the original Protocol would require even greater annual reductions than future commitments under the rules of the Converge & Contract approach. For the EU, it would simply require a continuation of the current trend towards reducing per-capita emissions although that trend for the 1980 -2000 period had been aided by the closure of inefficient industries in the United Kingdom and countries in eastern Europe.

For China and India, allowable per-capita emissions would have to be reduced only slightly below those projected based on current growth rates in emissions (see more detail below). The increase in per-capita emissions for these countries would constitute a move towards global equity to give all citizens of all countries the right to the same emissions entitlement. The Converge & Contract approach would nonetheless encourage those countries to achieve their increased economic output and greater standard of living with minimal emissions growth. If their projected emissions were above their allowable limit they would have to curtail emissions growth, and if their emissions were below their allowable limit they would have an excess emissions entitlement that could be traded. If they could curtail emissions growth even further they would have an even greater excess that could be traded with countries with excess emissions. In either case, all countries would benefit from keeping their actual emissions as low as possible.

An alternative set of targets is illustrated in Figure 1b, with an earlier convergence year of 2050 and a higher initial target of 2 tC per person per year, followed by a further contraction to 1 tC per person per year by 2100. Such an early convergence target would lead to very large increases in allowable emissions for countries such as India and China. These allowable emissions increases would be unlikely to be matched by corresponding increases in actual emissions which would give those countries substantial excess emission entitlements that could be traded with countries unable to meet their commitments.

It would be a matter of international negotiations to decide on the convergence year and target amount, with later convergence years allowing more time for making economic adjustments but earlier targets achieving better control of atmospheric CO_2 concentrations for environmental protection and achieving earlier global equity. Similarly, a high target above 1 tC per person per year might impose fewer restrictions on future economic development, whereas a target of 1 tC per person per year, or less, would ensure more certain protection of the environment.

Data and Calculations

Fossil-fuel based emissions for 1990- 2000 for each country were obtained from the UN Millenium Indicators (http://millenniumindicators.un.org/unsd/mi/). Emissions for 1980-1990 were obtained from the data compilation of the Carbon Dioxide Information Analysis Centre (CDIAC) through the spreadsheet made available by the World Resources Institute (WRI) at http://www.wri.org/. Where there were inconsistencies between the CDIAC data and those given by the UN, the CDIAC data were proportionately adjusted based on the 1990 data in the UN report, or, where there were no data for 1990, for another year with temporal overlap between the data sets. Some additional data, especially for some small countries with very low emissions, were obtained from the spreadsheets made available by the Global Commons Institute (http://www.gci.org.uk/contconv/cc.html). The analysis here considers only fossil-fuel based CO_2 emissions, but not those from net biospheric carbon changes such as deforestation or reforestation. It also ignores emissions from non-CO_2 greenhouse gases.

Population statistics were taken to be the UN population statistics up to 1999, and the medium variant of projections to 2100 (UN, 2002, 2004). Population was estimates for intervening years by fitting a smooth curve to the UN's population projections for all countries up to 2100. It is recognised that population projections to 2100 are highly uncertain, but it provides the most likely population path for calculating the overall emission projections for different prescribed per-capita emissions for the 21st century.

Per-capita emissions to 2010 were simply calculated as total emissions divided by a country's total population. For subsequent years, per-capita emissions were specified, and country emissions were calculated as the product of the assigned per-capita emission entitlement multiplied by the country's total projected population. A summary of the emission and population profiles of the main emitters and a number of other representative countries is given in the Appendix.

Global emissions were calculated as the sum of emissions of all countries. These were compared against the IPCC emission scenarios SRES A2 (a 'Business as usual' scenario) and SRES B1 (an optimistic scenario based on high energy efficiency and low use of fossil fuels) which form the basis of most assessment of climate change in recent years (SRES, 2000).

Resultant atmospheric CO_2 concentrations were calculated using the Bern model as described by Kirschbaum (2003) based on the relationships given by Meier-Reimer and Hasselmann (1987) and Wigley (1991), with the parameters given by Noble et al. (2000) and Fearnside et al. (2000). Temperature changes were assumed to follow changes in CO_2 concentration with a lag described by a time constant of 10 years (Kirschbaum, 2003).

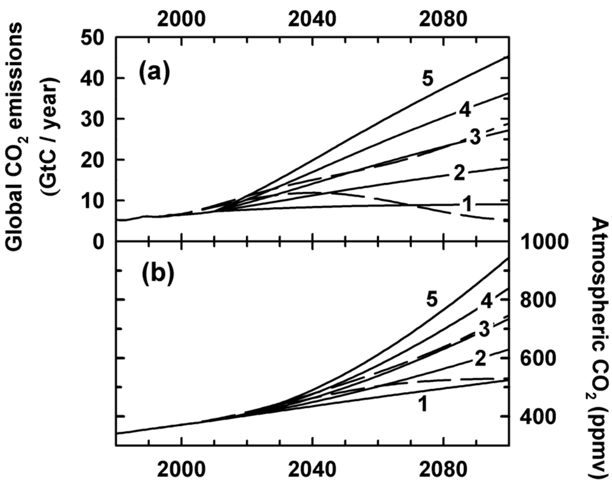
Climate-change impacts were quantified by the three separate kinds of climatic impacts identified by Kirschbaum (2003). These three types of impacts are instantaneous impacts of raised temperature, impacts through the rate of temperature increase and impacts through the cumulative effect of elevated temperature. More details and equations to quantify these impacts are given in Kirschbaum (2003).

In the simulations of country and global emissions, there is some obvious uncertainty about emissions late in the 21st century because population numbers are difficult to predict that far into the future. While the UN's medium variant was used for these projections, significantly different outcomes could be obtained with even slightly different assumptions about death and fertility rates in different countries. Similarly, the occurrence of future wars, important diseases, such as HIV/AIDS or bird-flu epidemics, and economic collapse or opportunities cannot be factored into these projections. There are also still uncertainties with respect to the global carbon cycle and the consequent link between CO_2 emissions and resultant atmospheric concentrations and global warming. CO_2 concentrations and climate-change impact assessment for late in the 21st century must, therefore, be accepted with a large degree of caution.

Results

With a convergence year of 2100 and a target of 3 tC per person per year, global CO_2 emissions would be similar to those under the SRES A2 scenario (Fig. 2a). It would lead to a global CO_2 concentrations of about 730 ppmv by 2100 (Fig. 2b). Higher convergence targets would lead to even higher emissions, and with a convergence target of 5 tC per person per year, CO_2 concentrations would reach about 950 ppmv by 2100.

Figure 2. Total global emissions (a) and resultant atmospheric CO_2 concentrations (b) with different convergence targets as shown in the Figure in tC per person per year. The year 2100 was set as the convergence year. SRES emission scenarios SRES A2 and SRES B1 are shown as dashed lines in the Figures. Scenario SRES A2 is very similar to the emissions and CO_2 concentrations under a convergence target of 3 tC per person per year.



