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Climate change: long-term targets and short-term commitments ☆

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Abstract

International negotiations under the UN Framework Convention on Climate Change could take several different approaches to advance future mitigation commitments. Options range from trying to reach consensus on specific long-term atmospheric concentration targets (e.g. 550 ppmv) to simply ignoring this contentious issue and focusing instead on what can be done in the nearer term. This paper argues for a strategy that lies between these two extremes. Internationally agreed threshold levels for certain categories of impacts or of risks posed by climate change could be translated into acceptable levels of atmospheric concentrations. This could help to establish a range of upper limits for global emissions in the medium term that could set the ambition level for negotiations on expanded GHG mitigation commitments. The paper thus considers how physical and socio-economic indicators of climate change impacts might be used to guide the setting of such targets. In an effort to explore the feasibility and implications of low levels of stabilisation, it also quantifies an intermediate global emission target for 2020 that keeps open the option to stabilise at 450 ppmv CO_2 If new efforts to reduce emissions are not forthcoming (e.g. the Kyoto Protocol or similar mitigation efforts fail), there is a significant chance that the option of 450 ppmv CO_2 is out of reach as of 2020. Regardless of the preferred approach to shaping new international commitments on climate change, progress will require improved information on the avoided impacts climate change at different levels of mitigation and careful assessment of mitigation costs.
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1. Introduction

Questions about the timing, level and form of the next round of mitigation commitments are moving to centre stage of the international negotiating agenda on climate change. A key will be to intensify and broaden participation in emission reduction so as to bring absolute global emissions trends down and allow stabilisation of concentrations of GHG to occur in a timely manner. The Kyoto Protocol calls for starting new negotiations on next steps by 2005.[1]

The guiding objective for these future negotiations is found in the UN Framework Convention on Climate Change (UNFCCC, 1992): "to achieve… stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change; to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner" (Article 2). In addition, the Convention calls for "precautionary, cost-effective and equitable measures to address climate change" (Article 3.3).

The Convention objective implies that questions pertaining to the level and timing of mitigation commitments derive from a common concern in the international community about the potential damages of climate change and the need to make timely progress in abating potentially "dangerous" climate change (Fig. 1). The IPCC Third Assessment Report laid out a way to begin to structure thinking about the risks of climate change, referring to five "areas of concern" (see Section 3 below): (i) risk of large scale singularities; (ii) aggregate impacts; (iii) distribution of impacts;

☆ This paper represents the views of the authors; it does not represent the views of the OECD nor its Member countries.

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[1] Review of the Kyoto Protocol at the second Meeting of the Parties, which may take place in November 2005 (Article 9.2) and initiation of consideration of commitments for Annex I Parties in 2005 (Article 3.9).

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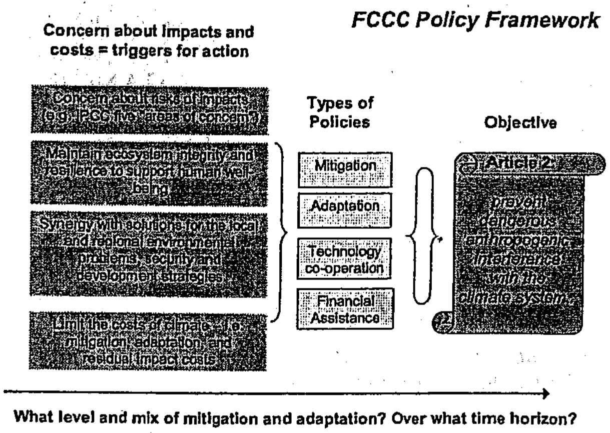

Fig. 1. Are benefits triggers for Climate Policy?

(iv) risks of extreme weather events; and (v) risks to unique and threatened systems. Nevertheless the climate change policy debate in the last few years has focused more on the costs of mitigation than on the avoided impacts or potential benefits of mitigation. This stems from concern about possibly high mitigation costs in the near-term, both in the aggregate and for individual countries (Hourcade et al., 2001). Yet we argue that avoided climate impacts, and a variety of other related benefits, are equally as important as mitigation costs as triggers for mitigation policy decisions. Further, when looking at the impact side of the debate, one can make a cogent argument for the setting and use of long-term targets to guide medium term decisions on mitigation commitments under the Convention.

Beyond avoided climate impacts (as characterised by the five "areas of concern" noted above), a number of other specific policy benefits may be triggers for mitigation. This includes eco-system stability and resilience (Root et al., 2003; Leemans and Eickhout, 2003; Parmesan and Yohe, 2003), and the ability for natural resource systems to continue to provide the necessary resource base for future economic development (OECD, 2001a, b). Another set of benefits maybe related to sustainability goals of nations, regions or local communities (Beg et al., 2002; Caspary and O'Connor, 2002; Barnett, 2003). For example, synergies with greenhouse gas mitigation can improve local environments and reduce health risks from urban air pollution, or, with adaptation, enhancing ability of agrarian communities to adapt practices to variability in climate, which also prepares these communities to deal with future climate changes (Davis et al., 2000). Thus in addition to concern about the magnitude and distribution of the direct impacts of climate change, and about the costs of mitigation, a variety of other policy "benefits" may begin to drive national and international action to strengthen climate policies.

The Framework Convention lays out the main structure for action, and types of measures to be undertaken (Fig. 1). The main questions at the international level are not what types of policies are needed but rather how to approach policy, at what level of stringency and in what timeframes? In turn, these questions relate to both the costs and benefits of action (for a recent discussion, see Pearce, 2003). Compared to mitigation cost assessment, much less research has been devoted to comprehensive assessment of the long-term benefits of mitigation (see IPCC, 2001b,c; Weyant and Hill, 1999; OECD, 1999).[2]

This article begins by reviewing general arguments for and against the need for long-term targets. It moves on to highlight the complex relationship between emissions and impacts and to explore the use of the "five areas of concern" as a guide for the setting of long-term mitigation targets. Based on a qualitative review of the recent literature on these "areas of concern," we find that even the relatively low stabilization target of 450 ppm CO_2 has significant impacts in the five areas of concern. The article explores only one aspect of the implementation challenge in detail, by looking at the implications of a global 450 ppm CO_2 stabilisation objective for Annex I and non-Annex I GHG emissions in 2020, under three different emission allocation schemes, compared to IPCC baseline (SRES) scenarios. It leaves to other researchers the important task of investigating the economics of alternatives explored here.

2. Is there a need for long-term targets?

The long-term objective of the UN Framework Convention on Climate Change is expressed in Article 2 as stabilisation of greenhouse gas concentrations. Fig. 2 provides illustrative examples of pathways of global emissions that lead to stabilisation of greenhouse gas concentrations at different levels (IPCC, 2001a–d) showing three steps of the cause-effect chain that lead to climate change: emissions (a), concentrations (b) and change in global mean temperature (GMT) (c). In all cases, global emissions peak and decline within the next century, leading eventually to stabilising concentrations within 100–300 years, which in turn leads to stabilising temperatures within a few centuries.

Four aspects are important:

- Stabilisation of atmospheric concentrations in the 21st Century at any level requires a significant departure from current emission levels. Global emissions will need to drop radically compared to

[2] The authors recognise the existence of a large climate impacts literature, as summarised in WG II report of the IPCC. However this information is unfortunately not structured in such a way so as to be easily used in the mitigation policy debate. See Corfee Morlot, 2003 reporting on a recent OECD workshop on this issue.

