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Interim Report **IR-08-034**

The Kyoto Policy Process in Perspective: Long-term Concentration Targets versus Short-term Emission Commitments

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Foreword

This is the third IIASA Interim Report written by Andriy Bun during his participation in IIASA's Young Scientists Summer Program (YSSP) in 2006. In contrast to Bun's other two reports (coauthored with Matthias Jonas; IR-06-053 and IR-06-054), which are physically and mathematically well grounded, this report is meant to expand on the two initial Interim Reports but to take on the form of a vision paper.

In his three Interim Reports, Bun focuses on the detection of uncertain net greenhouse gas (GHG) emission changes under the Kyoto Protocol. Uncertainty always comes in as true emissions are unknown. Typically, only best estimates are available for emissions of whole countries, which are the principal units for reporting emissions and removals under the Protocol.

In IR-06-053 and IR-06-054 Bun applies a selected preparatory signal detection (SD) technique to assess the emission changes (termed emission signals) reported by the Member States of the European Union and to monitor their emissions reduction performance since 1990 more appropriately than done so far, that is, in an 'emissions change-versus-uncertainty' context instead of an 'emissions change-only' context.

Preparatory SD allows generating useful information beforehand as to how great uncertainties can be depending on the level of confidence of the emission signal, or the signal one wishes to detect, and the risk one is willing to tolerate in not meeting an agreed-upon emission limitation or reduction commitment. It is generally assumed that the emissions path between base year and commitment year/period is a straight line or of low dynamical order (i.e., historical emissions are typically not taken into consideration). Preparatory SD can be kept highly flexible so as to meet a number of conditions ranging from SD quality (defined adjustments, statistical significance, detectability, etc.) to the way uncertainty is addressed (if, in fact, any way is to be addressed: trend uncertainty or total uncertainty). It is this knowledge of the required quality of reporting vis-à-vis its underlying uncertainty that one wishes to have at hand before negotiating international environmental treaties such as the (post-) Kyoto Protocol. In addition, preparatory SD exhibits another useful asset: it can also be used to monitor the success of a country in reducing its emissions along a prescribed (usually linear) emissions target path between its base year and the commitment year/period, which opens up a range of policy-relevant applications.

It is the first characteristic, that Bun takes advantage of in this Interim Report. He transfers the idea of preparatory SD to 'post-Kyoto', i.e., to the ongoing discussion on bridging short-term emission commitments with long-term concentration targets by introducing mid-term emission windows. Bun convincingly argues that preparatory SD can help adjust these allowable windows to make sure that they compensate for not, or only inaccurately, knowing true emissions. Not considering this uncertainty can result in excluding low concentration targets in the long-term; that is, climate stabilization at a level that is not dangerous.

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Abstract

Greenhouse gas emissions are believed to be the main reason of climate change. Thus, it is essential to limit and reduce emissions of greenhouse gases in order to stabilize climate. Short-term policies such as the Kyoto Protocol stipulate emission limitation or reduction commitments. However, it is also, if not more, important to keep an eye on the long-term effects of these policies since it takes decades to centuries to manifest the consequences of greenhouse gas emissions. And vice versa: it is a problem to translate long-term targets to near-term commitments that will allow reaching the given target.

This study is meant to serve as a vision paper. Building upon the preparatory detection of emission changes (emission signals) under the Kyoto Protocol, it addresses the problem of correcting allowable mid-term emission windows that have been suggested to link short-term emission commitments with long-term concentration targets. Correction of the emission windows accounts for our inappropriate knowledge of emissions at the scale of countries and the risk that true (unknown) emissions can exceed observed emissions. Not considering this risk can result in excluding low concentration targets in the long-term; that is, climate stabilization at a level that is not dangerous.

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About the Author

Andriy Bun graduated from Lviv National Polytechnic University, Ukraine with B.Sc in Applied Mathematics in 2005. He is currently a Master's degree student at the same university. This study is the third result of his participation in IIASA's 2006 Young Scientist Summer Program under the supervision of Matthias Jonas of the Forestry Program.

The Kyoto Policy Process in Perspective: Long-term ConcentrationTargets versus Short-term Emission Commitments

Andriy Bun

1 Introduction

The global average surface temperature has increased since 1861. Over the 20th century (1901–2000) the increase has been 0.6 ± 0.2ºC (IPCC, 2001c: p.2).[1] The prevailing scientific opinion for the reasons of this phenomenon, called global warming, is that it is the consequence of the greenhouse effect. Increasing concentrations of CO_2 and other greenhouse gases (GHGs) enhance the human-induced component of the greenhouse effect.