The emissions that would eventuate with convergence of 3-5 tC per person per year are likely to be similar to those that might eventuate if there were no international emissions control at all. All countries might then increase their per-capita emissions to approach those currently seen in Europe or even the USA (see Fig. 1). It could lead to emissions that even exceed those incorporated into the high-emission SRES scenarios.

It is unlikely that CO_2 concentrations in the range of 730 to 950 ppmv could be considered to be consistent with prevention of *'dangerous anthropogenic interference with the climate system'* as stipulated by the UN Framework Convention on Climate Change (UNFCCC, 1994). To avoid that dangerous interference, convergence targets of 1 or 2 tC per person per year would have to be considered, or alternative combinations of an earlier convergence year followed by further contraction thereafter.

Some recent research findings have suggested that atmospheric concentrations could rise even more once full account is taken of climate-change induced effects on vegetation (Cox et al., 2004). It is also possible that actual population growth will exceed that under the UN's medium variant leading to even larger global CO_2 emissions. These consideration of possible even higher CO_2 concentrations demand a further cautionary approach to CO_2 emissions in the near term.

Convergence targets of 1 or 2 tC per person per year would keep atmospheric CO_2 concentrations to more moderate increases (Fig. 2b). With a convergence target of 1 tC per person per year, global emissions would not exceed 9.1 GtC per year (Fig. 2a) and restrict atmospheric CO_2 increases to a more moderate 525 ppmv (Fig. 2b). This CO_2 concentration for 2100 would be similar to that projected under the SRES B1 scenario. However, unlike CO_2 concentrations under the SRES B1 scenario, atmospheric CO_2 concentration under a convergence target of 1 tC per person per year would still increase in 2100 and beyond.

Some scientists believe that even CO_2 concentrations of 525 ppmv (and rising) are still too dangerously high, and Kinzig and Kammen (1998) explored the possibility of much deeper cuts. It is questionable, though, whether enough global consensus could be built to work towards targets below 1tC per person per year. The effects of such deeper cuts are therefore not explored in the simulations shown in the following.

To consider what impacts could result from any changes in CO_2 concentration, a variety of possible impacts need to be considered (Peck and Teisberg, 1994, 1995; Petschel-Held et al., 1999; Smith et al., 2001; Corfee-Morlot and Höhne, 2003). There are at least three kinds of impacts of climate change that can be separately identified (Kirschbaum, 2003). They are:

1) the direct and instantaneous effect of elevated temperature;
2) the rate of temperature increase;
3) the cumulative impact of raised temperatures.

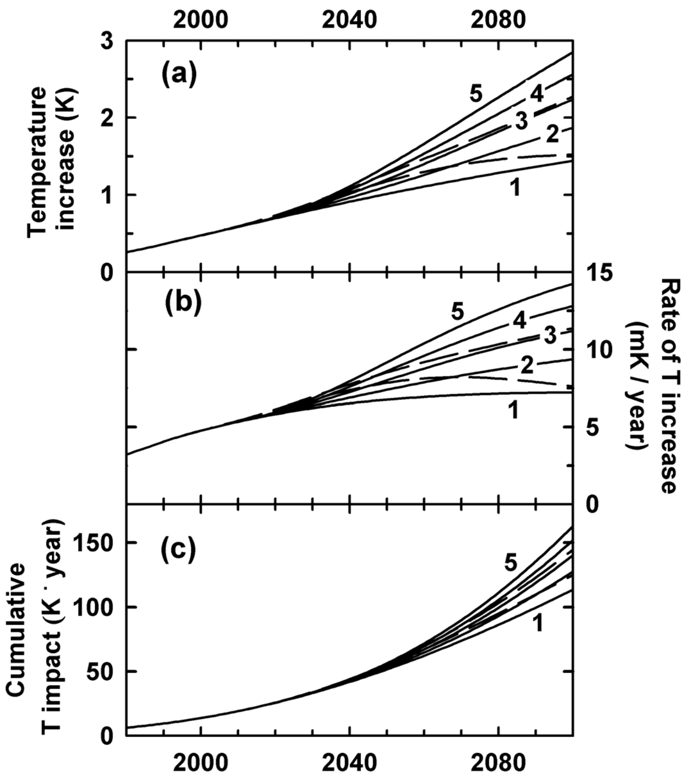
The direct and immediate effect of temperature is related to impacts such as heat waves and other extreme weather events. The rate of change is a concern because a warmer world may not be inherently worse than it is under current conditions, but the change from the current to a future, warmer world will be difficult for both natural and socio-economic systems. If the change is slow enough then systems can be moved or adapted, but faster change may be too rapid for such adjustments.

The third type of impact acts via the cumulative impact of raised temperatures. This is critical for impacts such as sea-level rise. Sea-level rise is related to both the magnitude of warming and the length of time over which oceans and glaciers can be warmed by increased temperatures.

Instantaneous temperature impacts are closely related to CO_2 concentrations except that temperature only logarithmically depends on CO_2 concentration and that there is a time lag before temperatures reaches the level that would be in equilibrium with a given CO_2 concentration. Across the levels of convergence targets, there would be a near two-fold difference in direct temperature impacts at the end of the 21st century, with temperatures impacts still increasing under all convergence targets (Fig. 3a). Stabilisation of direct temperature impacts by the end of the 21st century would be achieved only under the SRES B2 scenario.

For impacts related to the rate of temperature increase, there would similarly be a two-fold range of impacts across the range of convergence targets (Fig. 3b), with impacts stabilising by the end of the 21st century under a convergence target of 1 tC per person per year. Under the SRES B1 scenario, impacts via the rate of change would even begin to diminish by the end of the 21st century.

Figure 3. Climate-change impacts under the SRES A2 and B1 scenarios (dashed lines) and with the Contract & Converge approach with convergence targets of 1-5 tC per person per year (as shown in the Figure) and 2100 as the convergence year. Impacts are independently quantified for instantaneous temperature impacts (a), impacts via the rate of change (b) and via cumulative temperature increases (c) as defined by Kirschbaum (2003).