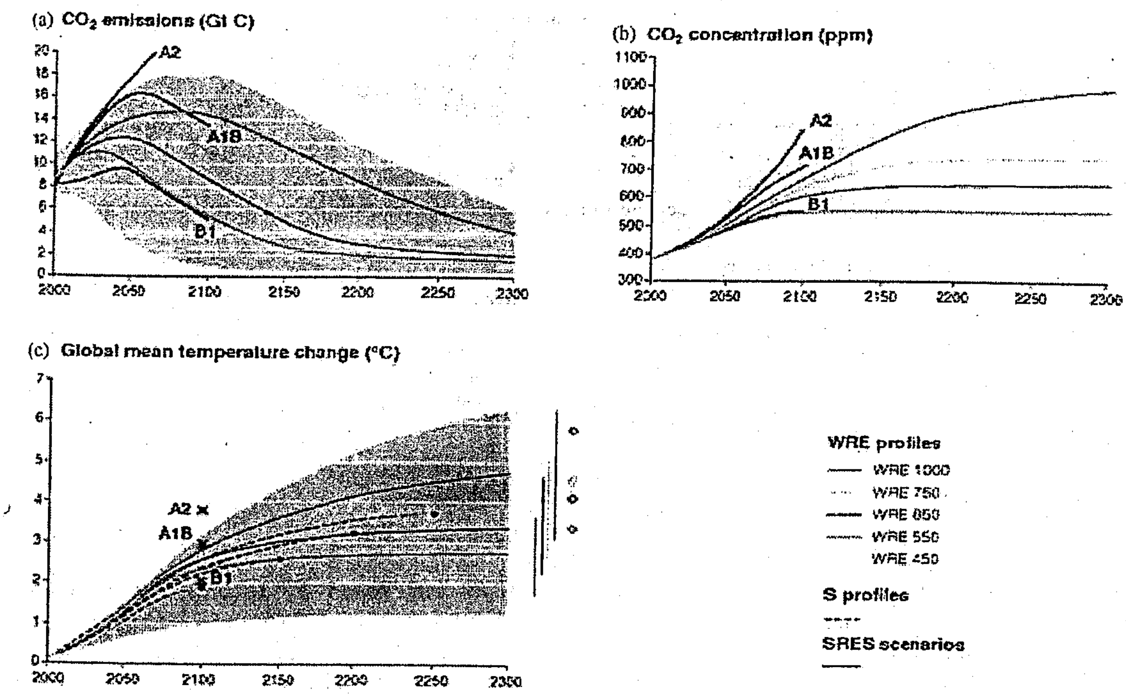

Fig. 2. Stabilisation Pathways. *Source*: IPCC (2001d), Fig. 6.1.

today, dropping below 1990 levels and declining to zero over time (Fig. 2). The earlier the emissions peak and decline, the lower the stabilised concentration level, the lower the absolute level of climate change and the earlier that climate change is attenuated.

- If, in the short term, emissions rise above a certain level, low long-term stabilisation levels may be out of reach.
- Due to the inertia and delays in the climate system, even with stabilised concentrations, the world will still be committed to some significant climate changes for centuries to come. For higher stabilisation levels and delayed stabilisation, the longer the time period over which there will be a "commitment to climate change".
- The rate of warming is important as it drives ecosystem impacts and possibly other impacts such as non-linear, abrupt climate changes. Curbing the rate of warming requires reversing the trend of growing emissions so that they decline in the near term. With increasing emissions, the rate of change in GMT will remain high, whereas with decreasing emissions, the rate of increase in GMT will slow.

2.1. *The physics of stabilisation of greenhouse gas concentrations*

Before discussing long-term targets for climate policy, it may be helpful to first take a look at the cause–effect chain from emissions of greenhouse gases to changes in climate and impacts (Mitchell and Karoly et al., 2001). This chain can be described in a simplified form in roughly six steps (Fig. 3):

1. Human activities result in emissions of greenhouse gases, precursors and aerosols.
2. These change the concentration of these and other gases in the atmosphere.
3. Changed concentrations influence radiative forcing, the amount of heat radiation that is reflected by the atmosphere back to the surface of the earth.
4. Changed radiative forcing influences surface temperature.
5. The absolute change in temperature, as well as the rate of its change, influences the sea level and other parameters such as precipitation and related damages.
6. In addition, several feedbacks exist, e.g. changes in climate may change vegetation cover, influencing the build-up of concentrations in the atmosphere.

Policy decisions are made difficult by cascading uncertainty and delays in the cause–effect chain due to inertia in the systems involved. Uncertainty cascades throughout this chain effect, as the uncertainty range at the top of the chain grows in significance after moving through the intermediate drivers and indicators of change. The broadest bands of uncertainty found at the bottom of the chain (Jones, 2000; Moss and Schneider, 2000). Characterising uncertainty in each of

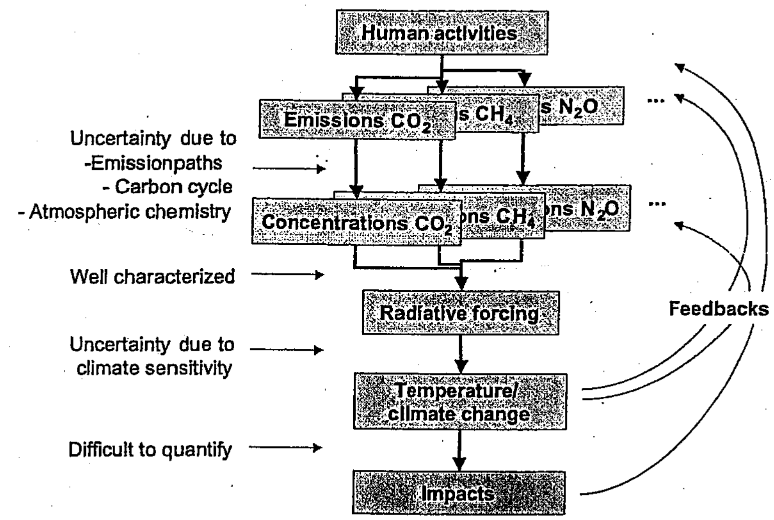

Fig. 3. Cause–effect chain from emissions to impacts.

the steps of the cause–effect chain is therefore essential to understanding and interpreting the results of assessment of emissions and their impacts for policy assessment (Moss and Schneider, 2002; Pittock et al., 2001; Schneider, 2003). Despite the uncertainty, climate changes are already underway and these are having a discernable effect in some sensitive sectors (see for example Root et al., 2003 and Parmesan and Yohe, 2003 on ecosystems and Nicholls, 2003 on sea level rise). Further, resolving the wide uncertainty even in key variables, such as climate sensitivity (see Section 3.2), will not change the conclusion that profound changes in the energy system are needed in the next decades to make possible long-term climate protection objectives and lower emission futures (Caldeira et al., 2003).

2.2. *What is dangerous? The definition of a long-term target*

Are long-term targets necessary and, if so, given the uncertainties outlined above, can they be defined by policymakers such that they are supported by credible science? Review of the progress on this issue in the negotiations might suggest a negative answer. More than a decade of discussion in international negotiations and earlier scientific consideration of this issue, has not led to specific consensus on what is "dangerous anthropogenic interference with the climate system". Tolerable rates and thresholds as a driver for climate policies were discussed by the UNEP and WMO advisor to the Advisory Group on Greenhouse Gases (AGGG) the late 1980s and also in the Villach/Bellagio conferences of the same period (Agrawala, 1999). This select Group of advisors proposed numerical estimates for tolerable rates of climate change to policy makers *before* the drafting of Article 2 of the Framework Convention. After the adoption of the Framework Convention, the IPCC was asked by governments to address issues related to its Article 2 (IPCC, 1996). This led to an IPCC workshop on this topic in 1992 (Forteleza) and to the treatment of relevant "what if" issues regarding stabilisation scenarios in the Second Assessment Report (IPCC, 1996).[3] But the IPCC has consistently avoided or delayed making specific recommendations on this topic, pointing instead to the role of policy-makers (rather than scientists) in dealing with this value-laden aspect of interpreting what is "dangerous" (IPCC, 2001d).

