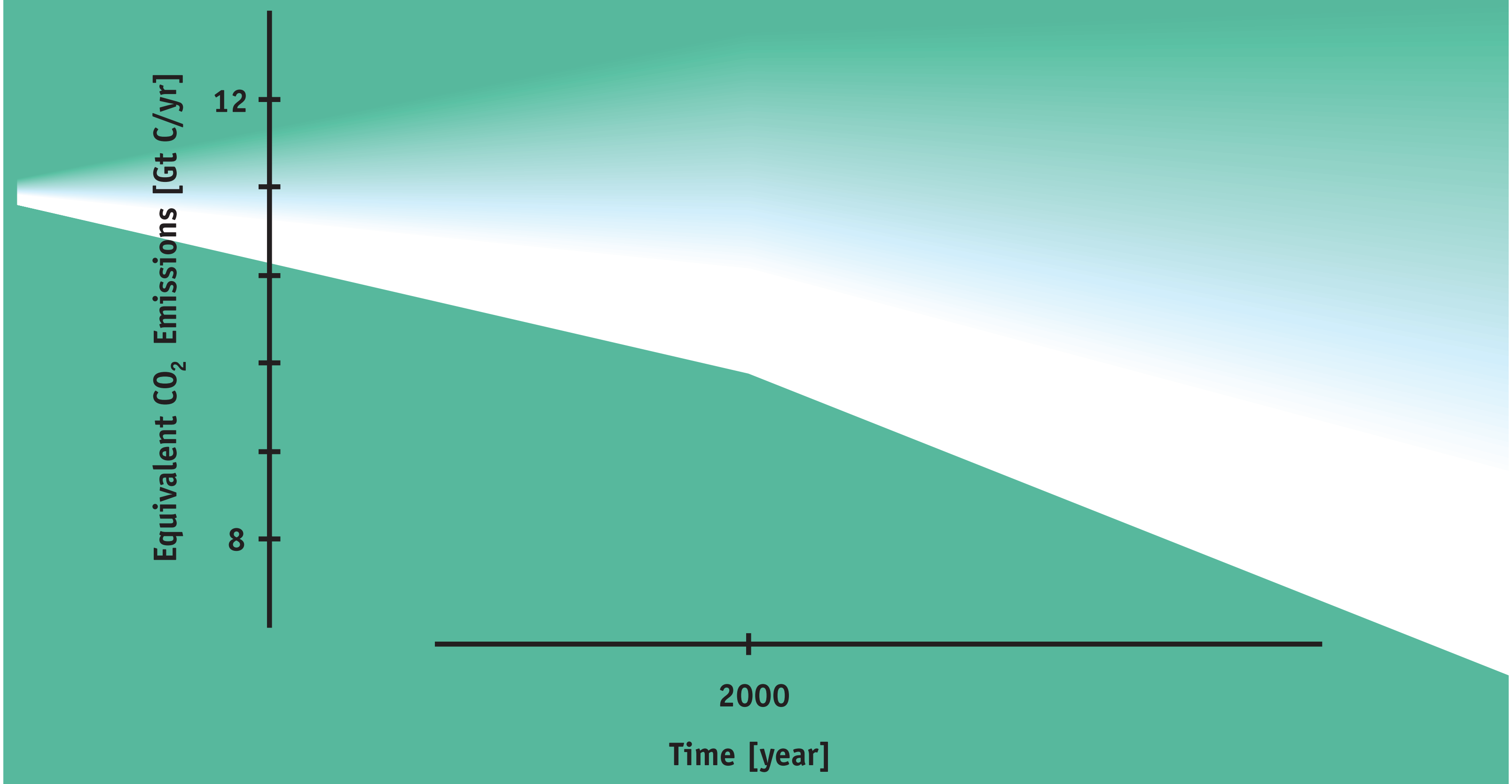
Climate Protocols and Climate Protection:

An evaluation of proposals leading up to Kyoto



Center for Environmental Systems Research,
University of Kassel, Germany

National Institute of Public Health and the Environment,
the Netherlands

Climate Protocols and Climate Protection:
An evaluation of proposals leading up to Kyoto

Joseph Alcamo*, Robert Swart**, Janina Onigkeit*, Marcel Berk**, Eric Kreileman**

** Center for Environmental Systems Research, University of Kassel, Germany*
*** National Institute of Public Health and the Environment (RIVM), the Netherlands*

Prepared as a Background Report for the German and Dutch Delegations
to the Third Session of the Conference of Parties
to the U.N. Framework Convention on Climate Change.
Kyoto, Japan. 1-10 December, 1997.

Center for Environmental Systems Research, University of Kassel, Germany
National Institute of Public Health and the Environment (RIVM), the Netherlands

Report A9703

Center for Environmental Systems Research
University of Kassel
Kurt-Wolters-Straße 3
D-34109 Kassel, Germany
Phone +49.561.804.3266, Fax +49.561.804.7266
cesr@usf.uni-kassel.de, http://www.usf.uni-kassel.de

National Institute of Public Health and the Environment (RIVM)
P.O. Box 1
3720 BA Bilthoven, The Netherlands

Climate Protocols and Climate Protection:

An evaluation of proposals leading up to Kyoto

Joseph Alcamo, Robert Swart, Janina Onigkeit, Marcel Berk, Eric Kreileman

Summary

The aim of this report is to evaluate the consequences of proposed climate protocols on global climate protection. However, the scope of this report is limited to selected protocol proposals and selected consequences. The five protocol proposals examined are: AOSIS, EU, G77/China, Japan, USA. The evaluation consists of an examination of their effects on both emission trends and climate goals.

The global emissions of the five proposals are estimated for year 2010, under three cases of non-Annex I emissions, and then compared to 1990 emissions. Results from these 15 cases are:

- *For the medium and high cases, all protocol proposals have higher global emissions in 2010 than in 1990.*
- *For the low case, the AOSIS proposal is slightly below 1990 emissions, the EU and G77/China proposals are slightly above, and the USA and Japanese proposals are further above the 1990 level.*

For the two protocol proposals that specify climate goals (AOSIS and EU) we compute "safe emission corridors". These are the allowable short term range of emissions that comply with short and long term climate goals.

- *For the AOSIS climate goals (limits of 2.0°C global temperature increase and 20 cm sea level rise between 1990 and 2100) the emissions corridor in 2010 is relatively low and narrow, implying that stringent Annex I emission reductions would be necessary to fall within the corridor in year 2010.*
- *For the EU climate goal (a limit of 2.0°C global temperature increase) a wider and higher corridor is computed. To reach the middle of the corridor, Annex I emissions must be significantly reduced, and to reach the top of the corridor, increases in Annex I emissions are allowed.*
- *The estimates of global emissions from most protocol proposals fall outside of the AOSIS safe emissions corridor. By contrast, all protocol proposals fall within the EU corridor for a range of emission estimates. Hence, in principle, these proposals comply with the long term climate goal of the EU proposal. However, the path of emissions after 2010 is very important, as noted next.*

Although all protocol proposals fall within the EU safe emission corridor in 2010, their ***location within the corridor in 2010*** *has important consequences on Annex I and non-Annex I countries* ***after 2010****:*

- *The higher the global emissions in 2010, the faster they need to be reduced afterwards, leaving less policy flexibility. Put another way, if global emissions are high in the corridor in 2010 then both Annex I and non-Annex countries will have to work harder after 2010 to control emissions in order to achieve long term climate goals such as the temperature limit of the EU protocol proposal.*
- *The lower the emissions in 2010, the more flexibility available to both Annex I and non-Annex countries after 2010. For example, if emissions are low enough in the corridor in 2010 (as in the EU, G77/China, or AOSIS proposals), it may be possible to achieve the long term climate goal of the EU proposal even if non-Annex I emissions* ***continue to increase*** *after 2010.*

Climate Protocols and Climate Protection:

An evaluation of proposals leading up to Kyoto

Joseph Alcamo, Robert Swart, Janina Onigkeit, Marcel Berk, Eric Kreileman

Introduction

As a result of the Berlin Mandate[1] of 1995, negotiations are underway to agree upon a possible protocol to the Framework Convention on Climate Change (hereafter referred to as the "Climate Convention"). Such a protocol may be signed at the Kyoto Climate Summit of 1997. The aim of this report is to evaluate the consequences of proposed climate protocols on global climate protection. However, it is not possible at this time to present a comprehensive evaluation, so this report focuses on a few protocol proposals, and a few aspects of their consequences. We evaluate five proposals: that of the Alliance of Small Island States (AOSIS), the European Union (EU), the G77/ China, Japan, and the United States. Our evaluation concentrates on two important aspects of these proposals – their recommended emission controls, and their recommended climate goals. The evaluation consists of:

- Estimating the trends of emissions up to year 2010 that may result from the different proposals.
- Identifying the allowable short term emissions that comply with long term climate goals specified in the proposals.
- Examining whether the trends of emissions comply with the specified long term climate goals.