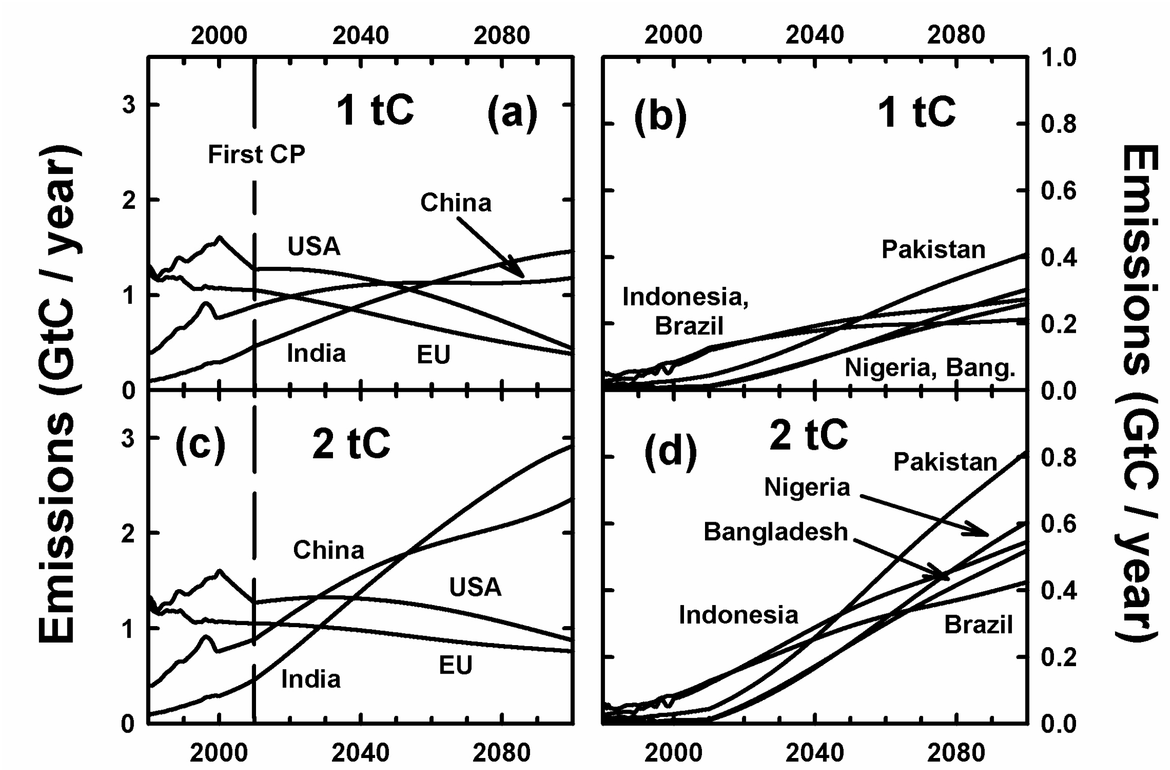


Impacts via the cumulative effect of increased temperature, on the other hand, show relatively much less separation between SRES scenarios or convergence targets (Fig. 3c). This is because much of the increasing impact is due to warming that has already taken place before 2000 and which would be common amongst all emission trajectories. Even if warming could be stopped immediately with temperature stabilised at the level it has reached to date, impacts through cumulative temperature effects would continue to increase. Sea levels would therefore continue to increase for many centuries even if there were no further increase in global temperatures. Hence, for impacts via cumulative temperature increases, a very long-term perspective is needed, and most impacts would be experienced not in the century when CO_2 is emitted but in centuries thereafter.

With these convergence targets, the USA would continue to be the world's largest emitter of greenhouse gases until about 2040 (Fig. 4a, c). India would eventually emerge as the largest emitter towards the end of the 21st century as it is already a large country with a high population growth rate. It is projected to continue to have a strongly growing population until well into the 21st century (UN, 2004).

Currently, the rest of the world (countries other than the USA, China, India and the EU) emit only about 70% more CO_2 to the atmosphere than the USA alone (see details in the Appendix), but by the end of the 21st century, their emissions will be many times those of the current main emitters. These increases are driven both by on-going population growth and emerging economic development.

Figure 4. Fossil-fuel based CO_2 emissions by the main emitters under convergence targets of 1 (a and b) or 2 (c and d) tC per person per year and 2100 as the convergence year. The countries shown here are those with current highest emissions and those expected to be the next most populous countries by 2100. The dashed vertical lines indicates the year 2010 and shows the commitments already made by the USA and the European Union, assuming the same annual percentage change from reported emissions in 2000 and committed target emissions in 2010.