Global warming can have a significant impact for both the environment and human life. These effects include the rise in sea levels, impacts on agriculture, and the spread of diseases. In some cases, the effects may already be experienced, although it is difficult to attribute specific natural phenomena to long-term global warming.

There are also some speculations that global warming can influence oceans currents. In particular, this would affect regions such as Scandinavia and Great Britain that are warmed by the North Atlantic drift.

Another serious impact of global warming may be increased intensity and frequency of extreme weather events. These are weather events that are, by definition, less likely to occur (such as heat waves, droughts and flooding). Small changes in climate may have a large impact on the probability distribution of weather events in space, time, and on the intensity of extremes (IPCC, 2001a: p.92).[2]

Apart from the influence on the environment climate change will have financial implications (Stern, 2006). For example, annual losses from the three major storm types affecting insurance markets (US hurricanes, Japanese typhoons, and European windstorms) could increase by two-thirds to $27 billion (bn) by the 2080s (ABI, 2005).

Actions need to be taken to reduce the extent and likelihood of global warming and its consequences. However, it is essential to set targets before taking decisions and measures. When adopting appropriate policies, it is essential to take into account the heterogeneity of the sensitivity of different regions to climate change. Developing countries are usually more vulnerable.

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[1] For 1906-20095 the temperature increase is 0.74 ± 0.18ºC according to the IPCC (2007a: p.30).

[2] See also IPCC (2007b: p.17).

The long-term objective of the United Nations Framework Convention on Climate Change (UNFCCC, 1992) is to achieve the "… 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).

However, the UNFCCC does not contain any specific targets in terms of GHG emissions and/or concentrations. Thus, it is crucial to agree upon a concrete long-term concentration target and to carry out a short-term emission policy, aiming at reaching this target. The problem arises when trying to translate long-term concentration targets to near-term emission commitments. An example of such a short-term policy is the Kyoto Protocol. However, the Kyoto process has one serious weakness as it has been focused on the short-term without rigorously factoring in targets to achieve in the long-term. This is an urgent issue and can not be postponed for too long.

The present study deals with the issue of linking long-term concentration targets with short-term emission commitments. An overview of progress in this direction and some results are presented in Section 2. Some difficulties that have been met so far and potential implications are discussed in Section 3. Some proposals for future research are presented in Sections 4 and 5.

2 Background

2.1 Emission and Concentration Scenarios

Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. A set of scenarios assists in the understanding of possible future developments of complex systems (IPCC, 2000: Section 1.2).

Future GHG emissions are the outputs of a complicated system that depends on parameters such as demographics, economics, and technological development. GHG emission scenarios are usually based on assumptions about these parameters and relationships between them.

At present, emission scenarios, published in the Special Report on Emission Scenarios (SRES; IPCC, 2000) called post-SRES scenarios, are widely used, e.g., in global circulation models to derive climate change scenarios. However, there are a large number of such scenarios, hence often only several of the most illustrative scenarios are used. Characteristics of three such "baseline" scenarios in comparison with the historical development are presented in Table 1. It is necessary to note that one scenario (labeled "revised SRES A2" scenario or "A2r"), while maintaining its main structural and qualitative characteristics, represents a major numerical revision (Riahi *et al.*, 2006), which reflects the most recent long-term demographic outlook with a corresponding lowering of future world population growth.

Table 1: “Baseline” scenario characteristics in comparison to 2000. Source: Riahi and Keppo (2006).

Year		**2000**	**2100**		
	Units		**A2r**	**B2**	**B1**
Energy demand	EJ	290	1250	950	800
Technological change	1	–	Low	Medium	High
Energy intensity impr.	%/year	–0.7[a]	–0.6	–1.2	–1.7
Carbon intensity impr.	%/year	–0.3[a]	–0.3	–0.6	–1.5
Fossil energy	EJ	340	1180	690	340
Non-fossil energy	EJ	95	1080	1050	1160
Emissions (Energy)	GtC	7	27	16	6
Atmospheric GHG concentrations	ppmv (CO_2 eqiuv.)	370	1390	980	790
Stabilization levels	ppmv (CO_2 eqiuv.)	–	1090–670	670–520	670–480

[a] Historical development since 1850.

Most studies of possible policy pathways have focused on stabilization of CO_2 concentration alone, since CO_2 has been and will continue to be the primary cause of anthropogenic climate change (Wigley, 2003: p.10).

The concentration profiles can be used to calculate emissions that will lead to a certain concentration stabilization target and in reverse order. Emission data are used as input to economical models to compute the costs of a certain policy.

2.2 Long-term and Short/Medium-term: Temporal Scales

Figure 1 represents possible pathways of reaching the long-term objective stated in Article 2 of the UNFCCC.

