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EDITORIAL

Reductions of greenhouse gas emissions in Annex I and non-Annex I countries for meeting concentration stabilisation targets

An editorial comment

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Abstract The IPCC Fourth Assessment Report, Working Group III, summarises in Box 13.7 the required emission reduction ranges in Annex I and non-Annex I countries as a group, to achieve greenhouse gas concentration stabilisation levels between 450 and 650 ppm CO_2-eq. The box summarises the results of the IPCC authors' analysis of the literature on the regional allocation of the emission reductions. The box states that Annex I countries as a group would need to reduce their emissions to below 1990 levels in 2020 by 25% to 40% for 450 ppm, 10% to 30% for 550 ppm and 0% to 25% for 650 ppm CO_2-eq, even if emissions in developing countries deviate substantially from baseline for the low concentration target. In this paper, the IPCC authors of Box 13.7 provide background information and analyse whether new information, obtained after completion of the IPCC report, influences these ranges. The authors concluded that there is no argument for updating the ranges in Box 13.7. The allocation studies, which were published after the writing of the IPCC report, show reductions in line with the reduction ranges in the box. From the studies analysed, this paper specifies the "substantial deviation" or "deviation from baseline" in the box: emissions of non-Annex I countries as a group have to be below the baseline roughly between 15% to 30% for 450 ppm CO_2-eq, 0% to 20% for 550 ppm CO_2-eq and from 10% above to 10% below the baseline for 650 ppm CO_2-eq, in 2020. These ranges apply to the whole group of non-Annex I countries and may differ substantially per country. The most important factor influencing these ranges above, for non-Annex I countries, and in the box, for Annex I countries, is new information on higher baseline emissions (e.g. that of Sheehan, Climatic Change, 2008, this issue). Other factors are the assumed global emission level in 2020 and assumptions on

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land-use change and forestry emissions. The current, slow pace in climate policy and the steady increase in global emissions, make it almost unfeasible to reach relatively low global emission levels in 2020 needed to meet 450 ppm CO_2-eq, as was first assumed feasible by some studies, 5 years ago.

1 Introduction

The level of ambition for reductions by developed countries (Annex I countries) and developing countries (non-Annex I countries), in a future international agreement on climate change, is one very important element in the current climate negotiations. The Ad-Hoc Working Group on Further Commitments for Annex I countries under the Kyoto Protocol (AWG-KP), agreed on the wording of the level of its ambition. At a preparatory meeting in August 2007, it noted the usefulness of the contribution of Working Group III to the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), which states that emissions need to peak within the next 10 to 15 years and that emissions must be reduced to well below half of the 2000 level by the middle of the twenty-first century, in order to stabilise their concentrations in the atmosphere at the lowest level assessed by the IPCC. In addition, AWG-KP recognised that Annex I countries need to reduce their emissions within a range of 25% to 40% below 1990 levels in 2020, in order to reach the lowest stabilisation levels assessed by the IPCC. The reduction range of −25% to −40% refers to Box 13.7 of the Working Group III report of the IPCC AR4 (Table 1) (Gupta et al. 2007). Agreement on this formulation was possible under the Kyoto Protocol because (1) it is only a recognition of this range and not a decision on it and (2) the USA did not take part in this agreement, as it has not ratified the Kyoto Protocol.

At the Conference of the Parties (COP) 13 in Bali in December 2007, the issue of the reduction range for the Annex I was discussed again, this time with all countries, including the USA. Initial drafts by the EU called for the same wording as already agreed to under the Kyoto Protocol. The Box 13.7 of the IPCC report received large attention, including by the media. But in the end, agreement could not be reached on the reduction percentages in the negotiations under the Convention and, instead, it called for “deep cuts in global emissions” and a reference to the IPCC AR4 was included in a footnote.

The conference also agreed to complete the negotiation process on comparable mitigation commitments or actions by all developed countries and nationally appropriate mitigation actions by developing countries by the end of 2009.