What Consequences Do the Proposals Have on Emissions?

We begin by estimating the impact of the proposals on Annex I emissions in year 2010 (Table 1). We use year 2010 as a target year because it is used for this purpose in many proposals. Our assumptions for these calculations are given in Appendix A for the Japan proposal and Table 1 for the rest of the proposals. We note that emissions here and elsewhere in this report are the sum of anthropogenic carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions in units of equivalent CO_2 and reported as Gt C/yr.

We estimate the following reductions of Annex I emissions in 2010 (relative to 1990):

- AOSIS proposal: 25% reduction
- EU proposal: 15% reduction
- G77/China: 15% reduction
- Japanese proposal: 2.4% reduction
- USA proposal: 0% reduction

The global emissions of the proposals are computed by adding an estimate of the non-Annex I emissions to the Annex I emissions in Table 1. For this purpose we assume that non-Annex I emissions will be uncontrolled in 2010, and will follow the scenarios of the Intergovernmental Panel on Climate Change (IPCC, 1992)[2]. For 2010, non-Annex I emissions range from 5.5 to 7.0 Gt C/yr, with a medium estimate of 6.3. Table 2 gives the resulting global emissions. The main points are:

For the medium and high cases, all protocol proposals have global emissions in 2010 that are higher than in 1990.

For the low case, the EU and G77/China proposals are slightly above, and the AOSIS proposal slightly below 1990 emissions. The USA and Japanese proposals are about 1 Gt/yr above the 1990 level

What About Substances Not Covered by Most of the Proposals?

Although several different types of emissions contribute to the greenhouse effect, only CO_2, CH_4 and N_2O, are covered by most protocol proposals. Other substances such as fluorocarbons and precursors of ozone are not covered. In Box 1 we discuss the implications of this omission, called by some a "loophole" in the protocol proposals.

What Consequences Do the Proposals Have on Climate Protection?

Two of the proposals evaluated in this paper, namely the AOSIS and the EU proposals, specify not only emission targets, but also climate goals such as limits on temperature increase and sea level rise. Using a procedure described in Alcamo and Kreileman[3] and Swart , et al.[4], a global model can be used to derive "safe emission corridors" which are the allowable range of emissions over time that comply with long and short term climate goals. In this paper we use the IMAGE 2 model[5] to compute emission corridors, but other models can and have been used for this purpose[6].

A safe emission corridor is computed after setting constraints on four main indicators:

1. Cumulative increase in global average surface temperature in °C (1990-2100).
2. Rate of temperature increase in °C per decade (and the number of decades this rate may be violated).
3. Cumulative increase in global average sea level in cm (1990-2100).
4. Rate of global emission reduction in % per year.

These indicators are related to goals and conditions specified in the Climate Convention. The first two relate to the objectives "to allow ecosystems to adapt naturally to climate change" and "to ensure that food production is not threatened" which are specified in Article 2 of the Convention. The third addresses Section 8 of Article 4 which calls for special consideration of climate impacts

Table 1: Estimates of Annex I Greenhouse Gas Emissions (Units: equivalent CO_2 (Gt C/yr)[1])

	Protocol Proposals			
	USA [2]	**Japan** [3]	**EU & G77/China** [4]	**AOSIS** [5]
1990	5.3	5.3	5.3	5.3
2010	5.3	5.2	4.5	4.0

[1] Anthropogenic CO_2, N_2O and CH_4 emissions. GWP factors: $N_2O = 320 \frac{\text{kg } CO_2}{\text{kg } N_2O}$; $CH_4 = 24.5 \frac{\text{kg } CO_2}{\text{kg } CH_4}$.

[2] Assuming stabilisation in 2010 at 1990 emissions.

[3] Estimated reduction in Annex I countries of 2.6% in 2010 (relative to 1990). See Appendix A.

[4] Estimated reduction in Annex I countries of 15% in 2010 (relative to 1990).

[5] Estimated reduction in Annex I countries of 20% in 2005 (relative to 1990, from AOSIS protocol proposal). Estimated reduction in Annex I countries of 25% in 2010 based on interpolation of 20% in 2005 and 35% in 2020 (from G77/China protocol proposal).

in low-lying coastal areas and in small island countries. The last indicator considers the technical and economic limitations of reducing emissions and is therefore relevant to the statement in Article 2 that climate policies should "enable economic development to proceed in a sustainable manner".

After setting constraints on the four main indicators for the years 1990 to 2100, the IMAGE 2 model is run "backwards" to compute the allowable range of emissions between 1990 and 2010, and between 2010 and 2030 that complies with these constraints. This range of emissions is the safe emission corridor.

Between the end of the corridor (year 2010 or 2030) and the year 2100, there is at least one emission pathway that will comply with the specified constraints on the indicators. More information about safe emission corridors is given in Box 2.

Table 2: Estimates of Global Greenhouse Gas Emissions (Units: equivalent CO_2 (Gt C/yr)[1]).

	Protocol Proposals			
	USA [2]	**Japan** [3]	**EU & G77/China** [4]	**AOSIS** [5]
1990	9.8	9.8	9.8	9.8
2010				
Low estimate [6]	10.8	10.7	10	9.5
Medium estimate [7]	11.6	11.5	10.8	10.3
High estimate [8]	12.3	12.2	11.5	11.0

[1] Anthropogenic CO_2, N_2O and CH_4 emissions. GWP factors: $N_2O = 320 \frac{\text{kg } CO_2}{\text{kg } N_2O}$; $CH_4 = 24.5 \frac{\text{kg } CO_2}{\text{kg } CH_4}$.

[2] Assuming stabilisation in Annex I countries in 2010 at 1990 emissions and no reduction in non-Annex I countries.

[3] Estimated reduction in Annex I countries of 2.6% in 2010 (relative to 1990) and no reduction in non-Annex I countries.

[4] Estimated reduction in Annex I countries of 15% in 2010 (relative to 1990) and no reduction in non-Annex I countries.

[5] Estimated reduction in Annex I countries of 20% in 2005 (relative to 1990, from AOSIS protocol proposal). Estimated reduction in Annex I countries of 25% in 2010 based on interpolation of 20% in 2005 and 35% in 2020 (from G77/China protocol proposal). No reduction in non-Annex I countries

[6] Sum of Annex I emissions from Table 1 plus low IPCC estimate (IS92c) of non-Annex I emissions (5.5 Gt C/yr).

[7] Same as footnote 6 except using medium IPCC estimate (IS92a) of Non-Annex I emissions (6.3 Gt C/yr).

[8] Same as footnote 6 except using high IPCC estimate (IS92e) of Non-Annex I emissions (7.0 Gt C/yr).

Box 1. Emissions not Covered by Most of the Protocol Proposals

Several types of gases contribute to the greenhouse effect, but most protocol proposals cover only anthropogenic sources of CO_2, CH_4 and N_2O. A group of greenhouse gases not covered by the protocol proposals but potentially important are chlorofluorocarbons and their substitutes (HFC, PFC and SF_6). Recently, these substances have gained attention in the climate negotiations because they are covered by the USA proposal but not other proposals. But since CFC's and HCFC's are governed by the Montreal Protocol we assume that they will not be included in the 1990 reference emissions of a climate Protocol. However, the substitutes of these substances, namely, HFC's, PFC's and SF_6 are also important greenhouse gases. Therefore, in the following paragraphs we present a preliminary analysis of their impact on the protocol proposals up to 2010.

For emissions in year 1990, we estimate that including these substances would lead to an increase of 0.1 Gt of global anthropogenic CO_2 equivalent emissions (from 9.8 Gt C to 9.9 Gt C). Here, the contribution of Annex I countries to fluorocarbon emissions is estimated to be 90%.

For emissions in year 2010, the contributions of Annex I and non-Annex I are assumed to be 50%. For the emission trends between 1990 and 2010 we evaluated two cases, reflecting the EU and USA proposals:

1. For the EU case we assume a reference emission trend from Kroeze[7] that complies with the 1992 Montreal Protocol but with no further control of these gases stimulated by climate policy. This leads to an increase of 0.38 Gt C of CO2 equivalent emissions (11.2 compared to 10.8 Gt C) for the EU proposal in 2010.
2. The USA proposal involves stabilizing all greenhouse gases of Annex I countries, including fluorocarbons at their 1990 level. In this case we add baseline emissions of fluorocarbons to the emissions of non-Annex I for 2010, while Annex I emissions remain at their 1990 level. This results in an increase of 0.31 Gt C of CO_2 equivalent emissions (11.9 compared to 11.6 Gt C) for the USA proposal in 2010.

Hence, because of the continuing increase of emissions of fluorocarbons in non-Annex I countries, the control of these substances in Annex I countries does not lead to a large difference between the USA and EU proposals in 2010. In our preliminary analysis, the difference is only 0.07 Gt C/yr.
Nevertheless, the overall contribution of fluorocarbons to global emissions will probably increase (perhaps up to 2.5 Gt C/yr equivalent CO_2 in 2100, according to Kroeze[8]) if they are not included in a climate protocol.