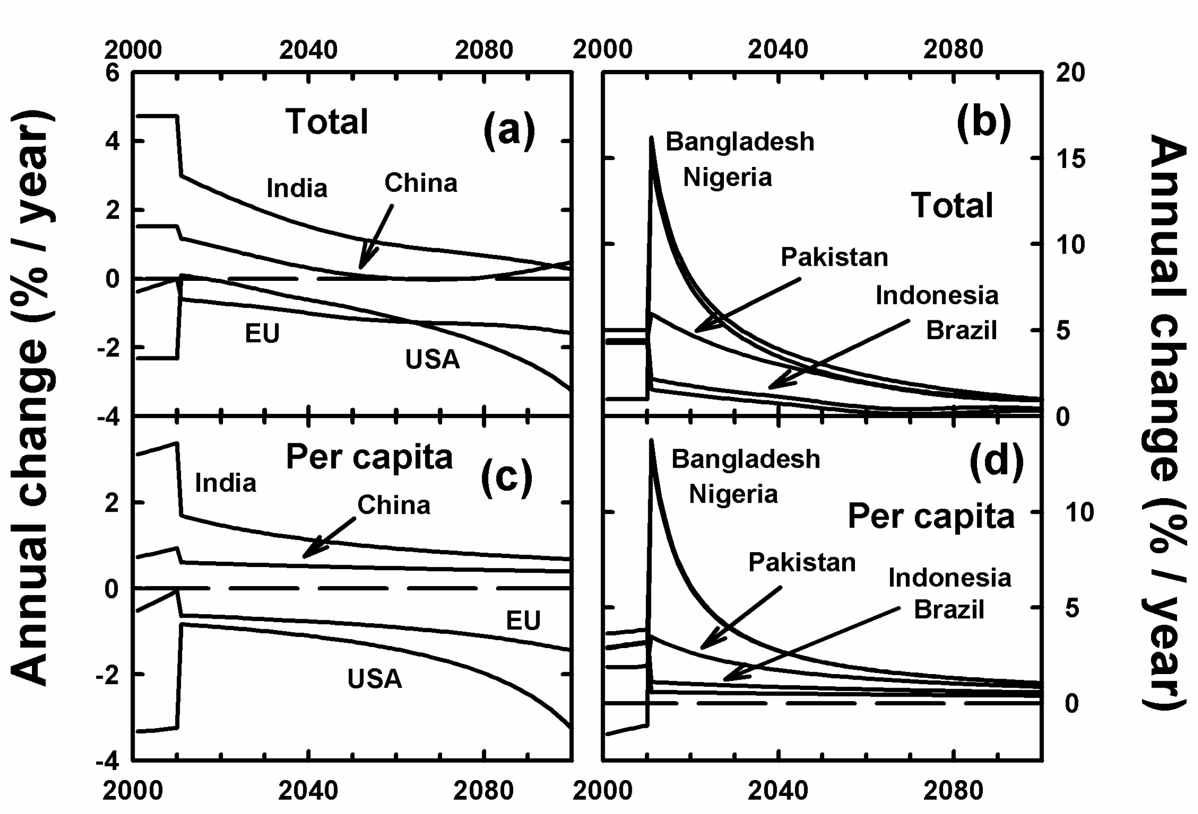


The five largest contributors to the emissions of the rest of the world are projected to be Pakistan, Nigeria, Indonesia, Bangladesh and Brazil. Their current emissions are only 1 tenth to 1 two-hundredth (in the case of Bangladesh) of those of the USA (see details in the Appendix). With on-going population growth and convergence of emissions, the emissions of those countries will be similar to those of the USA or the European Union by 2100. Global emission control cannot be achieved without the future emissions of those emerging economies ultimately being controlled as well, and the Converge & Contract approach could provide an equitable approach towards achieving that.

Figure 4 also shows the commitment already undertaken by the USA under the original Kyoto Protocol (7% below 1990 emissions). Reported actual emissions indicate that by 2000, the USA had, instead, increased its emissions by 18% over 1990 levels, and it would take extraordinary efforts between now and 2010 for the USA to actually meet its commitments under the Protocol. The situation is similar for many other Annex I countries (data not shown), but the European Union as a whole could meet its commitments, aided in part by the closing down of many inefficient and highly polluting industries in countries of eastern Europe.

Convergence targets of even 1 tC per person per year could be implemented without major economic disruption as assessed by the required relative annual changes in country total and per-capita CO_2 emissions. For the USA, total country emissions would even be allowed to still increase for a few years (Fig. 5a) because the USA's on-going population growth still exceeds their required relative reductions in per-capita emissions (Fig. 5c). This is in stark contrast to the required annual emission reductions of more than 2% per year that would be needed for the USA to achieve their agreed Kyoto target by 2010 (starting from reported emissions in 2000). Per-capita emissions for the USA would need to fall immediately (Fig. 5c), but even those relative reductions would be moderate until late in the 21st century when emissions would be quite low so that a constant linear reduction would correspond to a large proportional change.

Figure 5. Annual change in emission entitlements per country or per capita for the main groups and countries if the convergence target is set to 1 tC per person per year and 2100 as the convergence year. The top panels give the change in total emissions and the bottom panels express the emission changes on a per capita basis.



For the European Union, and with a convergence target of 1 tC per person per year, there would be a need for only a small change of about 0.6% per year in total or per-capita emissions because the EU's per-capita emissions are already close to 2 tC per person per year. In contrast, developing countries, such as India and China, could still increase their emissions even under these low convergence targets. Between 1990-2000, annual emissions growth rates of India and China were 4.7% and 1.5%, respectively (Fig. 5a). Their future emission growth would have to be marginally curtailed relative to those recent rates for the next few decades and more strongly later in the 21st century at a time closer to the convergence year. China already has higher per-capita emission rates than India so that it would have less scope for further on-going increases in emissions and China's emission growth would have to be less than that of India.

For countries such as Nigeria and Bangladesh, the allowable emission growth could be as much as 15% per year, which is likely to be much greater than any probable actual emission growth (Fig. 5b, d). For Nigeria, emissions actually fell for much of the 1990s so that annual emission growth of 15% would require an extraordinary resurgence in economic development that would be highly unlikely in its magnitude. These excess emissions entitlements would then generate carbon credits that could be traded with countries that failed to curtail their emissions below their allowable limits.

Pakistan would also be likely to have emission entitlements that would exceed actual increases in emissions, although not by as much as for Nigeria and Bangladesh. For Indonesia and Brazil, growth in emission entitlements would be only about half the actual emission growth over the 1990s which would provide a requirements to curtail actual emission growth for those countries in much the same way as for India and China.

Discussion

The simulations shown here indicate that the Converge & Contract approach could be used as a framework for an international agreement for the control of future CO_2 emissions. If one sets 2100 as the convergence year, it would require convergence targets of 1 or 2 tC per person per year to achieve meaningful emissions control, whereas a convergence target of 3 tC per person per year would merely bring emissions close to the SRES A2 scenario which would not constitute the level of control of atmospheric CO_2 concentration that would be needed to prevent dangerous anthropogenic interference with the climate system.

If no international agreements could be reached at all and emissions allowed to increase without limit, emissions for most countries might naturally reach emissions of 3-5 tC per person per year, which are similar to current levels in countries with highest per-capita emissions. With per-capita emissions of 5 tC per person per year, global emissions would then exceed 45 GtC per year and atmospheric CO_2 concentration reach about 950 ppmv (Fig. 2). Ultimate CO_2 concentration could potentially be even higher through biospheric feedbacks (Cox et al., 2004), or if actual population growth exceeded that under the UN's medium variant.

Such emissions and concentrations would be unlikely to be sustainable, and lower targets would be required to forestall possible severe climatic impacts (Fig. 3). Even with convergence targets of 1 or 2 tC per person per year, atmospheric CO_2 concentrations would not stabilise by the end of the 21st century so that even deeper cuts in per-capita emissions might eventually be warranted (Kinzig and Kammen, 1998). Emission targets below 1 tC per person per year would be needed to achieve stabilisation of atmospheric CO_2, but rates of CO_2 increase under convergence targets of 1-2 tC per person per year might possibly be slow enough to be sustainable.

Even under convergence targets much below their current per-capita emissions, the USA is likely to continue to be the world's greatest CO_2 emitter until the middle of the 21st century (Fig. 4). However, by the end of the century, emissions (or at least emission entitlements) are likely to be dominated by those countries that have the greatest populations (as, by definition, per-capita emission entitlements would be the same for all countries). It would constitute a shift from emissions that are currently dominated by developed countries to those countries that are still rapidly expanding their economies.

While convergence targets of 1 or 2 tC per person per year would constitute a significant departure from 'Business as usual' scenarios, the resultant emission reductions could be achieved without major economic disruption (Fig. 5), with increases in total CO_2 emissions still being allowed for many countries and for some number of years. Especially, in the case of developing countries, considerable economic development and enhanced individual standard of living would still be possible while the Converge & Contract approach provides the incentive to achieve that economic growth with least possible CO_2 emissions.