In this paper the authors of Box 13.7 provide more details on the studies that were used to prepare the ranges and they analyse whether new information, obtained after completion of the IPCC report, influences these ranges. A first question is how the ranges were derived and whether new allocation studies would change the results (Section 2). A second question concerns the possibility of quantifying what is termed as “substantial deviation from the baseline” for non-Annex I countries and what the important determinants are. One important assumption is the reductions by the Annex I countries, but an even more important assumption is the baseline that was chosen (Section 3). Different baselines were tested, including those with rapid growth in emissions, in particular in the developing countries, as presented by

Table 1 IPCC Box 13.7: The range of the difference between emissions in 1990 and emission allowances in 2020/2050 for various GHG concentration levels for Annex I and non-Annex I countries as a group

Scenario category	Region	2020	2050
A—450 ppm CO_2-eq[a]	Annex I	−25% to −40%	−80% to −95%
	Non-Annex I	Substantial deviation from baseline in Latin America, Middle East, East Asia and Centrally-Planned Asia	Substantial deviation from baseline in all regions
B—550 ppm CO_2-eq	Annex I	−10% to −30%	−40% to −90%
	Non-Annex I	Deviation from baseline in Latin America and Middle East, East Asia	Deviation from baseline in most regions, especially in Latin America and Middle East
C—650 ppm CO_2-eq	Annex I	0% to−25%	−30% to −80%
	Non-Annex I	Baseline	Deviation from baseline in Latin America, Middle East, and East Asia

Source: Gupta et al. (2007, Section 13.3.3.3). The aggregate range is based on multiple approaches to apportion emissions between regions (contraction and convergence, Multi-Stage, Triptych and intensity targets, among others). Each approach makes different assumptions about the pathway, specific national efforts and other variables. Additional extreme cases—in which Annex I or non-Annex I undertake all reductions—are not included. The ranges presented here do not imply political feasibility, nor do the results reflect cost variances.

[a]Only the studies aiming at stabilisation at 450 ppm CO_2-eq assume a (temporary) overshoot of about 50 ppm (see den Elzen and Meinshausen 2006b).

Sheehan (2008). Also important are assumptions on the required global emission level and on CO_2 emissions from land use, land-use change and forestry (LULUCF).

2 Main assumptions underlying the studies quoted in the IPCC report

Several studies have analysed the level of commitment of different regions and countries and the timing of participation, which are required to ensure meeting the long-term concentration stabilisation targets, using different post-2012 regimes for differentiation of future commitments (allocation schemes). This has been summarised in Box 13.7 by IPCC AR4 (Gupta et al. 2007). Table 2 presents the main assumptions of the sixteen studies used and quoted in the IPCC analysis and two additional unquoted studies (i.e. Höhne et al. 2003; Leimbach 2003), which influence the results:

- *Allocation calculations for CO_2 only or all greenhouse gases (GHGs):* Some calculations were based on all GHGs and some only on CO_2. The share of non-CO_2 gases is usually higher in developing counties
- *Baseline:* The baseline emissions are a major determinant for the results, as more reductions are necessary if baseline emissions are higher
- *Kyoto implementation:* For the short term it is important whether studies have assumed that the Kyoto protocol targets are implemented or not.

Table 2 Main assumptions of the studies quoted by the IPCC and more recent studies (in chronological order) underlying Box 13.7