According to different scenarios, CO_2 emissions will peak before the end of the 21st century and will decline thereafter. This will eventually lead to stabilized CO_2 concentrations within the next 100–300 years at different levels. In the future, global mean temperatures are expected to stabilize. Furthermore, stabilizing CO_2 concentrations requires significant emissions reductions with respect to current levels, the sooner the better. As Figure 1 indicates, if short-term emissions exceed a certain level, stabilization in the long-term perspective may be unattainable (e.g., A2 scenarios).

Thus, a relative change in global mean temperatures will depend, in many respects, on the CO_2 emissions during the next few decades. This clearly requires setting limitations on short-term emissions or reduction commitments. Thus, the problem is how to ‘translate’ long-term (here) concentration targets to near-term emission commitments for Annex I and non-Annex I countries.

For CO_2, a widely-used set of CO_2 concentration stabilization pathways (or “profiles”) has been devised by Wigley *et al.* (1996). These profiles, commonly referred to as WRE (Wigley, Richels and Edmonds), are represented in Figure 1(b). It is obvious that each long-term target can be reached by more than one pathway, thus when passing short-term emission allowances, policy makers need to take into account different factors such as cost efficiency.

Moreover it is important to notice that:

- It takes some time for global GHG concentrations and climate change to manifest themselves; and
- Global mean temperatures and the rise in sea levels will be observed a long time after GHG concentrations are stabilized.

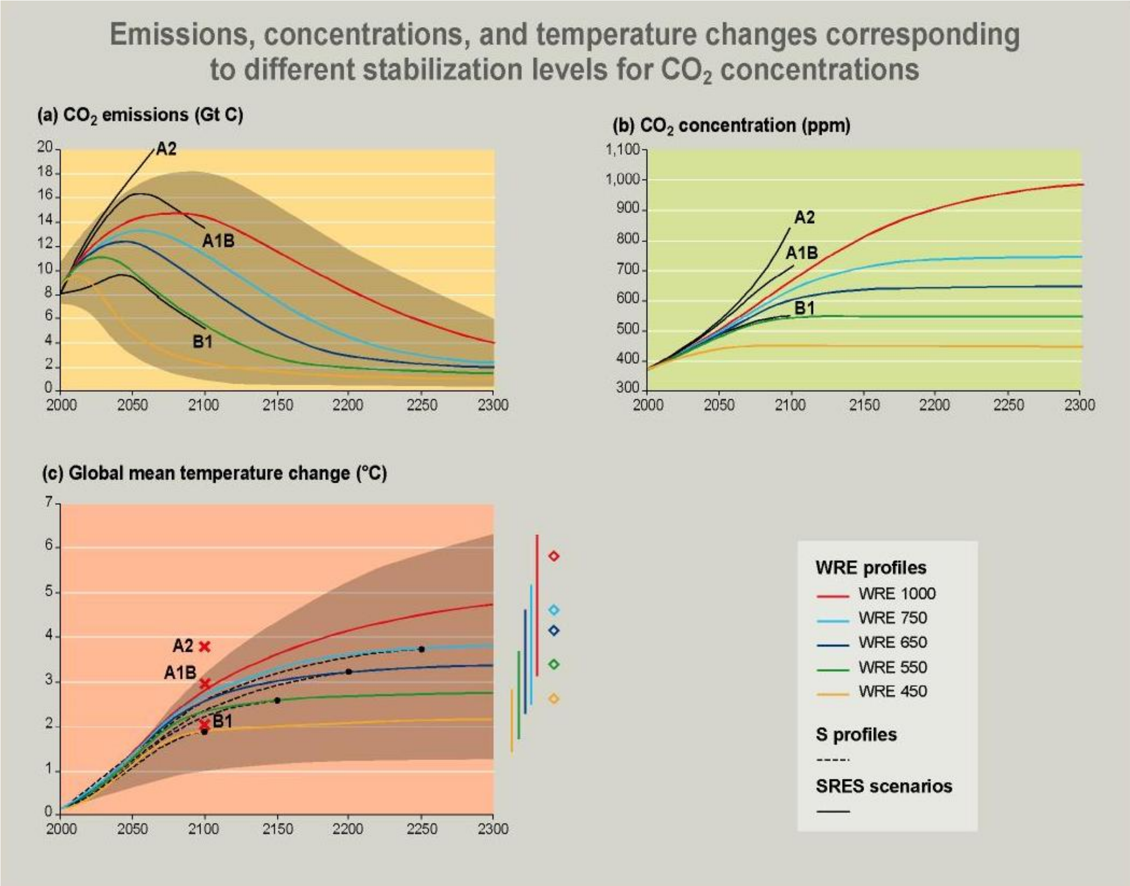

Figure 1: Stabilization pathways. Source: IPCC (2001c: Figure SPM-6). See also IPCC (2007b: Figure 5.1).