Later, in the negotiations leading up to Kyoto, proposals from governments to establish long-term stabilisation targets were not adopted despite extensive debate on the issue of the "adequacy of commitments" of the UNFCCC.[4] While the initial conclusion of this debate led to the Berlin Mandate to negotiate stronger mitigation commitments for Annex I Parties, which ultimately resulted in the Kyoto Protocol (Depledge, 2000), it has not resulted in agreement on long-term targets.

Since 1997, international climate negotiations have been dominated by short-term issues such as the design of rules of the Kyoto Protocol (Depledge, 2000). A discussion about the "second review of adequacy of commitments" was initiated in 1998 but never completed and is continually deferred to the "next" session of the Conference of the Parties. A substantive discussion has not taken place because of the fundamental disagreement between the Group of 77 and China (G-77) and the Annex I countries, whether negotiations would include consideration of developing country commitments. At the eighth Conference of the Parties

[3] A similar line of analysis can be found in the Third Assessment Report.

[4] The discussion on "adequacy of commitments" was formally addressed in the first Conference of the Parties to the Convention.

in New Delhi 2002, the issue was again brought up within the discussion of the "Delhi Declaration". The EU made a proposal to start a "dialogue to kick off a process for future action to achieve the ultimate goal of the Convention".[5] This was rejected by the G-77 since such activity was viewed as leading to developing country commitments. The final Delhi Declaration does not mention the ultimate goal of the Convention.[6]

If the past is any indication of the future, international negotiations could continue toward "ad hoc" incrementalism (Philibert et al., 2003). This could be seen as grasping for a next step based on the perception that mitigation costs are likely to be too high to achieve more ambitious objectives, regardless of whether such a step is strategically necessary to protect the climate. Yet, decisions on next steps should be influenced as much by the benefits of avoiding increments of climate change as by the costs of mitigation. This was recognised in debate leading up to FCCC and the drafting of Article 2 (Agrawala, 1999), however, negotiations related to mitigation since the entry into force of the Convention have largely bypassed the explicit consideration of climate change impacts.[7]

The Framework Convention implies that international climate policy must anticipate the various aspects of inertia and deal with these complex interactions of different types of systems to advance a common notion of what is "dangerous". The complexity of the various systems at play, and the widespread uncertainties associated within and between each dimension, may explain why policy progress on this issue is slow. Yet, we would agree with a number of observers who have argued that a decision on this issue is an essential part of future negotiations (Azar and Rodhe, 1997; Jacoby et al., 1998; O'Neill and Oppenheimer, 2002; Rijsberman et al., 1998). Loosely defined long-term targets, at least in the form of recognising that "the current targets are not enough", have already embedded themselves in discussions on the evolution of climate change commitments.[8] However, without a clear set of environmental objectives to drive negotiations, ad hoc approaches and incremental decisions may prematurely foreclose options for protecting the climate for coming generations.

[5]EU statement at COP 8.

[6]Available at www.unfccc.int.

[7]This may be due to the emphasis on the implementation of Kyoto Protocol. One exception can be found in the negotiations on "compensation" that is linked to Article 4.8 of the Convention. This Article foresees "*actions [by Parties] ... to meet the special needs and concerns of developing country Parties arising from adverse effects of climate change ...*". To help inform these negotiations, the UNFCCC Secretariat has held several workshops featuring recent information on impact assessments (see www.unfccc.int—workshop information).

[8]These discussions are grounded in the language of the UNFCCC (Article 4.2d) on the adequacy of commitments.

3. Linking mitigation policy decisions to the risks of climate change

Despite inability in the past to agree a long-term target for climate policy, the process of considering long-term objectives has potential to significantly shape short- to medium-term mitigation commitments. What types of information might assist policymakers to relate a long-term target to actions in the nearer term? This section moves step-by-step up through the cause–effect chain (Fig. 3) from impacts to be avoided, to associated changes in temperature and changes in concentrations to arrive at emission levels in various time frames that are consistent with various long-term objectives.

3.1. Relating damage to changes in temperature/climate

As a first step, we look at which impacts are expected from climate change at different levels of global mean temperature increase. The IPCC Third Assessment Report's five "reasons for concern" about the risk of climate change (see below; Smith et al., 2001; IPCC, 2001b) are described qualitatively rather than quantitatively. Using this as a starting point, a key question is how do we measure and communicate each type of risk? Another question is whether such information can help to guide decisions on next steps under the Convention. Some of the key issues are (see also Table 1):

1. *Risk of large scale singular events*: This includes a breakdown of thermohaline circulation which would drive significant shifts in warming and cooling patterns in the Northern Atlantic region (THC) or the disintegration of Western Antarctic Ice Sheet (WAIS) which could lead to sea level rise of 4–6 m in some regions (Rahmstorf, 1996, 2002; Vellinga and Wood, 2002; Alley et al., 2003; O'Neill and Oppenheimer, 2002; Schellnhuber, 2002). Such events are estimated to be low probability of occurring during this century with a higher probability over longer time frames or with rapid rates of human-induced radiative forcing (Stocker and Schmittner, 1997). One problem with estimating this type of risk is the huge uncertainty surrounding what conditions may trigger such an event.[9] Coming up with a reasonable estimate

[9]Uncertainty is not unique to the large scale events but is widespread in each of the areas of concern reviewed here. Moss and Schneider (2003) provided guidance to IPCC authors (and indirectly to the broader community) on how to take uncertainty explicitly into account and communicate it in assessments, recommending a range of steps from the use of standardised terminology to quantitative and statistical representation. Increasingly, policy analysts and scientists are moving toward more formal treatment of uncertainty with probabilistic assessment being one of the more sophisticated approaches to appear in recent literature (Wigley and Raper, 2001; Jacoby, 2003; Webster et al., 2003; Jones, 2003).

of the probability of such an event is said by some to be impossible (Azar, 1998). Nevertheless it is an active area of research for integrated assessment and climate modellers (see Schellnhuber, 2002; Mastrandrea and Schneider 2001; Alley et al., 2003) and progress in understanding the risk of abrupt climate change could have significant implications for policy (Alley et al., 2003; Baranzini and Chesney, 2003; Mastrandrea and Schneider, 2001).

2. *Aggregate impacts*:[10] This looks across all types of sectoral and regional impacts damages to aggregate global impacts. A limited number of economic studies provide aggregate global estimates in monetary terms (Nordhaus and Boyer, 2000; Tol et al., 2000). A number of other recent studies use alternative numeraires, such as numbers of people affected, by sector impact at different levels of stabilisation or global mean temperature change (Parry et al., 2001; Arnell et al., 2002).[11] Monetary estimates of impacts are an important input to policy assessment, in part because they provide a well-understood common metric for the comparison of disparate impacts and systems. Unfortunately, current economic estimates remain partial, inconsistent among studies and somewhat controversial. In addition to uneven treatment of adaptation, economic studies often leave out non-market damages entirely or use extremely simplistic representations of this important group of impacts. Market impacts receive more comprehensive and careful treatment (compared to non-market impacts) but even these estimates are characterised by large uncertainties stemming from lack of empirical data and theoretical formulations that do not yet account for the dynamics of economic interactions in a changing climate within and across sectors (Tol, 2002; Hanemann, 2003 forthcoming).

   Beyond problems of comprehensiveness and consistency (e.g. in treatment of adaptation), problems surrounding aggregation also need to be overcome to provide transparency about moral judgements embedded in whatever approach is chosen (Azar, 1998). Is one person's displacement in Bangladesh due to flooding equivalent to another person's displacement due to flooding in Fiji or in the southern United States? If not how should we compare these losses? Current studies that emphasise monetisation reveal disagreements on issues such as aggregation (Pearce, 2003; Jacoby, 2003; Tol, 2003). Some authors have advocated "equity-weighting" (Fankhauser et al., 1997; Tol, 2003), to explicitly address differences in wealth in the aggregation across regions (Pearce, 2003). Similarly, disagreements arise on the aggregation of climate change damage costs over long time frames, especially when changes are irreversible (Arrow et al., 1996; Schneider et al., 2000; Azar, 1998; Neumayer, 1999). Although there is no commonly accepted approach to aggregation—either through time or across regions—the assumptions underlying such aggregation will largely determine whether total impacts at lower levels of GMT change are positive or negative; at a minimum these assumptions need to be made explicit (Schneider, 2003; Pearce, 2003).