	Allocation calculations	Baseline scenario[a]	Assumptions on meeting Kyoto targets in 2008–2012	Allocation schemes covered[b]	Global emission target (excl. LULUCF CO_2) in 2020/2050 (%-compared to 1990 levels), for CO_2-eq concentration (ppm), IPCC categories		
					A—450	B—550	C—650
Studies used quoted in IPCC report							
Berk and den Elzen (2001)	CO_2	IPCC* A1	Annex I incl. USA	MS, CC, HR	+10/−20		
Blanchard et al. (2002)	CO_2	IPCC** A1	Annex I excl. USA; FSU BAU[c]	CC, HR, EI			+50/NI
Winkler et al. (2002)	CO_2	IPCC B1	Not considered; base-year 2000	HR, AP, EI	0		
Criqui et al. (2003)	CO_2-eq	CPI 2003	Annex I excl. USA & Australia	MS, CC		+35/−20	+50/+35
Höhne et al. (2003) *(not quoted)*	CO_2-eq	IPCC A2	Annex I incl. USA; FSU BAU[c]	MS, CC, EI, TY, other		+27/NI	
Leimbach (2003) *(not quoted)*	CO_2	Own	Not included; base-year 2000	CC			[40; 75]/+25
WBGU (2003)	CO_2	IPCC**	Annex I incl. USA	CC	+20/−60	+30/+5	
Bollen et al. (2004)	CO_2	IPCC A1	Annex I excl. USA & Australia	CC		+30/NI	+50/NI
Groenenberg et al. (2004)	CO_2	IPCC A1	Not included; base-year 1995	TY	+15/NI	[20; 30]/+5	[35; 60]/+50
Böhringer and Löschel (2005)	CO_2	DOE ref.	Annex I excl. USA & Australia	Other			+50
den Elzen and Lucas (2005)	CO_2-eq	CPI 2003	Annex I excl. USA & Australia	MS, CC, EI, TY, other		+35/−20	+50/+35
den Elzen et al. (2005b)	CO_2-eq	CPI 2003	Annex I excl. USA & Australia	MS, CC, HR		+35/−20	+50/+35
Höhne et al. (2005) (Höhne 2005)	CO_2-eq	IPCC all*	Annex I incl. USA; FSU BAU[c]	MS, CC, EI, TY, other	+10/−40	+30/−10	+50/+45
Michaelowa et al. (2005)	CO_2	Own	Annex I excl. USA & Australia	MS			+30[d]/NI
Böhringer and Welsch (2006)	CO_2	IPCC** A1	Not included; base-year 2000	CC		[30; 35]/−15	

den Elzen and Meinshausen (2006a, b)[e]	CO_2-eq	CPI 2003	Annex I excl. USA & Australia	MS, CC	[20; 30]/ [−30;−50]	+40/[−10; 10]	
Persson et al. (2006)	CO_2	IPCC A1	Annex I excl. USA	CC		+36	
Studies published after IPCC AR4							
den Elzen et al. (2007a)[e,f]	CO_2-eq	CPI 2003	Annex I excl. USA & Australia	Other	[20; 30]/ [−30;−50]	+40/[−10; 10]	
den Elzen et al. (2008b)[e]	CO_2-eq	IPCC B2***	Annex I excl. USA & Australia	MS, CC	+20/−35	+35/−5	
den Elzen et al. (2008a)[e]	CO_2-eq	IPCC B2***	Annex I excl. USA & Australia	TY	+20/−35	+35/−5	
Höhne et al. (2006)[f]	CO_2-eq	IPCC* all	Annex I excl. USA; FSU BAU[c]	Other, CC		+35/−25	+50/+35
Vaillancourt and Waaub (2006)	CO_2	Own	Not included; base-year 2000	Other			+57/+65
Höhne et al. (2007)[f]	CO_2-eq	IPCC* all	Annex I excl. USA; FSU BAU[c]	MS, CC, HR, TY, other	+10/−40	+30/−10	+50/+45
Baer et al. (2008)	CO_2	WEO 2007[g]	Annex I excl. USA	Other	+10/−80		
Timilsina (2008)	CO_2	Own	Annex I excl. USA; FSU BAU[c]	EI			+46/NI
Number of studies					11	16	14

NI Not included

[a]Own: scenario based on own assumptions; IPCC*: IMAGE implementation of IPCC SRES 2001 scenarios (IMAGE-team 2001); IPCC**: IIASA (1998) implementation; CPI: common POLES-IMAGE baseline (van Vuuren et al. 2003, 2006); DOE reference scenario (DOE 2003); Update IPCC B2***: updated IMAGE/TIMER implementation of the IPCC-SRES B2 scenario (van Vuuren et al. 2007), which roughly follows the reference scenario of the World Energy Outlook (WEO) 2004 (IEA 2004)