The Converge & Contract approach does not mandate how emission targets are to be achieved. Hence, CO_2 emissions could be reduced through adoption of technologies with greater efficiency or increased use of renewable sources of energy, such as wind, solar, hydro or biofuels. CO_2 emissions could also be reduced through a shift from fossil fuels with high carbon intensity, such as coal or oil, to fossil fuels that emit less carbon, such as natural gas. Carbon could also be captured and prevented from reaching the atmosphere through geosequestration. Finally, any remaining excess emissions for some countries could be balanced through carbon trading with other countries with emissions that are below their entitlements. All of these mechanisms could play an on-going role as long as their contribution assists in the important ultimate goal of reducing CO_2 emissions to the atmosphere in a globally fair and effective manner.

Key Attributes

Any system that is to be considered as a framework for emission control agreements needs to have a number of key attributes that makes it practical, enables it to achieve its ultimate objectives and makes it acceptable to the international community (see also Aldy et al., 2003). These include the following attributes which are briefly discussed in relation to the Converge & Contract approach.

Equity and fairness

Future commitments must ensure that the burden of emission reductions does not unreasonably affect some sections of the international community more severely than others. A per-capita basis of setting future emissions targets would seem to be the only way in which fair and equitable targets could be set (Byrne et al., 1998; Meyer, 1999, 2004; Tonn, 2003; Najam et al., 2003; Pandey 2004).

Some countries may like to argue for special circumstances that would make a case for higher emission entitlements. For example, countries in cold regions could argue for the need of greater energy requirements for heating. However, essentially all countries could make their own special cases: hot countries could argue for extra energy needs for air-conditioning; large countries could argue for extra energy costs to overcome transport distances, while small countries could argue for limitations due to their limited potential to use renewable sources of energy. It would seem to be almost impossible to provide a fair means of allowing any country special dispensation for their unique circumstances. A uniform global approach without exceptions would therefore be the preferred approach.

A separate question is whether past emissions should be considered as well. It can be argued that developed countries have already been emitting high quantities of CO_2 for some decades that polluted the common global atmosphere and led to the temperature increases experienced to date. Those emissions led not only to a comfortable standard of living, but also enabled the building of economic and social infrastructure that will enable those countries to enjoy more efficient economic production into the future. Hence, countries with low past emissions could argue that they should receive a higher future emissions entitlement that would enable them to build the same efficient infrastructure that richer countries had been able to build through their higher past emissions (the 'Brazilian Proposal' – see Rosa et al., 2004 and Trudinger and Enting, 2005).

On the other hand, it can be argued that those past heavy emissions by the developed countries enabled the development of modern technologies that will enable all countries, including developing countries, to achieve their future economic production more cleanly and efficiently. In the analysis shown here, past emissions are not included, and all countries are afforded the same convergence target irrespective of past emissions. It clearly keeps the approach simple, global and transparent. However, it is recognised that international negotiations will ultimately decide whether to include consideration of these past emissions.

Comprehensiveness

As climate change is a global problem, the world clearly needs global solutions. It is, therefore, important to include all countries, including those that currently contribute the bulk of emissions, and those that are likely to significantly contribute to future emissions (Aldy et al., 2003; Sugiyama and Deshun, 2004). It is, however, not the size of individual countries that is important as two small countries can add as much to global emissions as one larger one. Every individual person's and every country's emissions add to the global total, and emission control needs to be inclusive of all these contributors. Global comprehensiveness must be achieved, however, while ensuring adequate fairness.

The Converge & Contract approach can achieve global comprehensiveness by giving developing countries the incentive to become part of future emission-control initiatives and minimise their emissions. Minimising emissions would be beneficial for low-emitting countries under the Converge & Contract approach because they could sell any excess emission entitlements to countries that exceed their targets. The more a country's emission can be curtailed the greater would be the surplus that could be traded.

Simplicity

There is an advantage for a system to be clear, simple and transparent. Rules should be the same for everyone, and the broad principles need to be simple and readily understood by policy makers and the public. The current Kyoto Protocol has suffered from a lack of clarity and transparency. In particular, there is no obvious logic to the setting of targets and commitments for the First Commitment Period. Different countries have adopted different targets, and there is no obvious logic to the adoption of those different commitments.

The Converge & Contract approach possesses this essential simplicity as it can be effectively described in the four simple rules outlined above. The task of international negotiators thus simplifies to the setting of a convergence year and target, the rules for setting initial per-capita emissions and to the decision as to whether to include consideration of cumulative pre-1990, or pre-2010, emissions.

Practicality of Implementation

The system also needs to accept the historical starting point. Allowable emissions in the near future must not be too different from countries' current actual emissions or it would be practically impossible for countries to meet those commitments. While that constitutes a degree of unfairness to those countries with historically low emissions, it is nonetheless a recognition that energy production systems and standards of living cannot be modified too rapidly without causing economic disruption and loss of public support for emission-control policies.

Acceptance of this historical starting position does to some extent perpetuate an unfairness to poorer, or more efficient, countries, but that unfairness is tempered by the fact that it requires richer, or less efficient, countries to lower their emissions while allowing poorer countries to increase theirs towards eventual convergence. For very poor countries, that would even translate into emission entitlements that are unlikely to be matched by their actual emissions growth so that it would provide the added incentive of financial compensation through trading with countries that exceeded their emission entitlements.

Flexibility through carbon trading

While the broad goals of emission reductions should be simple and transparent, actual implementation is enhanced by the flexibility of emission trading between countries that are above and countries that are below their respective allowable emission limits (Christiansen, 2003; Aldy et al., 2003). This flexibility makes it easier for developed countries to meet their emissions targets even if it is achieved through a transfer of money to developing countries that have emissions below their entitlements. Carbon trading is now operating successfully at various levels in the European Union and is achieving significant levels of sales (Johnson and Heinen, 2004). There is no obvious impediment to its extension to the global level.

Carbon trading is thus a key component of the overall approach. It ensures that global emissions reduction is accomplished in those countries or regions where that can be done most cost-effectively. It also provides the incentive for countries with low current emissions to participate in emission-control treaties as it can provide them with direct financial trading benefits. If they can keep their emissions as low as possible they will maximise their excess carbon emission entitlement that can be traded. It thus provides the incentive for countries with both and low emissions to achieve their development objectives with minimal CO_2 emissions.

Compliance regime

A key aspect of a trading scheme would be a penalty regime for non-compliance (Aldy et al., 2003). The simplest approach would be to set a global ‘reserve’ price that would be used if countries either cannot agree on a trade, or if the total of global emissions exceeded the combined total of all countries’ emission entitlements. If countries cannot restrict their emissions to their target amounts, and if they are not able to purchase carbon credits from any other country with excess emissions entitlements, they could then be forced to pay a penalty amount for their excess emissions at the reserve price. The reserve price would thus be the effective floor price for all trades.

If the reserve price is set too low, there may be little effective climate control, and countries with excess emissions might simply pay for their excess emissions at the reserve price as a form of ‘guilt money’ without affecting any real emission control. If the price is set too high, it might constitute an undue transfer of money between countries even after the richer countries might have exhausted all avenues for emission reductions. Setting an agreed global reserve price would thus be one of the key negotiation points that will determine the success of the overall approach.