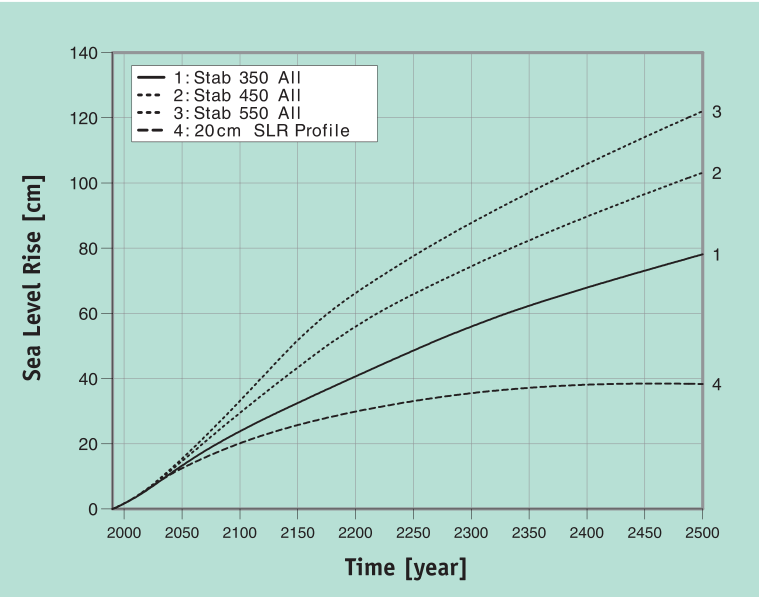


Figure 1: Long-term sea level rise computed by IMAGE 2 model. Lines 1 to 3 correspond to stabilization of CO_2 and other gases in the atmosphere according to IPCC pathways. Line 4 shows a sea level rise consistent with the AOSIS protocol proposal.

What Are the Emission Corridors of the AOSIS Proposal ?

The protocol proposal of the Alliance of Small Island States (AOSIS) sets limits on global mean sea level rise of 20 cm, and global temperature increase of 2.0 °C above its pre-industrial value. The temperature limit is equivalent to an increase of about 1.5 degrees above its present level. To compute the emissions corridor of the AOSIS proposal we must make some additional assumptions about other constraints. First, we assume that the target year for achieving the limitation on sea level rise and temperature increase is 2100. We will see shortly that the selection of this target year for sea level rise has important policy implications. We also assume that the global rate of temperature increase is limited to 0.15 °C/decade (being

Box 2. What are Safe Emission Corridors?

The concept of safe emission corridors was developed during a series of informal international workshops between 1995 and 1997 that aimed to promote a dialogue between global modelers and policy makers engaged in the climate protocol negotiations (Alcamo, et al.[9] van Daalen, et al.[10]). Safe emission corridors are the allowable range of emissions over time that comply with long and short term climate goals. The term emission corridors arose from an analogy with aviation: In order to land safely an aircraft needs to approach the airport in such a way that it neither hits the ground too early by going down too quickly, nor crashes behind it by going down too late. To land safely it should stay within a so-called safe corridor, guiding it to the landing strip. In the context of the climate issue, the future pathway of emissions of greenhouse gases should be such that it neither disrupts socio-economic development by reducing emissions too fast or too early, nor leads to serious climate impacts by reducing emissions too slow or too late. As a consequence, like the airplane, the short term emissions of greenhouse gases should stay within a corridor; the so-called "safe emission corridor".

The procedure for computing safe emission corridors requires results from a global climate model. Repeated runs are required with the model, so it is desirable to use a model with a fast turnaround time. The first corridors were computed using IMAGE 2, an integrated model of global change.[11] However, other global models are now also being used to compute emission corridors (see, for example, Matsuoka, et al.[12]), and results from different models are being standardized and compared.[13] In this paper we use IMAGE 2 to compute emission corridors.

Results from a global model are employed in such a way that an analyst can select certain climate and other goals, and the emission corridors are automatically calculated. The procedure is described in Appendix A. Other applications of the approach are given in Alcamo and Kreileman[14] and Swart, et al.[15] The emission corridors approach has been automated in an interactive program, and in this report we use Version 3 of this program (Kreileman and Berk[16]).

In the current version, the safe emission corridor is computed after setting constraints on four main indicators:

1. Cumulative increase in global average surface temperature in °C (1990-2100).
2. Rate of temperature increase in °C per decade (and the number of decades this rate may be violated).
3. Cumulative increase in global average sea level in cm (1990-2100).
4. Rate of global emission reduction in % per year.

These indicators can be related to the goals and conditions stated in the ultimate objective of the Framework Convention on Climate Change as noted in the main text. Given the level of uncertainty about the future level of climate change and related impacts, and the normative nature of evaluating these impacts, the safe emission corridor approach does not use any predefined values for the selected indicators. Instead, it offers decision makers a flexible framework to evaluate their own sets of climate goals. The fast accounting software enables this to be done in an interactive way.

For each set of indicator values, an emission corridor can be calculated for global greenhouse gas emissions (in CO_2-equivalent emissions) for the target year selected (e.g. 2010 or 2020). Between the target year and year 2100, there is at least one emission pathway emerging from the emission corridor that will comply with the specified set of indicator values. The top of the corridor indicates the maximum allowable emissions in the target year compatible with the selected climate goals. Near the top of the corridor, there are only few emission pathways that comply with these goals. Lower in the corridor there are many more pathways available after the target year that are compatible with the climate goals, and there is more room for a tightening of constraints if future scientific knowledge of climate change would make this desirable. The bottom of the corridor is defined by the constraint on maximum rate of emission reduction. To account for the present rate of climate change, resulting from historical emissions, the analysis also allows for specifying a number of decades after 2000 that the specified rate of temperature increase may be violated.

the average rate for an 1.5 °C increase over the next century) except for the first two decades, and that the maximum rate of global emission reduction is 2% per year. These are taken to be intermediate values, although the emission reduction rate is considered to be an upper limit by some[17]. Global sulfur emissions, which lead to sulfate particles in the atmosphere that somewhat compensate for global warming, are assumed to remain constant at their 1990 level.

The computed global emission corridor for these assumptions is shown in Figure 2a. In year 2010, emissions range from 7.6 to 9.5 Gt C/yr. Since global emissions in 1990 are estimated to be approximately 9.8 Gt C/yr[18], the bottom and top of the corridor correspond to 78% to 97% of estimated 1990 emissions (Figure 2a). (We remind the reader that these emissions are the sum of anthropogenic emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) in units of equivalent CO_2 and reported as Gt C/yr.) These are the short term range of global emissions that comply with the long range climate goals of the AOSIS protocol proposal.

To compute the allowable emissions in Annex I (industrialized) countries, we substract non-Annex I emissions from the above global emissions. Our assumptions for non-Annex I emissions are the same as those described on the first page of this report. (Emissions in 2010 range from 5.5 to 7.0 Gt C/yr, with a medium estimate of 6.3)

Because of the narrow global emissions corridor, we also compute a narrow corridor for Annex I emissions, spanning from 1.3 to 3.2 Gt C/yr in 2010 (Figure 2b). This is equivalent to 25% to 60% of 1990 emissions (5.3 Gt C/yr).

The main point is that the climate goals of the AOSIS proposal lead to a very low and narrow emission corridor between 1990 and 2010. To fall within the corridor, emissions in Annex I countries must be stringently reduced by 2010 relative to 1990.