[b]The abbreviations of the schemes are given in Table 3

[c]The emissions of the former Soviet Union (FSU) and Eastern European countries are assumed to equal the baseline or business-as-usual (BAU) emissions (which are far below their Kyoto targets)

[d]For the period 2013–2017

[e]Assuming a (temporary) overshoot of about 50 ppm

[f]Uncertainty ranges presented in this study also include uncertainties in scenarios, but this effect is limited, and not included in Fig. 1

[g]Reference scenario of the WEO 2007 (IEA 2007)

- *The assumed allocation scheme covered:* Some studies in Table 2 focus on one scheme, whereas others include a wide range of about ten schemes (see for example, den Elzen and Lucas 2005).
- *Global emission limits:* Many global emission pathways can lead to the same long-term concentration stabilisation level. Pathways with higher emissions in the earlier part of the century have lower emissions in the later part of the century. Therefore, it is important which global emission level in 2020 and 2050 was chosen from a possible range that represents one long-term stabilisation level (i.e. 450, 550 and 650 ppm CO_2-eq).

Table 2 (bottom part) also shows the seven new allocation studies that became available after the finalisation of the IPCC report. In fact, the first four of these studies were already included in the calculations of the presented reduction ranges, but at the last moment of publication of the IPCC AR4 report, their citations were excluded, as these studies were still unpublished, at the time.

Figure 1 presents the resulting emission reduction targets for the Annex I and non-Annex I countries as a group, which are mainly based on information provided by the authors of the studies or, for some studies, are derived from detailed information in the papers themselves. The figure also presents the adopted IPCC AR4 reduction ranges (Gupta et al. 2007). The IPCC AR4 based these ranges on the outcomes of all studies mentioned in Table 2 (except for Leimbach 2003; Vaillancourt and Waaub 2006; Höhne et al. 2007; Baer et al. 2008; Timilsina 2008). We listed all studies that were available to us. Outliers that provide substantially different results compared to other studies were excluded and more weight was given to the more recent multi-gas studies. We did not make judgements on the way the studies allocated emission reductions across regions and countries.

A brief overview of the studies is given below.

The study by Berk and den Elzen (2001) is one of the first, quantifying post-2012 CO_2 emission allocations for meeting long-term concentration stabilisation targets, based on three regimes, i.e. Multi-Stage, Contraction & Convergence (C&C) and Berk and den Elzen's implementation of the Brazilian proposal (see Table 3). The study assumed that all Annex I countries would meet their Kyoto targets (the USA had not rejected ratification), a low global emission target of only 10% above 1990 levels, by 2020, and 20% below 1990 levels, by 2050. Based on its low short-term emission this study is clustered under the lowest IPCC 450 ppm CO_2-eq category (Table 2).The Annex I countries, as a group, need to reduce their emissions from about 30% to 45% below 1990 levels, which is at the lower end of the IPCC AR4 range (see Fig. 1). The reductions for the non-Annex I countries, as a group, range from 15% to 35% below the baseline emissions. Later, den Elzen (2002) also included Triptych regime calculations and an extensive sensitivity analysis. Similar work has been done by Blanchard (2002), focussing on stabilisation at 550 ppm CO_2 concentration (about 650 ppm CO_2-eq). Winkler et al. (2002) also calculated the CO_2 emission allowances of the key developing countries, using three allocation schemes, and assuming global CO_2 emissions returning to 1990 levels by 2020, and using the lowest IPCC SRES B1 scenario.