2.3 Modeling Framework

The climate system can be represented by models of varying complexity, i.e., for any one component of the climate system a hierarchy of models can be identified. The main differences between models within a given hierarchy are (IPCC, 1997: p.3):

- *the number of spatial dimensions of the model*;
- *the extent to which physical processes are explicitly represented*;
- *the level at which empirical parameterizations are involved*; and
- *the computational costs of running the model*.

The last characteristic is often the crucial one because simple climate models (SCMs) are computationally more efficient than more complex models. These models can be used to investigate future climate change in response to a large number of different scenarios of future GHG emissions. More complex models (atmosphere-ocean general circulation models) cannot be used for such scenario analyses. However, they can be used to study a certain scenario in greater detail.

The SCMs are used for translating future emissions trends (e.g., Figure 1(a)) to changes in the atmospheric composition (e.g., Figure 1(b)), which are later used for calculating the radiative forcing resulting from the computed GHG concentrations; the global mean temperature response (e.g., Figure 1(c)) to the computed radiative forcing; and the sea level rise due to thermal expansion of sea water and the response of glaciers and ice sheets as well as the other risks of temperature increase. The structure of such calculations is illustrated in Figure 2.

Such models can also be used in reverse order to determine the pathways needed to obtain certain concentration levels or a certain global mean temperature change.

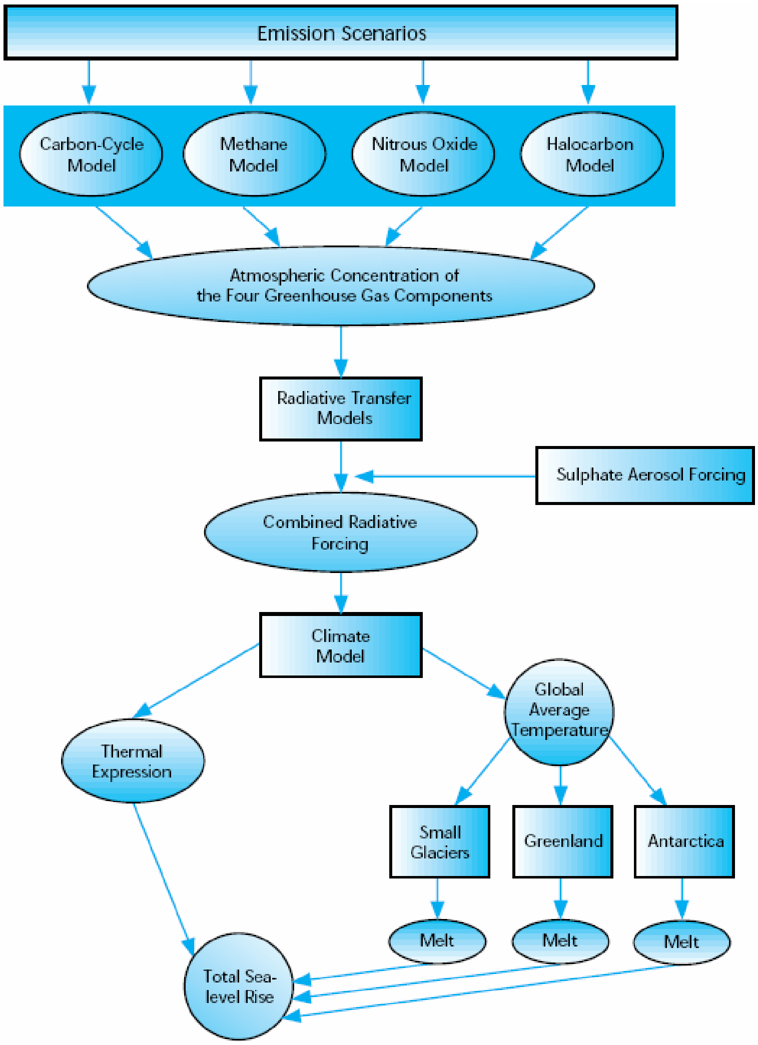

Figure 2: Steps involved in calculating GHG and aerosol concentration changes, climatic change, and sea level rise using simple climate models. Source: IPCC (1997: Figure 4).

3 Challenges

It is important to identify a long-term (here) concentration target that will "prevent dangerous anthropogenic interference with the climate system". Policy makers interpret this objective differently, especially the phrase "dangerous interference", since countries differ in the way that they are vulnerable to a climatic change. Thus, suggestions on the stabilization target and its pathway should contain possible impacts of such policies on the climate system. On the other hand, this analysis must consider costs and benefits so we can commit ourselves to reductions levels that are in agreement, to the extent possible, with economic development.