Carbon sinks and deforestation

An additional question that needs to be resolved is whether to include biospheric carbon management. The simulations shown above have only included fossil-fuel based CO_2 emissions, but net biospheric emissions can clearly add to, or reduce, the problems posed by fossil fuel emissions. The Contract & Converge approach could be adopted with biospheric carbon exchange either omitted or negotiated separately, or net biospheric exchange could be simply added to fossil-fuel based emissions.

Various analyses have suggested that biospheric carbon management has the potential to significantly contribute towards the management of atmospheric CO_2 concentrations (e.g. Brown et al., 1996; van Kooten et al., 2004). A number of countries (i.e. Australia, New Zealand) are also anticipating that changes in their net biospheric carbon exchange will help significantly in meeting their Kyoto commitments for the First Commitment Period Kirschbaum and Cowie, 2004).

Biospheric carbon management, thus, has considerable potential to add a cost-effective option of managing atmospheric CO_2 concentrations, especially if that can be combined with meeting other desirable objectives (Watson et al., 2000). Its inclusion in the overall task of managing global CO_2 would thus be desirable, but it would be important to adopt a biospheric accounting approach, such as the average carbon-stocks approach (Kirschbaum et al., 2001; Kirschbaum and Cowie, 2004), that avoids countries gaining undeserved windfall gains or suffering losses through factors beyond their control. Inclusion of biospheric sources and sinks must also not lessen the emphasis on controlling fossil-fuel based emissions.

Summary and Conclusions

The analysis shown here has shown that the Converge & Contract approach could be used to guide the setting of future allowable CO_2 emissions. With 2100 as the convergence year, convergence targets would have to be of the order of 1-2 tC per person per year to achieve meaningful reductions in global CO_2 emissions. However, even with such targets, global CO_2 concentrations would still increase beyond the end of the 21st century, although at a rate that might be slow enough to be sustainable.

The Converge & Contract approach thus provides a possible approach for setting future commitments that is fair to all parties, globally comprehensive, flexible, simple and universal in its basic principles yet capable of numeric adjustment to achieve required emission reductions. It also facilitates involvement by developing countries to ensure universal participation in the goal of emissions reductions, and it achieves that aim in a fair and equitable manner.

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References

Brown, S., Cannell, M., Kauppi, P. and Sathaye, J., 1996. Management of forests for mitigation of Greenhouse gas emissions. In: Watson, R.T., Zinyowera, M.C. and Moss, R.H. (eds), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-*

Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, Cambridge University Press, pp. 773-797.

Aldy, J.E., Barrett, S. and Stavins, R.N., 2003. Thirteen plus one: a comparison of global climate policy architectures. Climate Policy 3, 373-397.

Byrne, J., Wang, Y.-D., Lee, H. and Kim, J., 1998. An equity- and sustainability-based policy response to global climate change. Energy Policy 26, 335-343.

Christiansen, A.C., 2003. Convergence or divergence? Status and prospects for US climate strategy. Climate Policy 3, 343-358.

Corfee-Morlot, J. and Höhne, N., 2003. Climate change: long-term targets and short-term commitments. Global Environmental Change-Human and Policy Dimensions 13, 277-293.

Cox, P.M., Betts, R.A., Collins, M., Harris, P.P., Huntingford, C. and Jones, C.D., 2004. Amazonian forest dieback under climate-carbon cycle projections for the 21st century. Theoretical and Applied Climatology 78, 137-156.

Fearnside, P.M., Lashof, D.A., Moura-Costa, P., 2000. Accounting for time in mitigating global warming through land-use change and forestry. Mitigation and Adaptation Strategies for Global Change 5, 239-270.

Johnson, E. and Heinen, R., 2004. Carbon trading: time for industry involvement. Environment International 30, 279-288.

Kinzig, A.P. and Kammen, D.M., 1998. National trajectories of carbon emissions: analysis of proposals to foster the transition to low-carbon economies. Global Environmental Change 8, 183-208.

Kirschbaum, M.U.F., 2003. Can trees buy time? An assessment of the role of vegetation sinks as part of the global carbon cycle. Climatic Change 58, 47-71.

Kirschbaum, M.U.F. and Cowie, A.L., 2004. Giving credit where credit is due. A practical method to distinguish between human and natural factors in carbon accounting. Climatic Change 67, 417 - 436.

Kirschbaum, M.U.F., Schlamadinger, B., Cannell, M.G.R., Hamburg, S.P., Karjalainen, T., Kurz, W.A., Prisley, S., Schulze, E.-D. and Singh, T.P., 2001. A generalised approach of accounting for biospheric carbon stock changes under the Kyoto Protocol. Environmental Science and Policy 4, 73-85.

Meier-Reimer, E. and Hasselmann, K., 1987. Transport and storage of CO_2 in the ocean - an inorganic ocean-circulation carbon cycle model. Climate Dynamics 2, 63-90.

Meyer, A., 1999. The Kyoto Protocol and the emergence of "contraction and convergence" as a framework for an international political solution to greenhouse gas emissions abatement. In: Hohmeyer, O. and Rennings, K. (eds.), Man-Made Climate Change: Economic Aspects and Policy Options. Physica Verlag, Heidelberg, Germany, pp. 291-348.

Meyer, A., 2004. Contraction and convergence. Engineering Sustainability 157, 189-192.

Najam, A., Huq, S. and Sokona Y., 2003. Climate negotiations beyond Kyoto: developing countries concerns and interests. Climate Policy 3, 221-231.

Noble, I., Apps, M., Houghton, R., Lashof, D., Makundi, W., Murdiyarso, D., Murray, B., Sombroek, W., Valentini, R., Amano, M., Fearnside, P.M., Frangi, J., Frumhoff, P., Goldberg, D., Higuchi, N., Janetos, A., Kirschbaum, M., Lasco, R., Nabuurs, G.J., Persson, R., Schlesinger, W., Shvidenko, A., Skole, D. and Smith, P., 2000. Implications of different definitions and generic issues. In: Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds.), Land Use, Land-Use Change and Forestry, (Cambridge University Press, Cambridge, UK), pp. 52-126.

Pandey, D.N., 2004. Equity in climate change treaty. Current Science 86, 272-281.

Peck, S.C. and Teisberg, T.J., 1994. Optimal carbon emissions trajectories when damages depend on the rate of or level of global warming. Climatic Change 28, 289-314.

Peck, S.C. and Teisberg, T.J., 1995. Optimal CO_2 control policy with stochastic losses from temperature rise. Climatic Change 31, 19-34.