   While aggregate indicators of impacts (monetary or non-monetary) and risk can provide a gross indication of levels of the severity of different levels of climate change (Tol, 2002; Smith and Hitz, 2003), they are far from conclusive or complete, especially at low levels of climate change where aggregate global impacts may be positive in some important market sectors (i.e. increased agricultural production). Looking across different metrics for aggregate impacts, Smith and Hitz (2003) point to increasingly negative impacts across all sectors for which there are data, at higher levels of change (e.g. 3–4°C). However they also suggest that there are still significant gaps and inconsistencies in the global impacts literature, thus highlighting a rich research agenda in this area.

3. *Distribution of impacts*: The distribution of impacts is uneven across regions for even for relatively small changes in global mean temperature (e.g. 1°C) (Tol, 2002). A given change in concentrations or in global mean temperature will result in widely varying regional temperature and precipitation patterns (IPCC, 2001a). Some regions will be particularly vulnerable to even low levels of climate change in part because they are extremely poor and have less capacity to adapt to change in general (Downing et al., 2001). Thus, differences in vulnerability may result from geo-physical factors, such as heavily populated low-lying coastal areas in a region (Nicholls, 2002, 2003) or from socio-economic factors, such as poverty levels and inadequate capacity to cope with change (Downing et al., 2001; Yohe and Tol, 2002). Climate and economic conditions may be even expected to improve in some regions at lower levels of temperature change, such as in the northern hemisphere, while an identical global mean temperature change may cause significant damages in tropical regions (Tol et al., 2003; Tol, 2002; Nordhaus and Boyer, 2000). Nevertheless regional impacts could drive the need for international climate policy; at a minimum they highlight the

[10] Emphasis on the "aggregate" area of concern is not a reflection of the relative importance of this item. Rather it reveals the level of debate around aggregate impacts as an indicator of the risk of climate change, which has been extensive. For a description of the controversy about aggregate estimates that arose in the course of preparing the IPCC Second Assessment Report, see Grubb et al. (1999, Appendix 2).

[11] See Smith and Hitz, 2003 for a recent review of the global impacts literature.

Table 1
Key indicators and measurement issues by area of concern

Area of concern	Benchmark impact indicators	Possible global mean temperature change thresholds[a]	Measurement issues for key indicators
Risk of large scale singularities[b]	Breakdown of the North Atlantic Thermohaline Circulation (THC); disintegration of the West Antarctica Ice Sheet (WAIS)	3°C–4°C	Probability distributions for such events are unknown; lack of knowledge about the type and rate of change. Limited evaluation of the range of potential .damage costs associated with catastrophic events, due to lack of data (possibly infinite) uncertainty, disagreement about key assumptions for evaluation
Aggregate impacts[c]	Aggregate monetary or economic welfare losses (e.g. change in GDP); changes in numbers of people affected (e.g. flooded)	2°C–3°C	Lack of comprehensive coverage and of agreement on valuation approaches for non-market losses; discounting techniques over long time frames for different types of costs; valuation of human life; failure to consider sector inter-relationships, e.g., between water and agriculture impacts. On numbers of people affected—number of studies is limited
Distribution of impacts[d]	Monetary or economic welfare losses by region; changes in numbers of people affected by region	2°C–3°C	Regional downscaling of global climate models; lack of consistent or clear climate signals at the regional scale; socio-economic and vulnerability baseline scenarios or choice of base year for comparison. Lack of agreement on how to represent and measure regional impacts
Risks of extreme weather events[e]	Frequency, intensity of tropical storms and precipitation events, drought; increase in maximum T and number of hot days, increase in minimum T and decrease in number of cold/frost days	1°C–2°C	Attribution to climate change, climate variability (natural variations around a mean) versus climate change (changes in the mean and distribution about the mean); socio-economic change and vulnerability, autonomous adaptation and cost of planned adaptation. Lack of consensus on definition of extreme events and lack of homogenous data (e.g. on costing approaches, baselines). Valuation of human life and health effects remains controversial with limited empirical data from developing countries. Selection of base scenario and/or years for points of comparison
Risks to unique and threatened systems[f]	Coral reefs, mangrove forests, mountain glaciers. For species key indicators are: population abundance, species distribution, morphology, behaviour, community structure and species survival; for glaciers: pace and magnitude of glacial retreat	1°C–2°C	How to measure the state of these systems over time? Thresholds for irreversible change; sensitivity to rate versus absolute T changes, precipitation or sea level changes? Varying views on the magnitude of losses and on the socio-economic value of such losses; lack of data required for valuation in different regional contexts

Sources: Authors, building on Smith et al. (2001), IPCC (2001a, b) and other sources noted below.
[a] See also Section 3.2 on corresponding concentration levels.
[b] Stocker and Schmittner (1997), Schneider et al. (2000), Narain and Fisher (2000), O'Neill and Oppenheimer (2002), Vellinga and Wood (2002), Tol (2003), Rahmstorf (2002, 1996), Alley et al. (2003), Baranzini and Chesney (2003).
[c] For surveys of work in this area see Tol (2002) and Pearce (2003). On numbers of people affected see Parry et al. (2001) and Arnell et al. (2002).
[d] Tol (2002), Arnell et al. (2002) and Parry et al. (2001).
[e] Easterling et al. (2000), Cubasch and Meehl (2001) and Milly et al. (2002).
[f] Root et al. (2003), Parmesan and Yohe (2003), Etterson and Shaw (2001), O'Neill and Oppenheimer (2002), and Leemans and Eikhout (2003). On the importance of preferences in valuation see Yohe (2003), Roughgarden and Schneider (1999) and Azar (1998).

close interaction between socio-economic development and vulnerability to climate change suggesting a potential link between the distinct policy areas of development and climate. Regional changes in climate may also threaten unique natural systems (see below).

Box 1
The risk of Climate Change Impacts and Mitigation Decisions

Extending the understanding of the risks of climate change may provide a means to assess the trade offs associated with decisions about mitigation (O'Neill and Oppenheimer, 2002; Arnell et al., 2002; Jacoby, 2003). Ideally such an assessment would include quantitative benchmark indicators for each "area of concern" in different time frames and for different levels of climate change. Table 1 outlines some possibilities drawing on the IPCC TAR and more recent literature. While this type of information is not yet available in a robust form today, if policy makers indicated a need for it today, then researchers could organise their work to fill in these information gaps (Parry, 2001; Pittock, 2002; Jacoby, 2003)

In one example of such an effort, O'Neill and Oppenheimer (2002) recently traced the development of global benchmarks for key impacts of climate change associated with two types of concerns outlined above—irreversible change and the risk of surprise, non-linear events (see also Table 1). Their work suggests that benchmarks indicators could guide policy decisions, exploring three distinct indicators of risk—extinction of coral reef systems, the breakdown of the THC, and disintegration of the WAIS—including the setting of clear thresholds where the risk of abrupt and irreversible change is high. Similar work in other areas, perhaps working from the local or regional to the global level, might help to identify thresholds for global mean temperature change or rates of change that limit the risk of irreversible damage to vital natural or human systems (Jones, 2003forthcoming). In turn, such thresholds provide a means to establish boundaries for near-term actions consistent with emission pathways that lead to stabilisation of concentrations within this century.