At its present state, science offers a multitude of mitigation scenarios. Hence, a certain long-term target can be reached by a number of different pathways. This, in turn, means that this target can be achieved under different regimes of short-term commitments.

All climate models have inherent uncertainties and they need to be taken into account when planning climate change mitigation and adaptation strategies.

There are different kinds of uncertainties in the projections of global mean temperature and GHG concentrations:

- *Ocean mixing and aerosol forcing uncertainties;*
- *Carbon cycle uncertainties;*
- *Emissions uncertainties; and*
- *Climate sensitivity uncertainties*.

These uncertainties and their influence on total uncertainties of the climate change projections are described in more detail by Wigley (2003: Section 4).

4 Existing Results/Suggestions

In the previous section, we emphasized the importance to agree on a long-term concentration target that is believed to satisfy Article 2 of the UNFCCC as well as on near-term emission commitments that will allow reaching this target. In this section, we follow up the idea of allowable emission windows, which are defined by excluding undesired emission paths. For instance, if we continue in a business-as-usual way, a low concentration target of 450 ppmv will be out of reach already in 2020.

This is at the core of an approach suggested recently (IPCC, 2001b: Figure 10.1; Corfee-Morlot and Höhne, 2003). The IPCC, e.g., makes use of the study by Ha-Duong *et al*. (1997) and suggests a least-cost emissions pathway given an uncertain concentration target. This analysis identifies an optimal strategy which requires a long-term target decision only in 2020 (Figure 3). However, this strategy is not a "get out of jail free card". It still requires the implementation of an emission policy prior to 2020 that will not prevent achieving the lower (450 ppmv) target in the long-term.

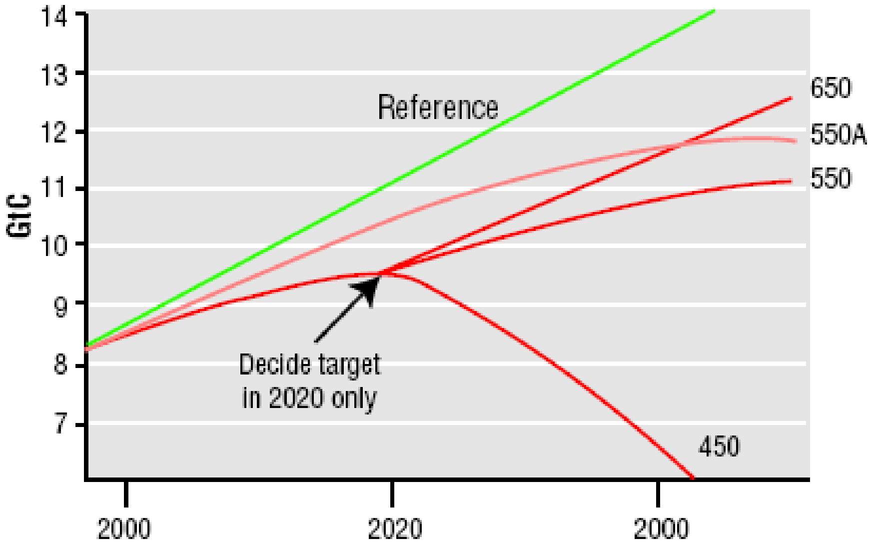

Figure 3: Optimal carbon dioxide emissions strategy, using a cost-effectiveness approach. Source: IPCC (2001b: Figure 10.1).

A similar approach is examined in the study by Corfee-Morlot and Höhne (2003). The authors consider global emission targets for 2020, which will still allow reaching a lower (450 ppmv) CO_2 concentration target in the long-term.

Figure 4 (a) shows the range of global CO_2 emissions, according to the SRES baselines. The figure also shows the range of global CO_2 emissions under the assumption that the Kyoto Protocol is implemented by all Annex I countries. Figure 4 (b) shows the resulting range of possible global CO_2 emission pathways that lead to different concentration levels (here: 450 and 550 ppmv), taken from the post-SRES mitigation scenarios. The spread of emission paths that lead to the same concentration levels is large.

Thus, a target for 2020, from which it will still be possible to reach the lower, 450 ppmv, CO_2 concentration target can be defined as falling between 8.5 and 10.5 Gt of carbon per year or between +23% and +50% above 1990 levels.