Petschel-Held, G., Schellnhuber, H.-J., Bruckner, T. and Toth, F.L., 1999. The tolerable windows approach: theoretical and methodological foundations. Climatic Change 41 303-331.

Rosa, L.P., Ribeiro, S.K., Muylaert, M.S. and de Campos, C.P., 2004. Comments on the Brazilian Proposal and contributions to global temperature increase with different climate responses - CO_2 emissions due to fossil fuels, CO_2 emissions due to land use change. Energy Policy 32, 1499-1510.

Smith, J.B., Schellnhuber, H.-J, Monirul Qader Mirza, M., Fankhauser, S., Leemans, R., Erda, L., Ogallo, L., Pittock, B., Richels, R., Rosenzweig, C., Safriel, U., Tol, R.S.J., Weyant, J. and Yohe, G., 2001. Vulnerability of climate change and reasons for concern: a synthesis. In: J.J. McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken, K.S. White (eds), Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, Cambridge University Press, pp. 913-967.

SRES, 2000. IPCC Special Report on Emissions Scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. (Cambridge University Press, Cambridge, UK), 599 pp..

Sugiyama, T and Deshun, L., 2004. Must developing countries commit quantified targets? Time flexibility and equity in climate change mitigation. Energy Policy 32, 697-704.

Tonn, B., 2003. An equity first, risk-based framework for managing global climate change. Global Environmental Change-Human and Policy Dimensions 13, 295-306.

Trudinger, C. and Enting, I., 2005. Comparison of formalisms for attributing responsibility for climate change: Non-linearities in the Brazilian Proposal approach. Climatic Change 68, 67-99.

UN, 2002. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, World Population Prospects: The 2002 Revision and World Urbanization Prospects. http://esa.un.org/unpp

UN, 2004. World Population in 2300. Proceedings of the United Nations Expert Meeting On World Population in 2300, United Nations, New York, 36 pp.

UNFCCC, 1994. The United Nations Framework Convention On Climate Change. UNEP/WMO.

UNFCCC, 1997. The Kyoto Protocol To The United Nations Framework Convention On Climate Change, UNEP/WMO.

van Kooten, G.C., Eagle, A.J., Manley, J. and Smolak, T., 2004. How costly are carbon offsets? A meta-analysis of carbon forest sinks. Environmental Science and Policy 7, 239-251.

Wigley, T.M.L., 1991. A simple inverse carbon cycle model. Global Biogeochemical Cycles 5, 373-382.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J., eds., 2000. Land Use, Land-Use Change And Forestry. A Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, 377 pp.

Appendix: Emission and population profile of the main emitters and some other representative countries.

	Emissions[1]					Change from 1990-2000 (% per year)		Population (millions)		Popl. growth rate in 2000
	1990 (MtC)	2000 (MtC)	2010 (MtC)[2]	% of global	Per capita[3]	Coun-try	Per capita	2000	2050	% per year
Algeria	22.0	24.4	27.1	0.38	0.81	1.06	-0.85	30.3	48.6	1.92
Argentina	29.9	37.7	47.5	0.58	1.02	2.33	1.00	37.1	52.7	1.32
Australia	75.8	95.2	81.8	1.47	4.98	2.31	1.04	19.1	25.5	1.25
Austria	16.4	17.7	15.1	0.27	2.19	0.77	0.30	8.1	7.4	0.47
Azerbaijan	15.2	7.9	8.8	0.12	0.97	-6.31	-7.49	8.2	10.9	1.27
Bahrain	3.2	5.3	8.7	0.08	7.89	5.23	1.92	0.7	1.3	3.25
Bangladesh	4.2	8.0	13.0	0.12	0.06	6.65	4.22	137.9	254.1	2.34
Belarus	27.9	16.1	17.8	0.25	1.61	-5.32	-5.10	10.0	7.5	-0.23
Belgium	32.1	34.5	29.5	0.53	3.36	0.71	0.42	10.3	10.2	0.28
Brazil	55.3	83.9	127.4	1.29	0.49	4.26	2.77	171.8	232.9	1.45
Brunei	1.6	1.7	1.9	0.03	5.14	0.79	-1.83	0.3	0.7	2.67
Bulgaria	28.1	12.8	20.8	0.20	1.58	-7.58	-6.89	8.1	5.3	-0.74
Cameroon	1.0	1.8	2.9	0.03	0.12	5.84	3.17	15.1	24.9	2.59
Canada	128.8	157.3	121.0	2.42	5.12	2.02	0.97	30.7	39.0	1.05
Chile	9.6	16.2	26.5	0.25	1.07	5.35	3.79	15.2	21.8	1.51
China	654.7	761.6	885.9	11.7	0.60	1.52	0.53	1274.9	1394.4	0.99
Colombia	15.3	16.0	17.6	0.25	0.38	0.44	-1.40	42.1	67.4	1.87
Cuba	8.7	8.4	9.3	0.13	0.75	-0.36	-0.87	11.2	10.1	0.51
Czech Rep.	44.7	34.9	41.1	0.54	3.40	-2.45	-2.42	10.3	8.5	-0.04
Denmark	14.4	14.4	13.2	0.22	2.70	0.02	-0.33	5.3	5.3	0.35
Dominican Republic	2.6	6.9	11.2	0.11	0.82	10.1	8.32	8.3	11.9	1.68
Ecuador	4.5	6.9	10.7	0.11	0.56	4.39	2.42	12.4	18.7	1.92
Egypt	20.6	38.8	63.2	0.60	0.57	6.55	4.46	68.0	127.2	2.0
Estonia	10.4	4.6	7.5	0.07	3.36	-7.84	-6.48	1.4	0.7	-1.45
Finland	17.0	17.0	15.7	0.26	3.28	-0.03	-0.40	5.2	4.9	0.38
France	107.8	111.1	99.2	1.71	1.87	0.30	-0.15	59.3	64.2	0.45
Germany	276.7	234.0	254.5	3.60	2.85	-1.66	-2.00	82.2	79.1	0.35
Greece	23.0	28.3	21.2	0.44	2.61	2.09	1.43	10.8	9.8	0.66
Hungary	16.0	16.1	15.0	0.25	1.61	0.08	0.44	10.0	7.6	-0.35
India	184.3	292.3	463.5	4.50	0.29	4.72	2.82	1016.1	1527.6	1.84