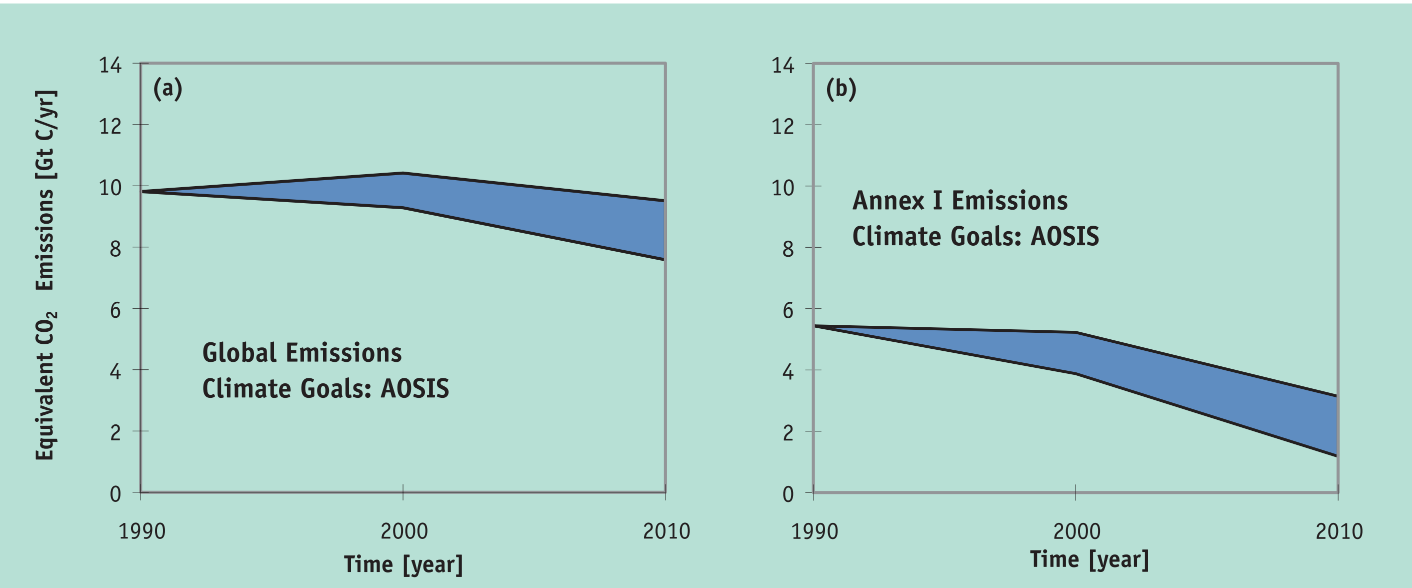


Figure 2: Emission corridors to achieve long term climate goals of the AOSIS protocol proposal. (a) Global emissions; (b) Annex I emissions calculated by subtracting uncontrolled non-Annex I emissions (medium estimate) from global emissions.

How Much Will Sea Level Rise Beyond 2100?

The long term trend of sea level rise is influenced by long time lags in the climate system[19]. Models that take these lags into account have computed that global sea level will continue to rise after 2100, even if emissions are sharply reduced and greenhouse gas concentrations are stabilized during the 21st century. Figure 1 shows such results from the IMAGE 2 model for various levels of CO_2 stabilization[20].

To illustrate this idea for the AOSIS protocol proposal, we select an emissions pathway that runs close to the global emissions of the "AOSIS" corridor (Figure 2a). This pathway was selected so that sea level rise is 20 cm in 2100 (relative to 1990).[21] Global emissions in this pathway decrease rather rapidly after 2010 (at a rate of 2% per year) reaching 2.0 Gt C/yr in 2100. Despite these severe emission reductions, sea level rises from 20 cm in 2100 to 38 cm in 2500 (Figure 1, line 4). In order to limit sea level rise to 20 cm in the very long run (up to 2500, for example) even sharper emission reductions are required.

To sum up, because of time lags in the climate system, sea level may increase after 2100 by a further factor of 2 to 3 before stabilizing. Hence, setting a target of 20 cm for 2100 does not guarantee that this will be maintained in the longer run, despite a sharp decrease in emissions.

What Are the Emission Corridors of the European Union Proposal ?

The EU protocol proposal stipulates that "global average temperature should not exceed 2 °C above the pre-industrial level", which we noted above is equivalent to about 1.5 degrees above the present level. To compute the safe emission corridor corresponding to this target, we make some of the same assumptions as in the AOSIS example: (i) the target year for this temperature limitation is 2100, (ii) the global rate of temperature increase may not exceed 0.15 °C/decade, and (iii) the maximum feasible rate of global emission reduction is 2% per year. An exception is that for the EU proposal we increase the constraint on sea level rise from 20 cm (in the AOSIS proposal) to 30 cm. We increase this constraint because the EU proposal does not specify a sea level target, and because a limit of 30 cm sea level rise does not have a strong influence on the width of the corridor (under the assumption that other constraints have values specified earlier in this paragraph). Figure 3a shows how the width of the corridor becomes very narrow when sea level rise is limited to less than about 25 cm.

Under the above assumptions, the global emissions corridor in 2010 ranges from 7.6 to 12.4 Gt C/yr, which is 78% to 127% of emissions in 1990 (Figure 4a). This is substantially wider than the AOSIS example (Figure 4a vs 2a) because of the higher limit set on sea level rise. Figure 4a shows the short term range of global emissions that comply with the long range temperature limit specified in the EU protocol proposal.

To compute the allowable emissions from Annex I countries, we follow the same procedure as in the AOSIS example and assume that emissions from non-Annex I countries in 2010 are 6.3 Gt C/yr. The corridor for Annex I emissions is then computed to span from 1.3 and 6.1 Gt C/yr in 2010, or between 25% and 115% of their 1990 level (5.3 Gt C/yr), with a median value of 3.7 (70%) (Figure 4b).

To sum up, the climate goal of the EU proposal leads to a wider corridor for allowable emissions than the AOSIS proposal. To reach the middle of the corridor, Annex I emissions must be significantly reduced, and to reach the top of the corridor increases in Annex I emissions are allowed.

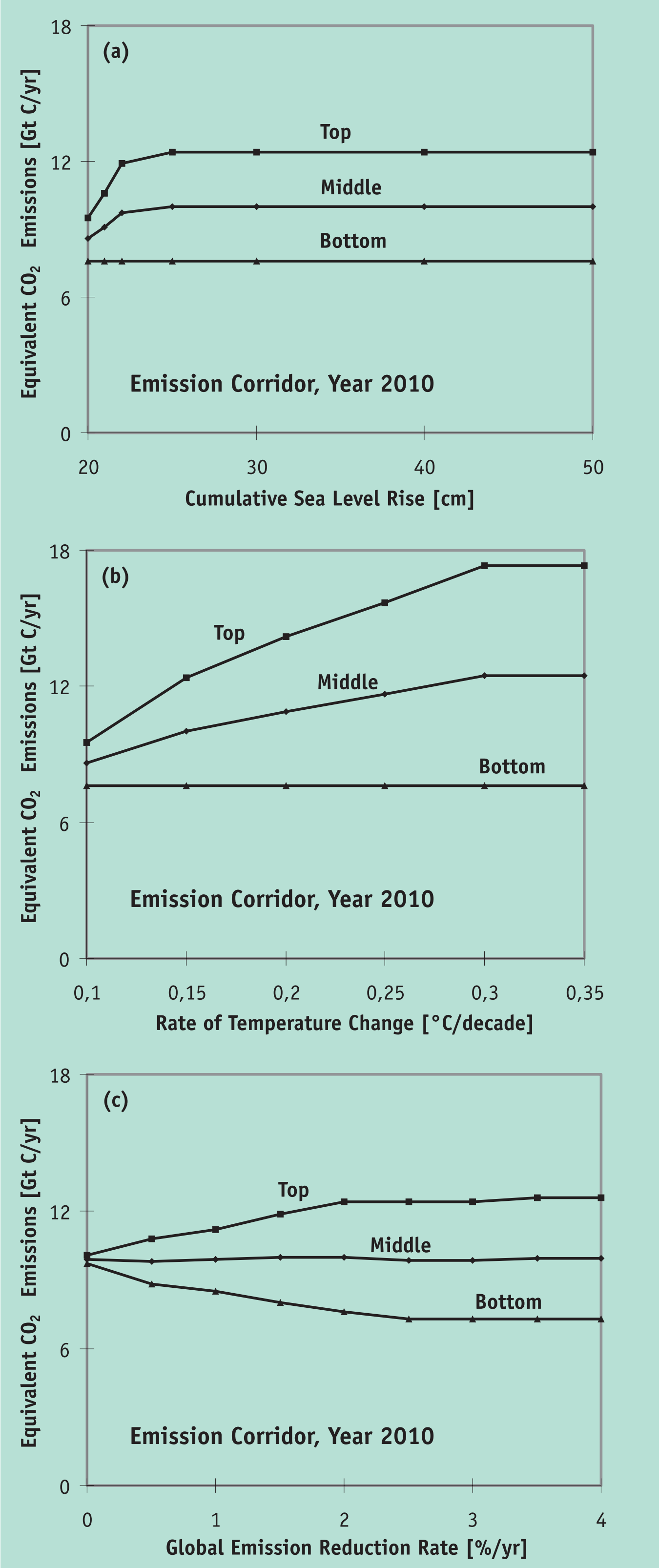


Figure 3: Sensitivity of width of safe emission corridor in 2010 to changing the limit of: (a) sea level rise, (b) decadal rate of temperature change, (c) emission reduction rate. Default values of indicators are set to cumulative increase in global average temperature relative to 1990 = 1.5 °C, rate of temperature change = 0.15 °C/decade (this can be violated during 2 decades in the period 2000 to 2100), sea level rise relative to 1990 = 30 cm, rate of emission reductions = 2%/year.

Do the Emission Pathways of the Protocol Proposals Fall Within the Safe Emission Corridors?