4. *Risk of extreme events*: This describes the risk of increased variance in climate change over the long term, including more hot days and fewer cold/frost days over nearly all land areas, and more intense precipitation events over many areas. It also covers more uncertain and complex extremes: potentially more intense drought and cyclone events, droughts and floods associated with El Nino events, increased Asian monsoon precipitation variability and intensity of mid-latitude storms. Risk within this "area of concern" varies significantly by region. Changes in variability or extremes may also have positive impacts as warmer nights and warmer winters should also reduce cold related deaths, while more extreme heat may have the opposite effect. There remain significant uncertainties as to the attribution of individual events and progress to be made in the collection of standard data to assess changes in extremes variability over time (Easterling et al., 2000; Milly et al., 2002; IPCC, 2002), however there is also some indication that such changes are already part of an observable trend (Easterling et al., 2000; Pittock, 2002; Milly et al., 2002) and thus that they are occurring at relatively low levels of change.
5. *Risk to unique and threatened systems*: Significant risk to ecosystems exists at even small levels of changes in global mean temperature, and may affect coral reefs, glaciers and mangroves, as well as indigenous people's livelihoods in some parts of the world (O'Neill and Oppenheimer, 2002; Barnett, 2003; Agrawala et al., 2003 forthcoming). Observed changes in plants and animals and their ecosystems under current levels of climate change (apporiximate 0.6°C over the last century) indicate that increasingly rapid rates of climate change in the future could significantly disrupt species communities and their "connectedness" over time (Root et al., 2003; Parmesan and Yohe, 2003; Leemans and Eickhout, 2003; Etterson and Shaw, 2001). These disruptions occur even at relatively low levels and rates of global mean temperature change. Concern about risks to unique and threatened systems could lead to agreement on regional thresholds for climate change (e.g. temperature change or decadal rates of temperature change), which in turn can be related targets for long-term global climate change (Jones, 2003 forthcoming; O'Neill and Oppenheimer, 2002) (see also Box 1).

Estimating systematic changes in eco-systems due to climate change requires careful study across long time-frames and consideration of rates of change as well as absolute changes in climate. It will also require the development and application of standard indicators of change over time and at different levels of climate change, including but not limited to monetised indicators of change. Monetising eco-system (non-market) losses is important to help complete our understanding of the economic impacts of climate change yet coverage of non-market impacts in economic studies remains partial and inconsistent (see above) at best. Viewpoints on the magnitude of non-market losses also vary widely depending upon perceptions of risk (Schneider et al., 2000; Roughgarden and Schneider, 1999; Yohe, 2003) pointing to the need to be transparent about assumptions and explicit about uncertainty underlying estimates of economic damages.[12]

3.2. Relating changes in temperature to concentration levels

A wide range of concentration may correspond to any given "target" with respect to global mean temperature increase (Smith et al., 2001; Cubasch and Meehl, 2001; IPCC, 2001d). Fig. 4 provides the relationship between concentration levels and resulting changes in global-average surface temperature. As the climate system changes only slowly (see Fig. 2) the global mean temperature increase in 2100 is below the change

[12]Non-market impacts, including human health, stand out as a priority area for future research; see Smith and Hitz (2003) and Jacoby (2003) for a discussion.

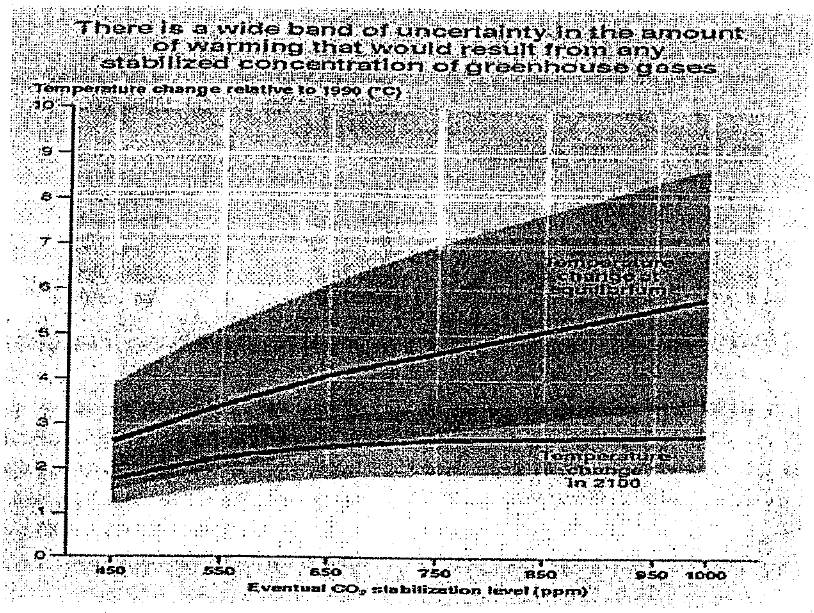

Fig. 4. Relating concentration levels to global mean temperature change. *Source*: IPCC (2001d), Fig. 6.2.

realised once the climate is completely stabilised (in a few centuries). Hence the figure shows two curves, a lower one for the year 2100 and a higher one for a stable situation much later. Both curves include the full possible range resulting from uncertainty in the climate sensitivity (i.e. the GMT increase is in the range of 1.5–4.5°C for a doubling of CO_2 concentrations) and from uncertainty about other GHG emissions.

Stabilisation of greenhouse gas concentrations will need to include both CO_2 and other greenhouse gases. Historically emissions have increased the CO_2 concentration from 280 ppmv to the current level of 360 ppmv. CO_2, CH_4 and N_2O together produce today an amount of radiative forcing that is equivalent to the forcing of CO_2 alone at roughly 400 ppmv (400 ppmv CO_2 eq.). Stabilising the CO_2 concentration at 450 ppmv and concentrations of the other gases at similar levels would lead to a radiative forcing equivalent to a concentration 550 ppmv of CO_2 alone (550 CO_2 eq. ppmv). Fig. 4 provides on the *x*-axis concentrations of CO_2 only, and includes assumptions about the path of non-CO_2 gases to show the change in temperature relating to both CO_2 and non-CO_2 GHG concentrations on the *y*-axis.

Fig. 4 also shows the significant difference between the change in temperature in 2100 and the change in temperature at equilibrium, which is 50–100% higher. Further, the uncertainty is very wide (up to 50% of the point estimate), due in part to the uncertainty in the climate sensitivity. For the consideration of a long-term target, the most cautious approach would be to focus on the range of temperature change at equilibrium.

Using the relationships shown in Fig. 4, it is possible to map changes in a GMT increase threshold for selected climate change risks or impacts as outlined in Table 1. Stabilisation at 450 ppm leaves a realistic probability of the occurrence of large-scale singularities, since a stabilisation target of 450 ppm CO_2 could result in temperature changes as high as 3–4°C beyond the 21st century. Further, even this rather low stabilisation level still cannot prevent an expected increase in extreme weather events, nor the destruction of unique and threatened systems, as these are affected at lower levels of global mean temperature change of 1–2°C.

3.3. Relating concentrations to emissions

If a goal in terms of greenhouse gas concentrations were defined, which global emission pathway would lead to this concentration level? Using early Wigley, Richels and Edmonds (WRE) stabilisation profiles and carbon cycle models, the IPCC reports on allowable global CO_2 emissions required to achieve different CO_2 concentration targets (IPCC, 2001d). Stabilisation below 450 ppmv would require global GHG emissions to fall below 1990 levels no later than 2040. Making such a target attainable would require significant emissions reductions in the coming decade. By comparison, the window is much wider for stabilisation at 550 ppmv, with the time-frame for comparable emission reductions being between 2030 and 2100 (Table 2, Fig. 2).