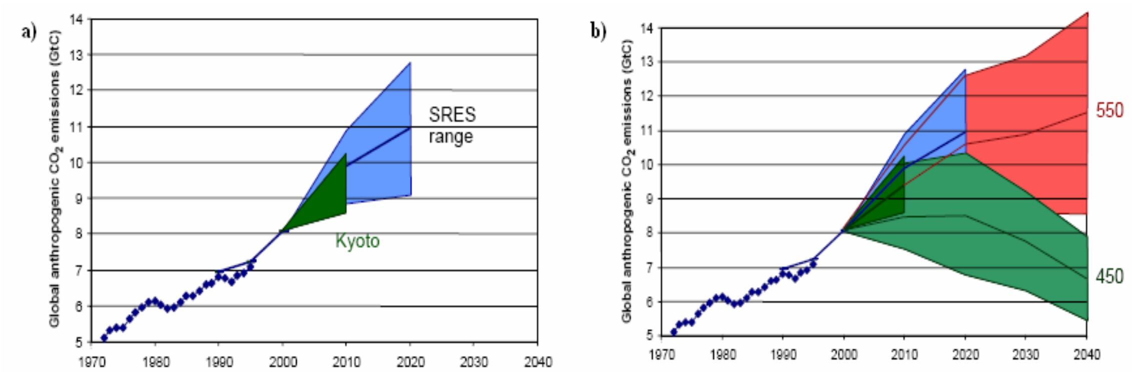

Figure 4: Possible global CO_2 emission pathways a) 2000–2020; b) 2000–2040. Source: Corfee-Morlot and Höhne (2003: Figures 5 and 6).

As a result of these calculations, emission allowances for Annex I and non-Annex I countries are derived (Figure 5). Such allowances are computed under three different assumptions on how targets are shared between Annex I and non-Annex I countries:

1. Status quo: Annex I countries are assumed to have emission targets and reduce emissions, while non-Annex I countries are assumed to not have emission commitments but follow SRES baseline emissions.
2. Increasing participation: Some major non-Annex I countries join the group of countries that reduce emissions and accept the long-term target. The remaining non-Annex I countries are assumed to not have emission commitments but follow SRES baseline emissions.
3. Contraction and convergence: All countries are assumed to have emission commitments.