Figure 5a shows the emissions from the five protocol proposals overlaid on the "AOSIS" emission corridor. These are the medium estimates of global emissions from Table 2. Note that all proposals are far above the corridor. For high estimates of global emissions (not shown) the proposals are even further above this corridor. For the lower estimates (not shown) only the AOSIS emission pathway touches the corridor on its upper boundary.

For comparison, Figure 5b shows the five protocol proposals overlaid on the "EU" emissions corridor. The USA and Japanese proposals are very close to each other, and sit in the corridor somewhat above the EU and G77/China. Emissions from the AOSIS proposal are further down in the corridor. These are also the medium estimates of global emissions from Table 2. The low estimates are presented in Figure 6a, which shows that under these circumstances all emissions fall comfortably within the corridor. For high emission estimates from Table 2 (Figure 6b) the EU, G77/China and AOSIS emissions fall well inside the corridor, but the USA and Japanese proposals are on the upper edge. Hence, the trend of emissions in non-Annex I countries will influence the degree to which these protocol proposals comply with long term climate goals.

Because most proposals under most emission estimates do not fall within the AOSIS corridor, we will focus on the EU corridor for the remainder of this report.

To sum up,
Most protocol proposals fall outside of the AOSIS safe emissions corridor of global emissions.
By contrast, all protocol proposals fall within the EU corridor for a wide range of estimates for non-Annex I emissions.

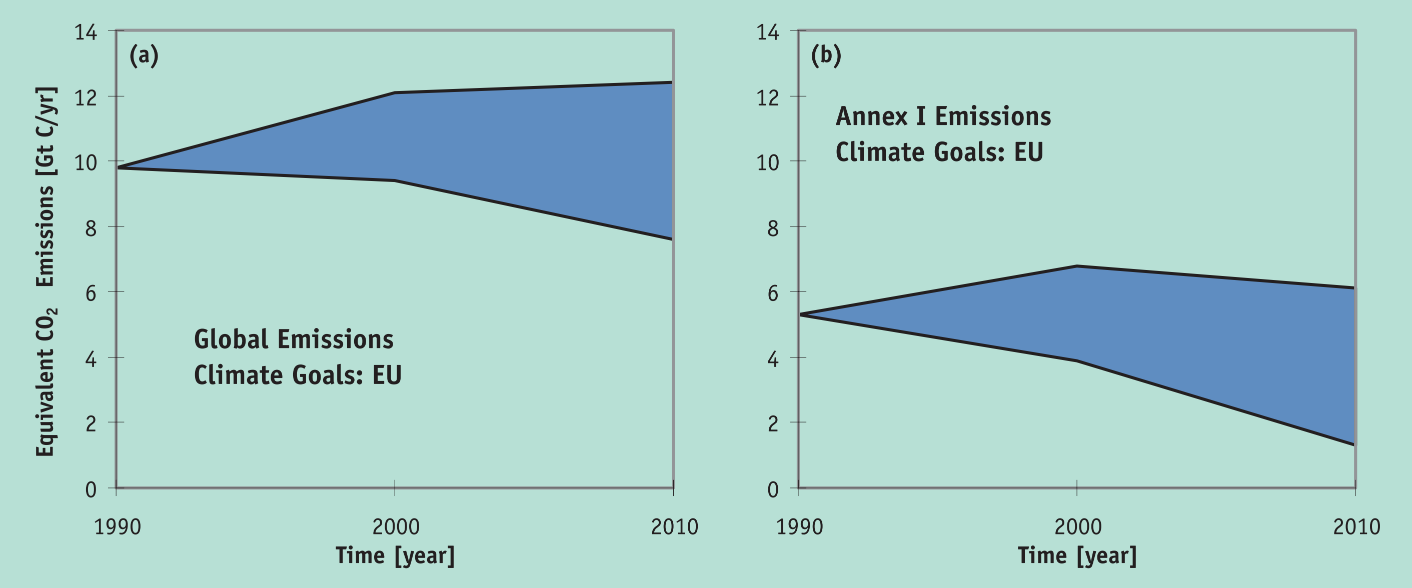


Figure 4: Emission corridors to achieve long term climate goals of the EU protocol proposal. (a) Global emissions; (b) Annex I emissions calculated by subtracting uncontrolled non-Annex I emissions (medium estimate) from global emissions.

Does it Make Any Difference Where Emissions Fall in the Corridor?

From an economics perspective it seems logical to allow emissions to rise to the very top of the emissions corridor because emissions here require the least amount of controls but still can meet the same climate goals as emissions lower in the corridor. However the higher the location in the corridor, the larger the quantity of gases pumped into the atmosphere between 1990 and 2010, and the smaller the quantity that can be emitted afterwards. Indeed there are far fewer emission pathways near the top of the corridor that comply with the specified climate goals, than lower down in the corridor. The lower in the corridor, the more flexibility available later on to tighten constraints if future scientific knowledge of climate change would make this desirable.

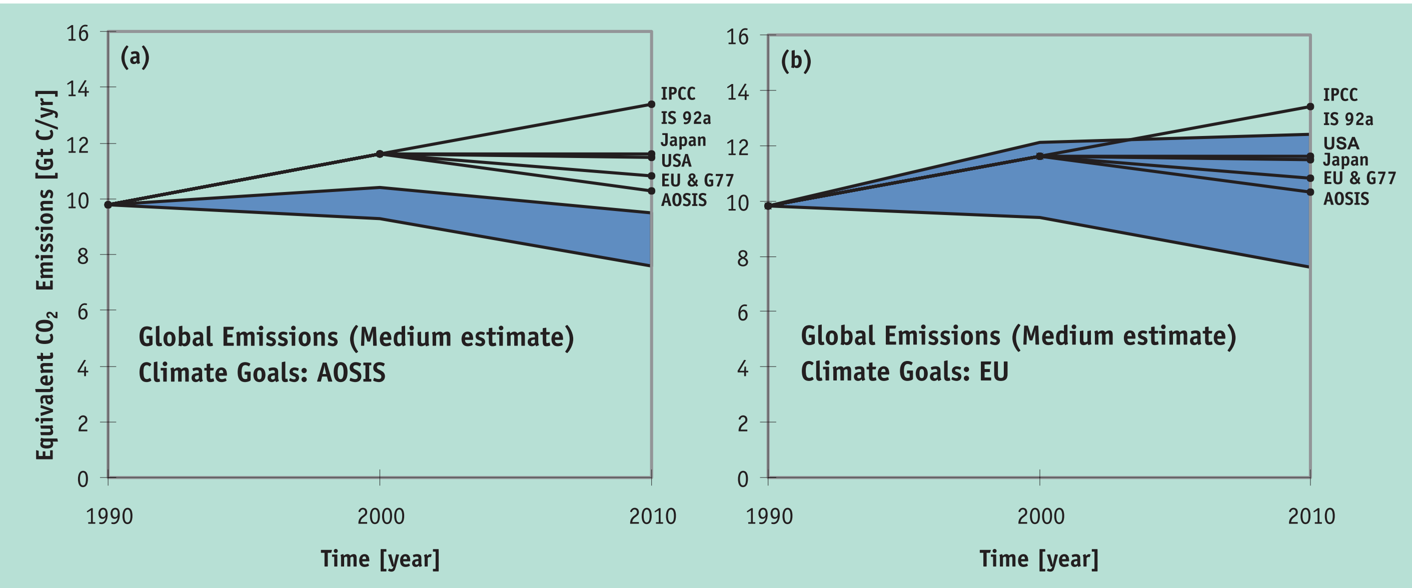


Figure 5: Comparison of emissions from five protocol proposals and IPCC IS92a scenario overlaid on (a) "AOSIS" emission corridor, (b) "EU" emission corridor. For these calculations non-Annex I emissions are assumed to be uncontrolled, and to be in accordance with IPCC´s medium estimate (IS92a).