Two factors influence this large range of uncertainty in the emission pathway: First, due to the long lifetime of CO_2 in the atmosphere (on the order of 100 years), aggregated emissions are more important determinants of the concentration level than the time of emission. Significant differences in the timing of required emission

Table 2
Level and timing of required global emission reductions

WRE CO_2 stabilisation profiles (ppmv)	Range of global mean T change (°C)		Accumulated CO_2 emissions 2001 to 2100 (Gt C)	Year in which global emissions peak	Year in which global emissions fall below 1990 level
	1990–2100	1990-equilibrium			
450	1.2–2.3	1.5–4	365–735	2005–2015	<2000–2040
550	1.5–2.9	2–5	590–1135	2020–2030	2030–2100
650	1.7–3.2	2.5–6	735–1370	2030–2045	2055–2145
750	1.9–3.4	2.8–7	820–1500	2040–2060	2080–2180
1000	2.0–3.5	3.5–8.5	905–1620	2065–2090	2135–2270

Source: Adapted from IPCC (2001d) Synthesis of the Third Assessment Report; Range of global mean T change is taken from Fig. 4.

reductions under various stabilisation scenarios, permits many alternative pathways to be possible. For example, global emissions could increase rapidly now, peak and then decrease rapidly; or they could increase moderately and then decrease also moderately. Both paths could lead to the same concentration level by the end of the century.[13]

The other reason for the large range is the uncertainty in the carbon cycle, which is also included in Table 2. Within the carbon cycle, plants absorb carbon from the atmosphere. Changes in climate can change the global vegetation and therefore this important sink mechanism for CO_2. Recent findings with climate coupled carbon cycle models (Cox et al., 2000) mention the possibility that the sink mechanism of the global vegetation would decrease substantially due to changes in climate. If this effect were included in the calculations of Table 2, the above-described WRE pathway for 550 ppm would then lead to 780 ppm (MetOffice, 2002). While this result still needs to be validated with other models, it suggests the need for leaving some margin for error in setting policy.

The foregoing discussion suggests that stabilisation at relatively low levels might be justified if there is significant concern about the five areas of risk identified by the IPCC. At a minimum, evidence suggests that a hedging strategy would have value—that is a strategy that leaves open the option to achieve stringent objectives in the future should new information emerge to indicate the need for it.

4. Relating long-term targets to near-term emission limitation commitments

If a long-term goal expressed in terms of *concentrations* or *temperature change* cannot be formally agreed, a short- or medium-term intermediate global *emission* goal could be an alternative. Ideally any near-term emissions goal would leave open the possibility to achieve low levels of concentration. This would allow achievement of low levels of climate change at a later stage should new information or societal consensus emerge to make this desirable (see also Berk et al., 2001 and Toth and Mwandosya, 2001).

4.1. A near-term global emission target that keeps the long-term options open

A key question is how to translate any long-term objective into concrete emission allowances for Annex I and Non-Annex I countries. A further step of course, and one that is beyond the scope of this paper, would be to assess the economic arguments for and against the near-term targets and distributional consequences associated with alternative allocation approaches.

Fig. 5 provides an overview of the range of global CO_2 emissions according to the standard set of possible baselines of the Special Report on Emission Scenarios (SRES) of the IPCC in comparison to historical emissions. The spread is quite substantial already in the next few decades. The figure also shows the possible range of global CO_2 emissions, under the assumption that the Kyoto Protocol is implemented by all Annex I Parties. Although the emissions of Annex I countries are constrained, the range of the global emission level is still wide, since the emissions of the developing countries are uncertain.

Fig. 6 shows the resulting range of possible global CO_2 emission pathways that lead to different stabilisation levels taken from the post-SRES mitigation scenarios (Morita et al., 2001). The spread of paths that lead to the same concentration levels is large. Some of the scenarios with low emissions in the coming decades gradually approach the concentration limit by the end of the century, whereas some with high emissions in the coming decades lead to concentration levels higher than the limit near the end of this century and then gradually reach the concentration limit from above (overshoot scenarios).[14]

[13] However the timing of emissions may affect the rate of climate change and the equilibrium temperature change beyond the 21st century associated with a given aggregate emission budget. See MetOffice (2002) and Wigley (2003).

[14] See (Wigley, 2003) for a discussion of overshoot scenarios.

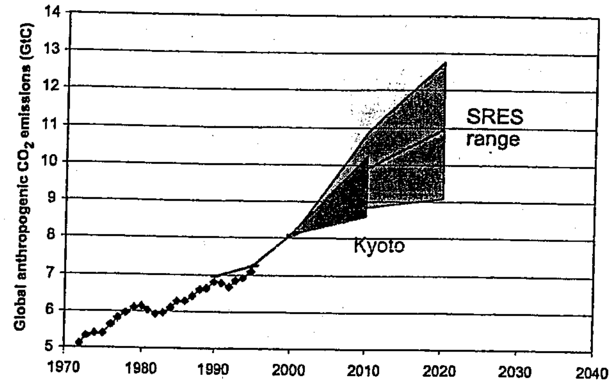

Fig. 5. Possible global CO_2 emission pathways to 2020. *Note*: Historical CO_2 emissions are taken from the EDGAR-HYDE 1.4 data base (EDGAR, 2001), which include the sources fossil fuels, industry and deforestation. Future emissions are based on the country-by-country 1995 emission levels of the EDGAR 3.2 data base applying the emission growth rates of the SRES scenarios to the emissions of individual countries within the respective SRES region or by applying the Kyoto targets. For simplicity we assume that all Annex I Parties reach their Kyoto Targets, which may be an overestimation of the short-term effects of the Kyoto Protocol: The USA has withdrawn from the Kyoto Protocol and US emissions are expected to grow well above their Kyoto target. Eastern European states and the Russian Federation are expected to be well below their Kyoto targets but are not expected to sell large amounts of their excess allowances not to flood the market. Calculations also do not include extra allowances through sinks as negotiated in the Marrakech Accords. We also simplistically assume that each of the SRES scenarios has equal probability of occurring, thus the range of baseline outcomes does not necessarily represent the true range of uncertainty in emissions over this time frame.

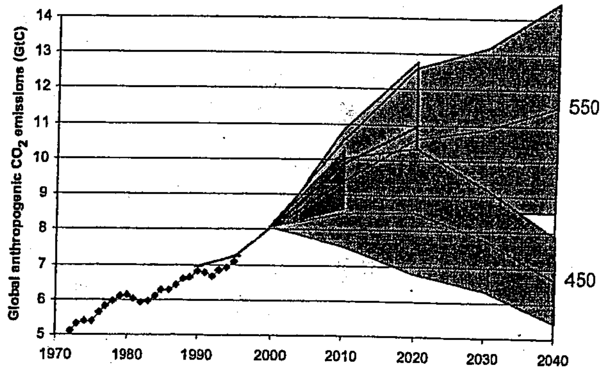

Fig. 6. Possible global CO_2 emission stabilization pathways: 2000–2040. *Note*: Since the post-SRES scenarios (Morita et al., 2001) were not harmonized, absolute global emissions of the scenarios in 1990 and 2000 are not the same for all scenarios. We therefore applied the emission growth rates of the scenarios to the absolute emissions estimated for the year 2000. Included are all post-SRES scenarios except two, whose emissions in 1990 and 2000 deviated completely from these values.