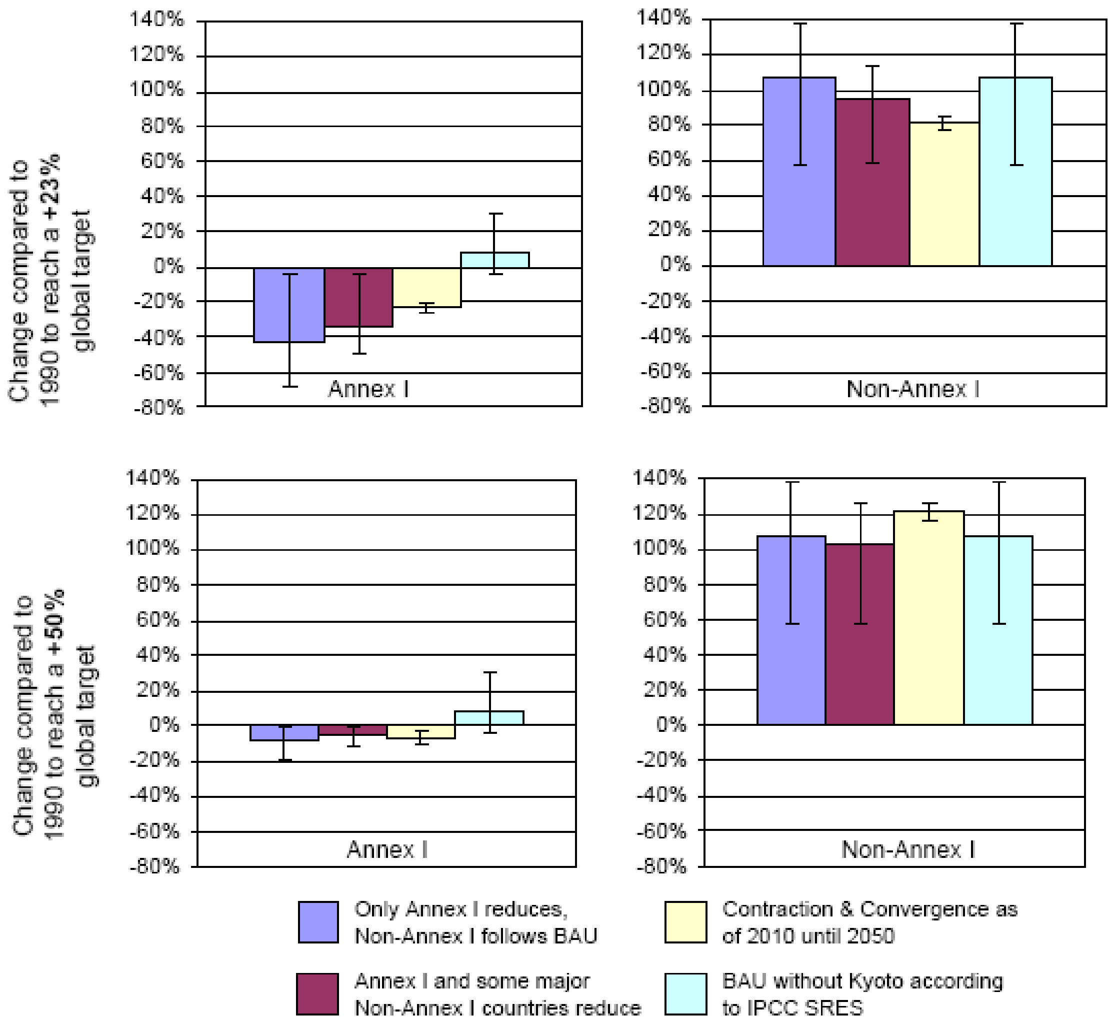

Figure 5: Emission limitation and reduction commitments for Annex I and non-Annex I Parties. Source: Corfee-Morlot and Höhne (2003: Figure 7).

The ranges in Figure 5, shown as error bars, arise from using different IPCC SRES scenarios. The spread of paths that lead to the same concentration levels is large. The mean emissions estimates are the averages over all emission scenarios. For simplicity, it is assumed that the SRES scenarios exhibit equal probability of occurrence. The baseline range according to the IPCC SRES baseline scenarios is shown as the last column.

5 What Can Be Done

In the previous sections we have recalled where discussions on linking long-term concentration targets with short-term emission commitments currently stand. However, even if using such an approach is agreed upon in future post-Kyoto negotiations, an additional problem will arise: *how to take into account uncertainties that underlie the emissions estimates reported by countries*? This uncertainty matters. If emissions do not undershoot a commitment by a certain level, as shown in Figure 6, a risk remains of not meeting this commitment. Hence, the risk exists of not reaching low long-term concentration targets; these get out of reach which, in turn, can seriously influence the Earth's climate.

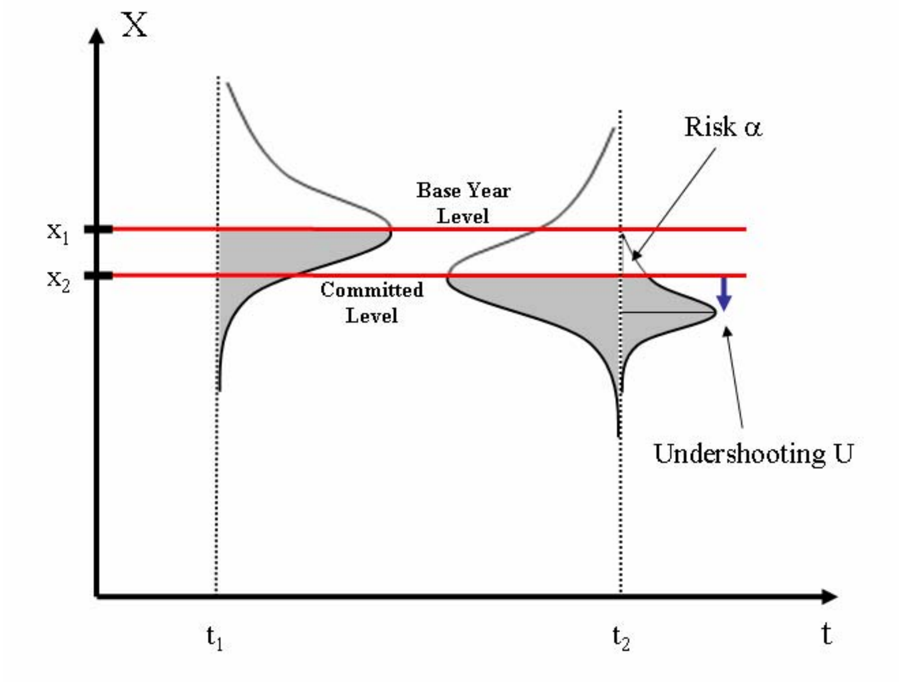

Figure 6: Undershooting concept (case of emission reduction). Source: Jonas *et al.* (2007: Figure 3).