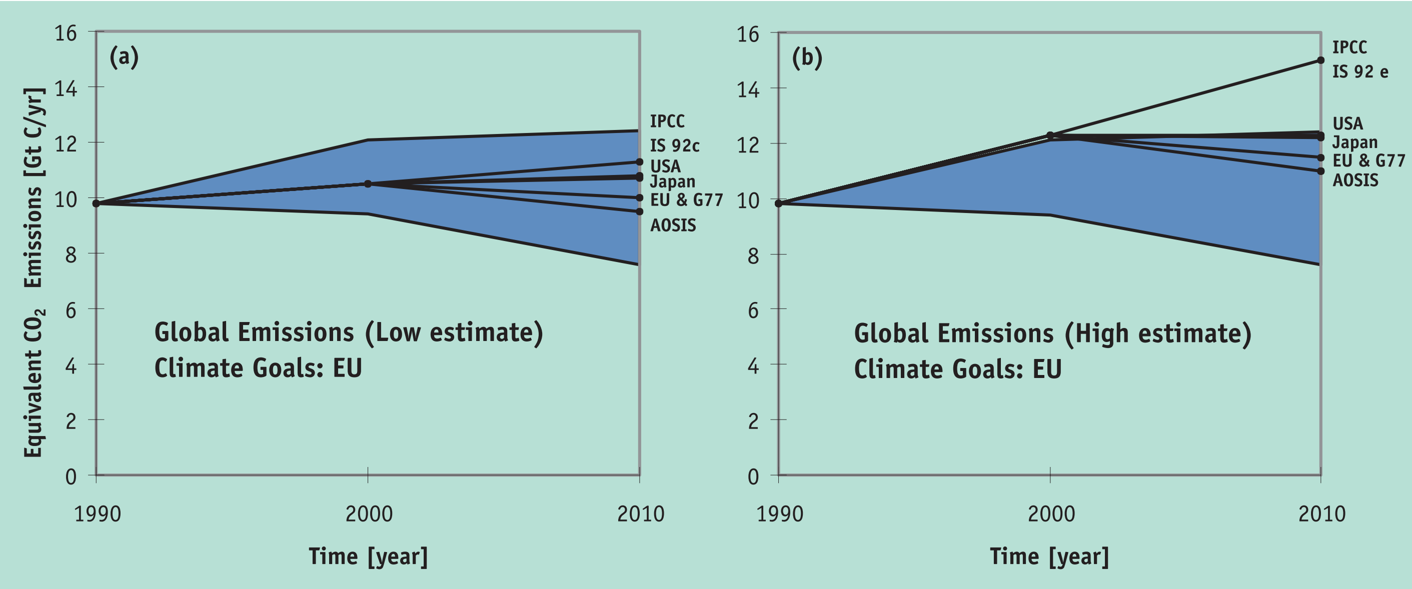


Figure 6: Comparison of emissions from five protocol proposals and IPCC IS92a scenario overlaid on "EU" emission corridor. (a) For these calculations non-Annex I emissions are assumed to be uncontrolled, and to be in accordance with IPCC´s low estimate (IS92a) (b) in accordance with IPCC´s high estimate (IS92e).

We now illustrate these ideas with the EU emission corridor, and by using emission estimates from the USA and EU proposals. These two are used as examples because the global emission estimates of the USA and Japanese proposals for 2010 are very close in this report (Table 2), and the estimates for the EU and G77/China proposals are identical for 2010 in this report. Hence, results for the USA proposal are also representative of the Japan proposal, and the EU proposal is representative of the G77/China proposal. A further analysis of the AOSIS proposal is outside the scope of this report.

The left side of Figure 7 depicts the EU corridor from *1990 to 2010*, and the right side shows the corridor from *2010 to 2030* starting from two different points in 2010. Note, by comparing Figure 7a with 7b, that:

- If global emissions are higher in the corridor in 2010 (Figure 7a), for example, at the estimated emissions from the USA proposal (about 11.6 Gt C/yr), then they must decrease to 8.9 in 2030, in order to stay in the middle of the corridor and to 10.1 to reach the top. This is a decrease of 13% to 23% in 2030 relative to 2010.
- If emissions are lower in the corridor in 2010 (Figure 7b), for example, at the estimated emissions from the EU proposal (about 10.8 Gt C/yr), then they must decrease to 9.0 in 2030 to reach the middle of the corridor, and may stay constant at 10.8 to reach the top[22]. This is a decrease of 0% to 17% in 2030 relative to 2010. Also noteworthy is that under the EU proposal, the corridor between 2010 and 2030 is not as steep or narrow as in the case of the USA proposal, suggesting that there could be pathways through the corridor that do not require sharply decreasing emissions.

The main point is, the lower in the corridor in 2010, the less stringent the reductions required after 2010. The EU proposal therefore leads to greater flexibility after 2010 than the USA proposal.

Implications on Annex I and Non-Annex I Countries After Year 2010

Are these findings for the years 2010 to 2030 important to Annex I and non-Annex I countries? Figure 8 and Table 3 show the

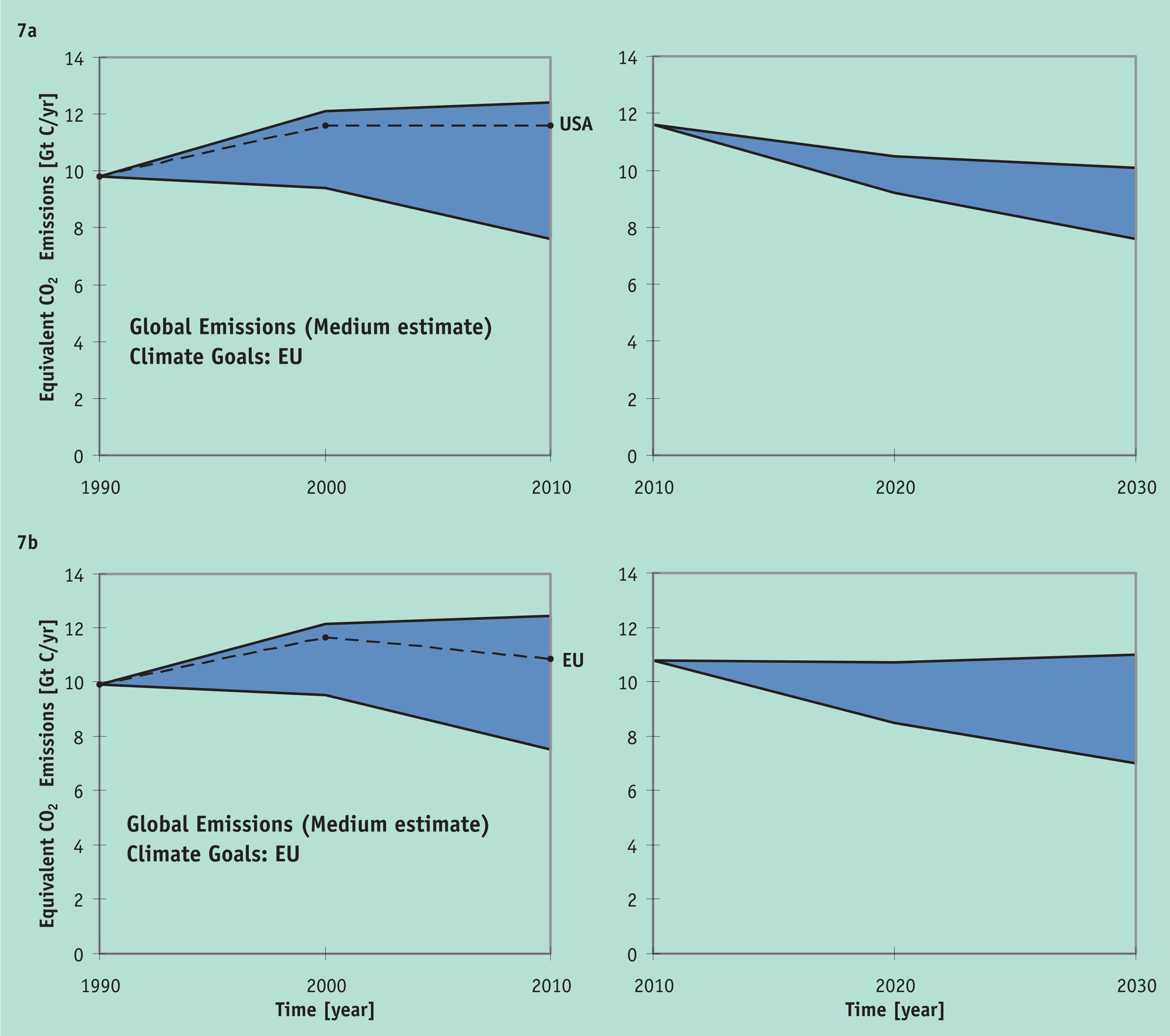


Figure 7: Safe emission corridors from 1990 to 2010, and their continuation from 2010 to 2030. The left side shows the same "EU" corridor as in Figure 4. On the left side of Figure 7a the emissions from the USA proposal are overlaid. The corridor to its right begins where the USA proposal ends in 2010. On the left side of Figure 7b the emissions from the EU proposal are overlaid. The corridor to its right begins where the EU proposal ends in 2010.

different combinations of reductions of Annex I and non-Annex I emissions that would allow global emissions to stay within the EU emission corridor between 2010 and 2030. In other words, these are the reductions needed to achieve the limit on temperature change of the EU proposal. We note that these reductions are not necessarily politically or economically feasible, nor ethically acceptable.