An intermediate global emission target for 2020, from which it would still be possible to reach 450 ppmv CO_2 concentrations could therefore lie in the upper half of the 450 ppmv corridor. Such an intermediate target for 2020 could be defined as lying between 8.5 and 10.5 Gt of carbon per year or +23% to +50% above 1990 levels. If the higher limit of the global target is met, 450 ppm CO_2 concentration can be reached but would require substantial decrease in emissions in the years following 2020 (e.g. a decrease in global emissions by 3% per year over a period of 20 years to 2040). If the lower limit is met, reaching 450 ppmv CO_2 concentration would require a less rapid decrease in emissions in the following years (e.g. decrease in global emissions by 2% per year over the period to 2040).[15]

We can assume that, if global CO_2 emissions are above this intermediate target in 2020 (above 10.5 Gt C), a 450 ppmv CO_2 concentration will be virtually out of reach. As more than half of the SRES range for 2020 lies above the range of this intermediate target, one can conclude that if no efforts to reduce emissions are made, and if the Kyoto Protocol is not implemented, there is a significant chance that the option of 450 ppmv CO_2 would be out of reach already as of 2020.[16]

These intermediate targets are only based on considerations of the most important greenhouse gas (CO_2) and take into account other GHGs only by looking at how concentrations of CO_2 link to changes in GMT. Stabilisation scenarios considering all greenhouse gases are rare in the literature (Hourcade et al., 2001). In assessing emission pathways to stabilise climate, however, other greenhouse gases are also important. Non-CO_2 emissions are a significant part of the Kyoto basket, even more so for Non-Annex I countries. In addition, non-CO_2 gases provide some low cost reduction options (Burniaux, 2000; Reilly et al., 1999). For simplicity, we assume that for a given concentration level, emissions of the non-CO_2 gases need to be reduced with the same percentage as the CO_2 emissions. Hence, the range in 2020 for an intermediate target for all greenhouse gases should be +23% to +50% above 1990 levels (11.8–14.4 Gt C eq.).[17]

[15] Both 2% and 3% annual decline in emissions represents ambitious rates of reduction especially considering that historical growth in emissions in OECD countries hovers around 2–3% per year. Thus these targets would essentially call for a reversal in emission trends to date requiring significant technical change over the period of the next century.

[16] This first estimation of an intermediate emission target does not take into account the uncertainty in the carbon cycle (see Section 3.3). This could decrease considerably (by one third) the amount of emissions that would be allowed to reach a given concentration level (Cox et al., 2000, see also Section 3.3).

[17] Calculations are based on CO_2, CH_4 and N_2O emissions data from EDGAR (2001).

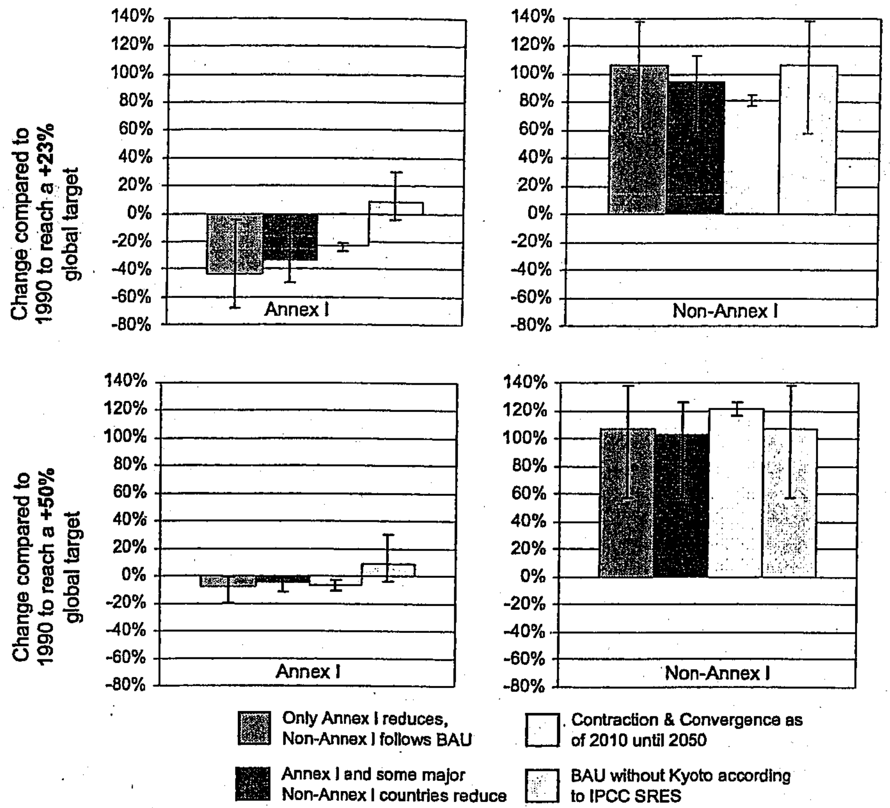

Fig. 7. GHG emissions/targets in 2020 relative to 1990 (=0%): Annex I versus Non-Annex I countries under different allowance sharing proposals and different global targets. *Note*: Calculations include CO_2, CH_4 and N_2O from EDGAR (2001) aggregated using 1995 GWPs. The ranges shown as error bars arise from using different IPCC SRES baseline scenarios. The point estimates are the averages of the results using all scenarios.

4.2. Emission allowances for Annex I and Non-Annex I countries

From a large variety of available options (Berk and den Elzen, 2001; Höhne et al., 2003) we selected three different ways to share this global emission budget among countries to test this intermediate global emission target[18]:

1. *Status quo*: Annex I countries are assumed to have emission targets and reduce emissions and Non-Annex I countries are assumed not to have an emissions target and follow their SRES baseline.
2. *Increasing participation*: Some Non-Annex I countries join the group of reducing countries, receive a target and divert from their SRES baseline, together with today's Annex I countries. The other Non-Annex I countries are assumed not to have an emissions target and follow their SRES baseline. Selection of the reducing countries is based on a GDP per capita threshold of 12,000 US$ in 2010 for illustrative purposes and includes here Argentina, Persian Gulf states, South Korea and Singapore. These countries are assumed to reduce with the same percentage as other Annex I countries.
3. *Contraction and convergence*: All countries are assumed to have targets, where per-capita emissions converge under a global emission ceiling. The proportions for countries of their emission allowances per capita are assumed to converge from 2010 to 2050. The absolute level of the emission allowances of countries is "tuned" so that in a given year, a certain global total is met (here +23% and +50% in 2020 compared to 1990).

[18]Though much of the preceding discussion focuses on avoided impacts, the "allocation" of responsibility for mitigation cannot be arrived at from the point of view of avoided impacts. Amongst others, the costs of mitigation can inform this discussion (see below).

Fig. 7 shows the results of sharing the more stringent limit of the intermediate global emission target (+23% above 1990 levels for 2020, top two diagrams) and the less stringent limit of the intermediate global emission target (+50% above 1990 levels for 2020, bottom two diagrams) among the current groupings of Annex I and Non-Annex I countries using these three approaches. Calculations include CO_2, CH_4 and N_2O from the same sources as in the previous section. The ranges shown as error bars arise from using different IPCC SRES baseline scenarios.[19] The diagrams always show the baseline range according to the IPCC SRES baseline scenarios as the last column.

For the first case, Non-Annex I countries are assumed to have no targets and always follow their baseline path, the first and the last bar in the diagrams on the right are the same. Annex I countries have to ensure through reductions that the global target is met. For the more stringent limit of the global target (+23%), Annex I countries have to reduce emissions by roughly 50% (between 5% and 70%) by 2020 compared to 1990, which would imply unprecedented rates of technical change as well as high costs for these Annex I economies. To achieve the less stringent limit of the global target (+50%), Annex I countries emission have to be between 0% and −20% below 1990 levels in 2020, which is clearly a more realistic case.

In the second case, some Non-Annex I countries are assumed to have a target with fewer allowances than under their baseline scenario. As one expects, the burden is shifted towards the Non-Annex I countries and Annex I countries have to reduce less than in the first case.

In the third case, all countries are responsible for meeting the global target. For the more stringent limit of the global target (+23%), Annex I countries' allowances would be roughly 25% below 1990 emission levels in 2020, Non-Annex I countries' emissions allowances would be somewhat lower than most of the SRES baseline scenarios. The less stringent limit of the global target for 2020 (+50%) is higher than global emissions in 2020 under half of the model runs of the SRES baseline scenarios. Thus distributing all emission allowances for this target creates "hot air" (more allowances than needed), if emissions were to develop according to those low SRES scenarios. Annex I countries' allowances are roughly 10% below 1990 emission levels and Non-Annex I emission allowances would be above their baseline level for most SRES scenarios but would be below their baseline level for some of the highest emission scenarios. For the middle of the global target (e.g. +35%), half of the SRES baseline range is above and half below the emission allowances for Non-Annex I countries.