Indonesia	45.2	73.6	119.7	1.13	0.35	4.99	3.43	211.5	293.5	1.5
Iran	59.1	84.7	121.3	1.30	1.27	3.65	2.02	66.5	105.6	1.6
Iraq	13.4	20.8	32.3	0.32	0.90	4.48	1.45	23.3	57.9	2.98
Ireland	8.7	12.0	8.0	0.19	3.15	3.34	2.48	3.8	5.0	0.84
Israel	9.5	17.2	28.1	0.27	2.85	6.09	3.04	6.0	10.0	2.95
Italy	116.8	125.7	107.4	1.94	2.19	0.74	0.61	57.5	44.9	0.13
Japan	306.0	337.8	287.7	5.20	2.66	0.99	0.72	127.0	109.8	0.28
Jordan	2.8	4.2	6.5	0.07	0.85	4.32	-0.08	5.0	10.2	4.41
Kazakhstan	75.6	33.1	36.6	0.51	2.10	-7.92	-7.31	15.7	13.9	-0.66
Kenya	1.6	2.6	4.1	0.04	0.08	4.86	2.24	30.4	44.0	2.55
Korea (N)	66.8	51.5	56.9	0.79	2.32	-2.55	-3.60	22.2	25.0	1.09
Korea (S)	65.8	116.5	189.8	1.79	2.49	5.88	4.94	46.9	46.4	0.89
Kuwait	11.8	13.1	14.4	0.20	5.87	0.99	0.61	2.2	4.9	0.38
Latvia	6.1	1.9	3.1	0.03	0.80	-11.1	-9.87	2.4	1.3	-1.32
Libya	10.3	15.6	23.6	0.24	2.97	4.22	2.17	5.3	9.2	2.01
Lithuania	10.6	3.6	5.8	0.05	1.02	-10.3	-9.72	3.5	2.5	-0.67
Malaysia	15.1	39.4	64.2	0.61	1.72	10.1	7.35	22.9	39.5	2.55
Mexico	102.4	115.7	130.7	1.78	1.17	1.23	-0.50	98.9	140.1	1.74
Morocco	6.4	10.0	15.5	0.15	0.34	4.52	2.75	29.1	47.0	1.73
Netherlands	43.4	47.4	40.0	0.73	2.98	0.88	0.27	15.9	17.0	0.61
New Zealand	6.9	8.4	6.9	0.13	2.21	1.95	0.76	3.8	4.5	1.18
Nigeria	12.4	9.9	10.9	0.15	0.09	-2.24	-5.02	114.8	258.2	2.93
Norway	9.5	11.2	9.6	0.17	2.51	1.66	1.13	4.5	4.9	0.53
Pakistan	18.6	28.6	44.1	0.44	0.20	4.42	1.83	142.5	348.6	2.54
Peru	5.9	8.1	11.0	0.12	0.31	3.15	1.36	25.9	41.0	1.77
Philippines	12.0	21.2	34.5	0.33	0.28	5.85	3.61	75.6	126.8	2.16
Poland	130.0	85.9	122.2	1.32	2.22	-4.06	-4.19	38.6	33.0	0.13
Portugal	11.9	17.3	11.0	0.27	1.73	3.78	3.65	10.0	9.0	0.13
Qatar	3.2	11.1	18.1	0.17	19.16	13.1	10.7	0.6	0.9	2.18
Romania	53.1	30.6	48.9	0.47	1.36	-5.37	-5.07	22.5	18.1	-0.32
Russia	647.0	398.2	647.0	6.13	2.74	-4.74	-4.54	145.3	101.6	-0.2
Saudi Arabia	33.7	102.2	166.4	1.57	4.59	11.7	8.48	22.2	54.7	3.0
Serbia & Montenegro	17.0	11.4	12.6	0.18	1.08	-3.92	-4.28	10.5	9.4	0.38
Singapore	12.3	16.1	21.1	0.25	4.03	2.74	-0.11	4.0	4.6	2.86
Slovakia	16.1	10.9	14.8	0.17	2.03	-3.81	-4.05	5.4	4.9	0.25
South Africa	77.9	89.3	102.4	1.38	2.04	1.38	-0.35	43.7	40.4	1.73
Spain	62.0	84.1	57.1	1.29	2.07	3.09	2.73	40.7	37.3	0.35
Sri Lanka	1.0	2.8	4.5	0.04	0.15	10.5	9.38	18.6	21.2	1.0
Sweden	15.4	14.7	14.2	0.23	1.65	-0.49	-0.84	8.9	8.7	0.35
Switzerland	12.1	11.9	11.1	0.18	1.67	-0.13	-0.60	7.2	5.8	0.47

Syria	9.8	14.8	22.4	0.23	0.89	4.22	1.50	16.6	34.1	2.68
Thailand	26.1	54.2	88.3	0.83	0.89	7.57	6.35	61.0	77.0	1.15
Trinidad & Tobago	4.6	7.2	11.2	0.11	5.58	4.53	3.92	1.3	1.2	0.59
Turkey	39.3	60.5	93.2	0.93	0.89	4.42	2.66	68.2	97.8	1.71
Turkmenistan	11.2	9.4	10.4	0.15	2.04	-1.70	-3.97	4.6	7.5	2.36
Ukraine	191.9	82.1	133.8	1.26	1.65	-8.14	-7.74	49.7	31.8	-0.44
United Arab Emirates	15.0	25.4	41.4	0.39	9.02	5.37	2.01	2.8	4.1	3.3
United Kingdom	159.5	148.5	146.8	2.29	2.53	-0.72	-1.05	58.7	66.1	0.33
USA	1364.6	1604.5	1269.1	24.7	5.63	1.63	0.54	284.9	408.6	1.09
Uzbekistan	31.2	30.5	33.7	0.47	1.22	-0.24	-2.16	24.9	37.8	1.97
Venezuela	32.1	43.1	57.7	0.66	1.77	2.97	0.74	24.3	41.7	2.22
Vietnam	5.8	15.7	25.5	0.24	0.20	10.4	8.53	78.2	117.6	1.69
Yemen	2.6	4.6	7.6	0.07	0.26	5.91	1.66	18.0	84.4	4.18
WORLD	6028	6494	7349	100	1.07	0.75	-0.68	6091	8935	1.43
EU	1148.6	1072.7	1052.1	16.5	2.37	-0.68	-0.96	451.8	431.0	0.28
Rest[4]	2676.0	2763.5	3678.3	42.6	0.90	0.32	-1.36	3062.9	5173.4	1.71

[1] Emissions are fossil-fuel based CO_2 emissions, expressed as tC (tonnes carbon).

[2] For countries that have accepted emissions reduction targets under the Kyoto Protocol, emissions in 2010 were calculated as the 1990 fossil-fuel based CO_2 emissions times the target value. If emissions in 2000 were below their 2010 target, emissions in 2010 were calculated as the lesser of the agreed Kyoto target amount or the value calculated from the 2000 emissions and with a 5% per annum growth rate. For other countries, the relative change from 1990 – 2000 was extrapolated to 2010, with the provisos that it had to be within the limits of 1-5% annual growth.

[3] Per-capita emissions (tC per person per year) are given for the year 2000.

[4] Rest of the world refers to countries other than the EU, USA, China and India (as in Fig. 1).