Figure 8a indicates that under the USA proposal, if *non-Annex I* countries were to stabilize their emissions after 2010 (i.e. 0% reduction in 2030 relative to 2010), then under the USA proposal, *Annex I* would have to reduce by 52% to reach the middle of the corridor and 28% to reach the top. By contrast, under the EU proposal (Figure 8b), *Annex I* countries would have to reduce 40% to reach the middle, and would not have to reduce at all to reach the top of the corridor.[23]

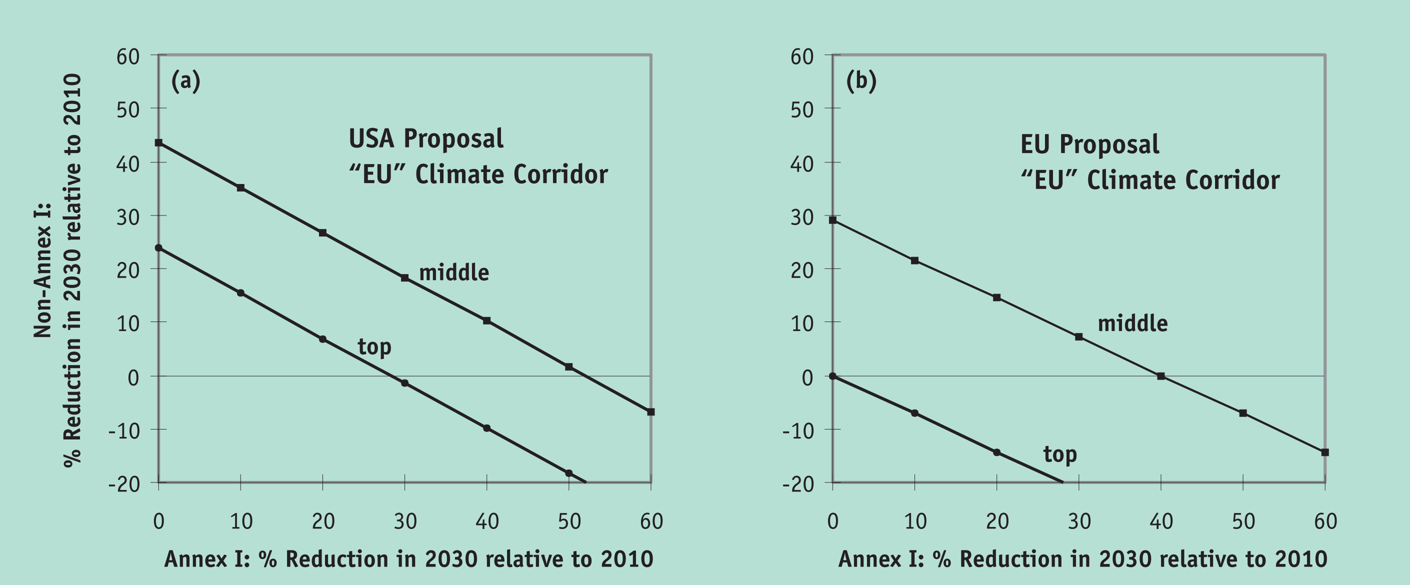


Figure 8: Emission reductions required (in 2030 relative to 2010) from either Annex I countries or non-Annex I countries, or both, in order to reach the middle and top of the "EU" Climate corridor in 2030. Results are presented for the (a) USA protocol proposal and (b) EU protocol proposal.

Another example, taken from a different point of view, is to assume that *Annex I* countries reduce their emissions by 15% in 2030 (relative to 2010). Under the USA proposal (Figure 8a) *non-Annex I* countries would then have to reduce their emissions by around 31% in 2030 (relative to 2010) to keep global emissions in the middle of the corridor. To reach the top of the corridor they would have to reduce a still substantial 12%. Results are different under the EU proposal (Figure 8b). Here, non-Annex I countries would have to reduce their emissions by around 19% (rather than 31% under the US proposal) to keep global emissions in the middle of the corridor. To reach the top of the corridor, non-Annex I countries could *increase* their emissions by about 11% between 2010 and 2030 (rather than *decrease* by 12% under the USA proposal).

In general, the EU proposal provides more flexibility to both Annex I and non-Annex I countries in selecting an emission pathway after 2010 because less emissions will accumulate under this proposal up to 2010. Put another way, less stringent emission reductions will be required, and in some cases even emission increases could be possible.

To sum up, some important points emerge from these and other analyses of safe emission corridors after 2010:

- *The higher the emissions in 2010, the faster they need to be reduced afterwards, leaving less policy flexibility. Put another way, if global emissions are high in the corridor in 2010 then both Annex I and non-Annex countries will have to work harder after 2010 to control emissions in order to achieve long term climate goals such as the temperature limit of the EU protocol proposal.*
- *The lower the emissions in 2010, the more flexibility available to both Annex I and non-Annex countries after 2010. For example, if emissions are low enough in the corridor in 2010, it may be possible to achieve the long term climate goal of the EU proposal even if non-Annex I emissions continue to increase after 2010.*

Sensitivity and Uncertainty

It is important to remind the reader at this point that results presented in this report have many sources of uncertainty. A significant source of this uncertainty is the model

Table 3: Emission reductions required (in 2030 relative to 2010) from either Annex I countries or Non-Annex I countries, or both, in order to reach top, middle and bottom of "EU" emission corridor in 2030. Results are presented for the (a) USA protocol proposal and (b) EU protocol proposal.

Annex I Reduction [%]	Non-Annex I Reduction [%]					
	USA Proposal			EU Proposal		
	top	middle	bottom	top	middle	bottom
0	24	44	64	0	29	57
10	15	35	55	-7	22	50
20	7	27	47	-14	15	43
30	-1	18	38	-21	7	36
40	-10	10	30	-29	0	29
50	-18	2	21	-36	-7	21
60	-27	-7	13	-43	-14	14

used to perform calculations in this report, namely the IMAGE 2 model. The IMAGE 2 model, as all global models, can only approximate and never accurately predict global environmental changes. Another important source of uncertainty is the method used to compute safe emission corridors. Alcamo and Kreileman[24] and Swart, et al.[25] point out some of the sources of these uncertainties, for example (i) the statistical correlations used to compute the corridors, (ii) the uncertainties of environmental impacts related to the limits of the indicators, (iii) the effect of sulfur emissions on global cooling, and the effect of this cooling on calculations of emission corridors. With regards to this last uncertainty, sulfur emissions in this report are fixed at their 1990 level but Alcamo and Kreileman[26] have pointed out that emission corridors could be significantly wider if sulfur emissions substantially increase in developing countries. Pitcher[27] has also reported that the width of an emission corridor is strongly dependent on the climate sensitivity of the global model used for computations. The model used in this report for computations has a climate sensitivity of 2.37, which is an intermediate value.

Finally, it is worthwhile repeating that computed corridors are very dependent on the selected values of indicators. For example, we showed earlier the dependence of corridor width on the specified limit to sea level rise (Figure 3a). Likewise, Figures 3b and 3c show the dependence of the corridor width (in year 2010) on limits to rate of temperature change and emission reduction rate, respectively. Figure 3b shows that the corridor width becomes quite narrow when the rate of temperature change is limited to 0.1 °C as proposed by some scientists to allow adaptation of ecosystems to climate change (see, for example, Swart et al.[28]). Meanwhile, Figure 3c indicates that the corridor sharply narrows when the maximum emissions reduction rate is less than 2%/year.

Main Findings

Emission Trends of the Protocol Proposals.
For medium and high emission estimates, all protocol proposals have higher global emissions in 2010 that in 1990. For low estimates, the EU and G77/China proposals are slightly above, and the AOSIS proposal slightly below 1990 emissions. The USA and Japanese proposals are about 1 Gt/yr above the 1990 level.

The AOSIS Proposal and its Safe Emission Corridor.
The climate goals of the AOSIS proposal lead to a very low and narrow emissions corridor between 1990 and 2010. To fall within the corridor, emissions in Annex I countries must be stringently reduced by 2010 relative to 1990.

The AOSIS Proposal and Sea Level Rise.
An important aspect of the AOSIS proposal is its limit on sea level rise. If this limit is set for year 2100, it is possible that the longer term sea level rise may be a factor of two to three greater than this. This is because of time lags in the climate system.

The EU Proposal and its Safe Emission Corridor.
The climate goal of the EU proposal leads to a wider corridor than the AOSIS proposal. To reach the middle of the corridor, Annex I emissions must be significantly reduced, and to reach the top of the corridor, increases in Annex I emissions are allowed.

Emission Trends and Safe Emission Corridors.
Most protocol proposals evaluated in this report fall outside of the AOSIS safe emission corridor in 2010. By contrast, all protocol proposals fall within the EU corridor for a wide range of estimates for non-Annex I emissions.
Hence, in principle, these proposals comply with the long term climate goal of the EU proposal. However, the path of emissions after 2010 is very important, as noted in the following points.

The Location Within the Corridor in 2010.
In general, the higher the emissions in 2010, the faster they need to be reduced afterwards, leaving less room for policy flexibility.

Implications on Annex I and Non-Annex I Countries After 2010.
If global emissions are high in the corridor in 2010 then both Annex I and non-Annex countries will have to work harder after 2010 to control emissions in order to achieve the long term climate goal of the EU proposal (a limit of 2.0°C global temperature increase). If emissions are lower in 2010, then both Annex I and non-Annex countries will have more flexibility to select an emission pathway after 2010. Indeed, if emissions are low enough in the corridor in 2010 (as in the EU, G77/ China, or AOSIS proposals) then it may be possible to achieve the long term climate goal of the EU proposal even if non-Annex I emissions continue to increase after 2010.