In all cases, the use of emissions trading would help to equalise the widely different marginal abatement costs across participating countries and emission sources. Converging per-capita emissions, is often described as stimulating large flows of resource from North to the South. In this case with a relatively ambitious intermediate target, the flows of resources from the North to the South would be relatively limited as only some Non-Annex I countries would have emission allowances to sell if they make no efforts to reduce emissions. If some developing countries start to reduce emissions below base levels from today, they could of course sell more allowances to Annex I countries.[20]

Under relatively stringent intermediate targets, contraction and convergence turns out to be beneficial for Annex I countries, as it requires those Non-Annex I countries that have relatively high per-capita emissions to reduce their emissions below possible baselines at a very early stage. Assigning targets for 2020 using contraction and convergence, based on the mid-point of the intermediate target proposed here, could be an interesting way forward as it would give Non-Annex I countries the convergence of per-capita emissions that they often called for. At the same time, it would give Annex I countries the early participation of developing countries that they often called for.

5. Assessing the costs of climate change mitigation strategies and trade-offs with benefits

Of course, the benefits of more aggressive, risk-averse mitigation objectives must also be balanced against the cost of that action taking into account uncertainty. The foregoing discussion reviews recent development in the impacts literature as it relates to the "five areas of concern" outlined in the IPCC's Third Assessment Report. But what do we know about mitigation costs?

The IPCC TAR points out that level of stabilisation and the timing of emission reductions is expected significantly to influence the marginal and absolute costs of mitigation. Many studies of the cost of mitigation exist (for surveys see Weyant and Hill, 1999; Hourcade et al., 2001) though often they focus on nearer-term rather than longer-term mitigation strategies. OECD (1999) found that the method of allocation of emission allowances influenced aggregate costs less than the timing of abatement and level of stabilisation target. The availability of emission trading as a means to "reallocate" the costs of required abatement can also significantly influence costs. Hourcade et al., (2001) concluded that costs of mitigation jump dramatically for scenarios that stabilise at 450 ppmv CO_2 compared to 550 ppmv, due in large part to the required early timing of abatement,[21] however

[19] For simplicity we assume that the SRES scenarios have equal probability of occurring. For other weightings see Webster et al. (2003).

[20] These results are consistent with recent analyses suggesting that per capita emission allocations may or may not be advantageous for some of the largest and rapidly developing countries and with the economic outcomes dependent on the details of implementation including timing and conditions for trade (Leimbach, 2002; Gupta, 2003).

[21] Presented as present value discounted at 5% per year for the period 1990–2100.

they also found that costs depend significantly on the assumed baseline.[22]

An alternative view on global costs is provided by Roehrl and Riahi (2000) who look at the total investment costs of the energy system. For scenarios of similar demographic and economic development within the IPCC SRES framework, they consider a wide range of possible technological developments and therefore a wide range of emissions. On the extremes, the A1T scenario would lead to 550 ppmv CO_2 in 2100 and the A1C scenario to 950 ppmv. Roehrl and Riahi calculate the cumulative discounted investment costs for the energy system, including investment, fixed and variable maintenance cost, excluding investments in research and development. For the A1T scenario leading to 550 ppmv, cumulative investment costs are only half of those of the A1C scenario leading to 950 ppmv. Their conclusion is that looking at the total energy system, efficient use of energy pays off in low energy fuel costs in the long run.

Azar and Schneider (2002) also suggest that mitigation costs need to be compared to expected growth rather than being presented simply as discounted, present value sums for the period to 2100. As the economy is expected to grow substantially to 2100, they note that estimated mitigation costs are relatively small when compared to the increase in welfare in this period. For example, the IPCC (2001c) reports on studies showing mitigation costs of up to 4% in GDP (upper bound) in 2050 for stabilisation at 450 ppm, while these studies also assume GDP growth rate of 2–3% per year. According to Azar and Schneider (2002), even the "worst case" loss of 4% would be overtaken in a few years, slightly delaying (rather than surpressing) impressive economic growth in this century.

The numerical estimates from modelling studies remain uncertain. They are therefore not of as much interest as the underlying relationships between various drivers and assumptions and future emissions. A robust result appears to be that any decision to achieve low stabilisation levels will require significant emission reductions in the near-term and this carries potentially high *economic* stakes in absolute and marginal terms (OECD, 2001a,b; OECD, 1999; IPCC, 2001c). When looking at the pattern of mitigation costs over time, delayed mitigation might appear to be justified (Wigley et al., 1996), yet the trade-offs between avoided costs of mitigation and avoided impacts or damages are not well understood (IPCC, 2001d). Delay in global mitigation efforts could preclude the achievement of stricter long-term climate targets. This paper argues that more needs to be known about the risks of climate change over the long-term before deciding to significantly delay mitigation, which could inevitably leave a legacy of climate change for future generations to deal with (see also Box 1).

[22] Baseline assumptions are of course also an important determinant of avoided impacts.

6. Conclusions

International negotiations under the UN Framework Convention on Climate Change could take several different approaches to advance future mitigation commitments to achieve the long-term objective of the Convention (Article 2). Options range from trying to reach consensus on specific long-term atmospheric concentration targets (e.g. 550 ppmv) to simply ignoring this contentious issue and focusing instead on what can be done in the nearer term. This paper argues for a strategy that lies between these two extremes.

Analysis and debate about the long-term implications of climate change can provide a means to explore common interests among those engaged in international climate negotiations. This includes common concerns about the impacts of climate change as well as concerns about equity and the costs of climate mitigation.

Building on the IPCC's "five areas of concern", (Smith et al., 2001) benchmark indicators of risk for each area could be developed, most likely drawing on local and regional climate impact information. In turn these could be used to guide policy decisions about desirable global emission objectives in the long-term. While significant data gaps prevent the rigorous development of such indicators and their use in decisions today, there is significant scope for research to improve the availability of such indicators to guide tomorrow's decisions. Such indicators may point the way to agreement on long-term objectives, which once acknowledged internationally, can be used to provide medium term or intermediate global emission targets to guide decisions about future mitigation commitments.

We have provided a quantitative intermediate global emission target for 2020 that keeps open the option to stabilise CO_2 at 450 ppmv (around 550 CO_2 equivalent) and thus limit the equilibrium increase in global mean temperature to below 3–4°C in the very long term. Although developed countries bear most responsibility for historical emissions and observed changes in climate, they cannot, through reducing their emissions alone, keep low concentration levels within reach. Leaving open the possibility of achieving 450 ppmv CO_2 in the long-term will require emissions in some developing countries to be below their assumed baseline levels in the 2020 time frame. Alternatively, if no efforts to reduce emissions in the coming decade are made and if the Kyoto Protocol is not implemented, there is a significant chance that the option of 450 ppmv CO_2 will be out of reach as of 2020.

The strong connection between long-term climate impacts and medium-term emission levels argues for taking long-term risks into account in the design of post-Kyoto mitigation commitments. Some authors note that this perspective highlights the ethical dimension implicit in today's climate policy decisions (Azar, 1998; Jaeger, 1998). Such an ethical dimension is common in other policy domains, for example in laws and norms protecting children's rights and preventing child labour, or in implementing minimum wages for all. Thus long-term climate policy requires integrating scientific information, socio-economic assessments and ethical judgements to determine just how risk-averse today's society chooses to be on behalf of future generations. Future climate negotiations could usefully acknowledge and agree to manage certain types of risks in a particular manner, at least until better information is available to support subsequent decisions. It requires careful assessment and collective decisions about the types of risks involved in climate change, about those that are acceptable and those that are not.

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