If a global target for 2020 has been agreed with individual commitments for countries, there is a need to take into account uncertainties of emission estimates to decrease the countries' risks of not meeting their commitments. Several approaches have been developed to address this problem. In particular, Jonas *et al.* (2004a) suggested four concepts listed below and Gillenwater *et al.* (2004) suggested two more techniques (for a summary see Jonas *et al*., 2007):

1. Critical relative uncertainty (CRU): The key question is *what are the critical (or maximal relative uncertainties that can be reported by Annex I countries so as to ensure favorable detection in the commitment year?*
2. Verification (better: detection) time concept (VT): The key question is *what are the times until the countries' emission signals outstrip uncertainty and can be detected?*
3. Undershooting concept (Und): The key question is *how much undershooting is required to decrease the risk that countries do not undershoot their true emission limitation or reduction commitments?* This concept is shown in Figure 6.
4. Undershooting and verification time concepts combined (Und & VT): This concept was designed to take advantages of both the VT and Und concepts.
5. Gillenwater—Approach 1: This approach requires adjusting emission estimates so that a reasonable level of confidence can be reached ensuring that actual emissions will not exceed emissions commitments by more than a certain level.
6. Gillenwater—Approach 2: This approach requires adjusting emission estimates so that a reasonable level of confidence can be reached ensuring that actual emissions reductions (increases) will not fall below (above) the committed level of reductions (increases).

The main features of these approaches are compared in Table 2.

Table 2: Characteristics of different techniques of combining uncertainties with emission estimates. Sources: Jonas *et al.* (2004a: Table 3) and Gillenwater *et al.* (2004); see also Jonas *et al.* (2007: Table 2). .

Taken into account by the technique	**Technique**					
	CRU	**VT**	**Und**	**Und&VT**	**App 1**[a]	**App 2**[a]
Trend uncertainty			✓			✓
Total uncertainty	✓	✓		✓	✓	
Intra-systems view			✓			✓
Intra-systems view but suited to support inter-systems (e.g., top-down) view	✓	✓		✓	✓	
Emission gradient between t_1 and t_2		✓		✓		
Detectability of when an emission signal outstrips total uncertainty	✓	✓				
Undershooting			✓	✓		
Upward adjustment of reported emissions					✓	✓
Risk with reference to the concept of significance			✓		✓	✓
Risk with reference to the concept of detectability				✓		

[a] Source: Gillenwater *et al.* (2004).
[b] Risk that the real emission reductions are below a certain level or that emissions are limited that is above the target.

These techniques were designed to address uncertainty in GHG emissions under the Kyoto Protocol. The Und&VT concept is applied to advance the monitoring of the GHG emissions reported by the Member States of the European Union (Jonas *et al.*, 2004b, c; Bun and Jonas, 2006a, b; Hamal and Jonas, 2008a, b). However, all these techniques can be used under any other commitment. The idea that is proposed is to apply any of these techniques to the 2020 commitments or, more generally, the allowable emissions window at the mid-term in order to take into account uncertainties. Applying such a technique will result in a new modified emissions window, which falls below the one suggested by Corfee-Morlot and Höhne (2003) (see Figure 4).

The important point here is that the risk that true (unknown) emissions exceed predefined/committed levels at mid-term can be grasped although the true emissions themselves are unknown. Not considering this risk can result in excluding low concentration targets in the long-term; that is, climate stabilization at a level that is not dangerous.

6 Conclusions

According to different scenarios, GHG concentrations leading to climate change will continue to increase for at least this century. In order to stabilize GHG concentrations and mitigate climate change in the long-term, significant reductions of GHG emissions compared to current levels are needed and the sooner the better. Furthermore, future levels of GHG concentrations and climate change will greatly depend on the emissions in the next few decades. Hence, actions need to be taken in the short-term in order to achieve the long-term climate change mitigation objective stated in Article 2 of the UNFCCC.

However, long-term concentration targets have not yet been linked rigorously to short-term emission commitments. Current discussions focus on the use of intermediate emission targets for 2020 that keep long-term concentration options open. That means that short-term emissions commitments will be set for 2020, while a long-term concentration target will only be chosen in 2020. The country commitments must allow reaching relatively low levels of GHG concentrations in the long-term perspective. Such an approach has been considered by Corfee-Morlot and Höhne (2003).

GHG emission, concentration, and global mean temperature pathways are used for projecting future changes in these parameters. However, these pathways have inherent uncertainties. Thus, some margin must be left when setting the target for 2020 so that uncertainties, described in the Section 3 are taken into account.

However, there is an additional uncertainty that must be considered prior to making post-Kyoto agreements. In this study it is suggested that the uncertainty underlying the GHG emissions estimates of countries must be considered when setting emissions commitments for 2020 in order to decrease the risk that the countries' true (unknown) emissions exceed committed levels. Considering this risk will allow establishing a modified 2020 emissions window, which falls below the one suggested by Corfee-Morlot and Höhne (2003) and which still leaves open the option of reaching low concentration targets in the long-term. Not considering this risk can result in excluding the option of reaching these targets.

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