Acknowledgments

The analyses in this report were supported by funds provided by the German Federal Environment Agency to the Center for Environmental Systems Research, University of Kassel under the project “Strategies for Stabilizing Greenhouse Gases”. The IMAGE Project is supported by the National Institute of Public Health and the Environment, the Netherlands (RIVM), the Dutch Ministry of Housing, Physical Planning and Environment (VROM) and the Dutch National Programme on Global Air Pollution and Climate Change (NRP). The authors are indebted to Paul Reuter for his assistance in this evaluation. This report is partly based on papers presented at two seminars in connection with the subsidiary bodies of the Framework Convention on Climate Convention, and a special IPCC meeting.[29]

Appendix A: Estimates of reductions for each Annex I country according to the Japanese protocol proposal.

	(1) **Reduction Rate (Emissions/GDP)** [%]	(2) **Reduction Rate (Emissions/cap)** [%]	(3) **Estimated Reduction Rate** [%]
Australia	3.1	a.a.	3.1
Austria	0.8	3.8	0.8
Belarus *	1.8	1.0	1.0
Belgium	1.0	4.4	1.0
Bulgaria	a.a.	a.a.	5.0
Canada	2.0	a.a.	2.0
Czech Republic	a.a.	a.a.	5.0
Denmark	0.9	4.9	0.9
Estonia	a.a.	a.a.	5.0
Finland	1.5	a.a.	1.5
France	0.8	3.3	0.8
Germany	1.1	a.a.	1.1
Greece	2.4	3.6	2.4
Hungary	4.3	3.3	3.3
Iceland	0.9	4.4	0.9
Ireland	2.7	a.a.	2.7
Italy	1.1	3.8	1.1
Japan	0.6	3.7	0.6
Latvia	a.a.	4.0	4.0
Lithuania *	2.8	0.6	0.6
Netherlands	1.3	a.a.	1.3
New Zealand	3.4	a.a.	3.4
Norway	0.9	4.3	0.9
Poland	a.a.	a.a.	5.0
Portugal	1.2	2.0	1.2
Romania	a.a.	4.2	4.2
Russian Federation	a.a.	a.a.	5.0
Slovakia	a.a.	a.a.	5.0
Spain	1.3	3.0	1.3
Sweden	0.7	3.3	0.7
Switzerland	0.5	3.3	0.5
Ukraine *	2.8	1.2	1.2
United Kingdom	1.5	4.8	1.5
USA	1.8	a.a.	1.8
Total Annex I [%]			**2.4**

a.a. - above average

All Emission-Data 1990, (Web Site of the Climate Change Secretariat) except:

* CO2-Emission-Data 1992 (Web Site of the Carbon Dioxide Information Analysis Center, CDIAC)

(1) The reduction rate of countries having emissions per GDP lower than the Annex I average is given by % = 5%(A/B) where A is the country's emission per GDP and B is the Annex I average emissions per GDP.
GDP-Data 1990 (World Resources Institute, 1996: World Resources (1996-97). Oxford University Press)

(2) The reduction rate of countries having emissions per capita lower than the Annex I average is given by % = 5%(C/D) where C is the country's emission per capita and D is the Annex I average emissions per capita.
Population-Data 1990 (World Resources Institute, 1996: World Resources (1996-97). Oxford University Press)

(3) Estimates in this Appendix are based on selecting the smallest of the values in columns (1) or (2).
When no values are given in columns (1) and (2), then a 5% reduction is assumed.

Endnotes

1 Conference of Parties of Framework Convention on Climate Change. 1995. The Berlin Mandate: Decision 1/CP.1. Climate Change Secretariat. Bonn, Germany.

2 Leggett, J., W.J. Pepper and R.J. Swart. 1992. Emission Scenarios for the IPCC: an Update. In: *IPCC, Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*. Cambridge University Press, Cambridge.

3 Alcamo, J. and Kreileman, G.J.J. 1996. Emission scenarios and global climate protection. Global Environmental Change **6**(4):305-334.

4 Swart, R.S., Berk, M., Janssen, M., Kreileman, G.J.J., Leemans, R. 1997. The safe landing approach: risks and trade-offs in climate change, In: Alcamo, J., Kreileman, G.J.J., Leemans, R. (eds.).Global Change Scenarios of the 21st Century: Results from the IMAGE 2 Model. Elsevier. Forthcoming.

5 Alcamo, J. (editor). 1994. IMAGE 2.0: Integrated Modeling of Global Climate Change. Kluwer Academic Press, Dordrecht, Boston, 314 pp., and Special Issue of *Water Air Soil Pollution*. **76**(1/2): 1-321.

6 A global modeling exercise is currently underway to compare emission corridors calculated under standardized conditions. The following global modeling groups are participating: the National Institute of Public Health, The Netherlands (RIVM), the University of Kassel, Germany, Batelle Northwest Laboratory, USA, the National Institute of Environmental Studies, Japan, and the Potsdam Institute of Climate Impact Studies, Germany.

7 Kroeze, C. 1995. Fluorocarbons and SF_6. Global emission inventory and options for control. RIVM Report no. 773001007

8 Kroeze, C. 1995, op cit.

9 Alcamo, J., Kreileman, G.J.J., Leemans, R. 1996a. Global models meet global policy. *Global Environmental Change*. **6**(4): 255-260.

10 van Daalen, E., Thissen, W., Grünefeld, H., Leemans, R. 1997. The Delft process: creating a dialogue between FCCC delegates and climate assessment scientists. *Change*. **35**: 8-10

11 Alcamo and Kreileman, 1996, op cit.

12 Matsuoka, Y., Morita, T., Kawashima, Y., Takahashi, K., Shimada, K. 1997. An estimation of negotiable safe emissions corridor based on the AIM model. In preparation.

13 Alcamo, J. 1997. Preliminary results of an international comparison of computed emission corridors. Paper presented at the Fifth international workshop on using the IMAGE model to support climate negotiations. Delft, the Netherlands. 5-6 June.

14 Alcamo and Kreileman, 1996, op cit.

15 Swart et al. 1997, op cit.

16 Kreileman, G.J.J., Berk, M. 1997. The safe landing analysis: users manual. RIVM Report 481508003. National Institute of Public Health and the Environment (RIVM). PO Box 1, 3720 BA Bilthoven, the Netherlands.

17 Swart, et al., op cit., point out some of the possible difficulties in achieving a 2%/year global reduction rate over the long run.

18 This is an estimate from the IMAGE 2 model based on original emissions data in Leggett, J., W.J. Pepper and R.J. Swart. 1992. Emission Scenarios for the IPCC: an Update. In: *IPCC, Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment*. Cambridge University Press, Cambridge.

19 Time lags in the climate system stem from the delay between the build-up of greenhouse gases in the atmosphere and its effect on global warming and sea level rise. These time lags arise from several factors including the slow circulation of heat in the ocean.

20 Swart et al., 1997, op cit.

21 The emission pathway that results in a 20 cm sea level rise is called “20 cm Sea Level Rise Profile”. It was selected so that a sea level rise of 20 cm is computed for year 2100 relative to 1990. After 2010 all global anthropogenic emissions decrease by 2% per year. Natural emissions remain nearly constant except those affected by certain climate feedbacks. Fluxes of CO_2 between the atmosphere and biosphere are computed automatically by the IMAGE 2 model in the course of the simulation. Sulfur emissions are assumed constant after year 1990.

22 This is not exactly consistent with the calculation of emission corridors because the only emission pathways that will reach the top of the corridor in 2030 have emission pathways that first decrease, and then increase between 2010 and 2030.

23 See note 22.

24 Alcamo and Kreileman, 1996, op cit.

25 Swart et al. 1997, op cit.

26 Alcamo and Kreileman, 1996, op cit.

27 Pitcher, H. 1997. Batelle Northwest Laboratories, at Note 6.

28 Swart et al. 1997, op cit.

29 Alcamo, J., Kreileman, G.J.J., Swart, R.S., 1997. The climate negotiations: climate goals and their emission corridors. Plenary paper at the IPCC Asia-Pacific Workshop on Integrated Assessment Models, Tokyo, 10-12 March, 1997 and Seminar held in connection with the Sixth Session of the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the Framework Convention on Climate Change, Bonn, Germany, 28 July, 1997. Alcamo, J., Onigkeit, J., Berk M. 1997. Emission corridors and emission trends: comparing protocol proposals of ASOSIS, EU, Japan and USA. Seminar held in connection with the Eighth Session of the Ad Hoc Group on the Berlin Mandate (AGBM) of the Framework Convention on Climate Change, Bonn, Germany, 30 October, 1997.