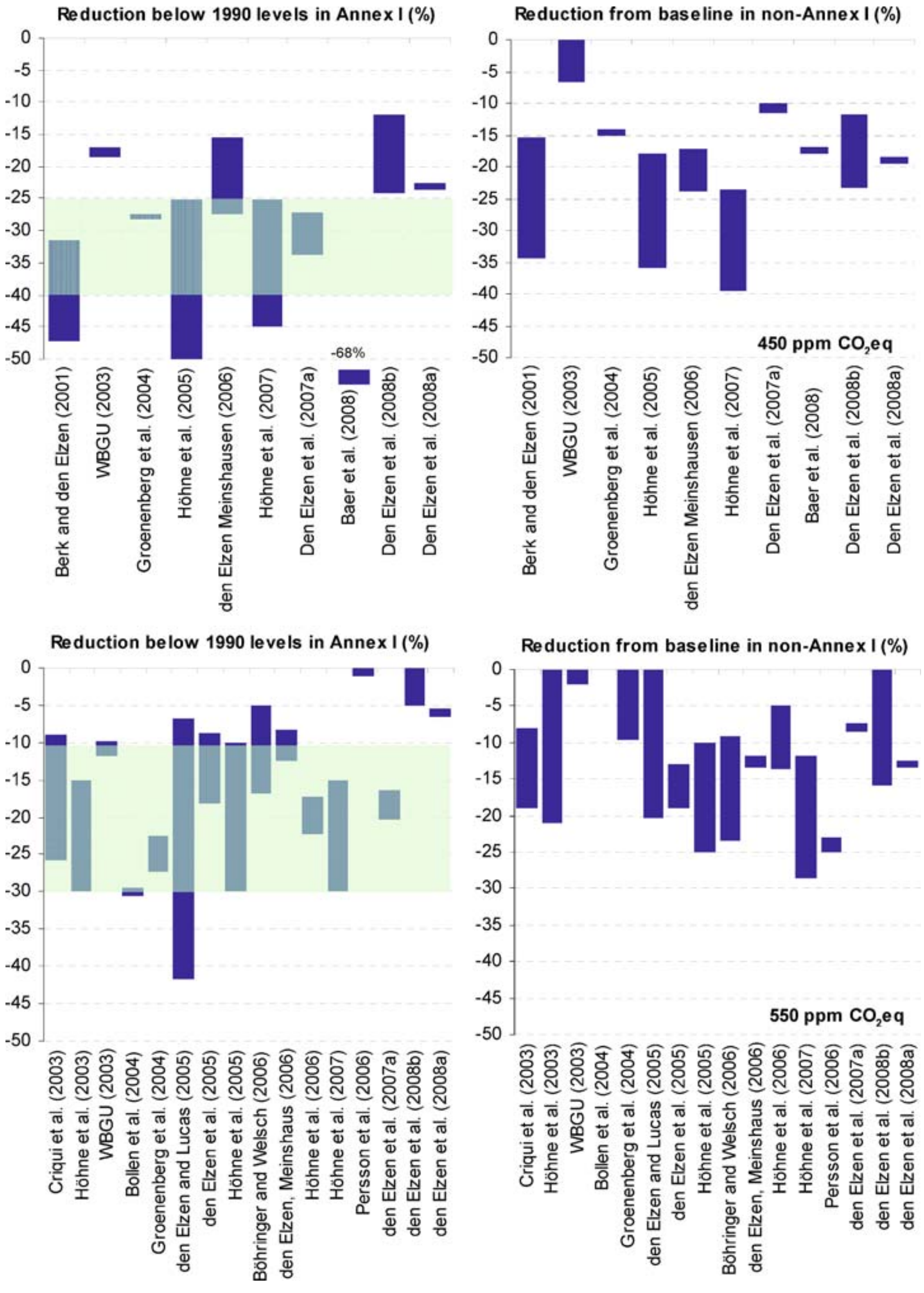


Fig. 1 Reductions in Annex I (below 1990 level) and non-Annex I countries (below baseline) as a group in 2020 for the studies quoted by the IPCC and more recent studies. Uncertainty ranges indicated here, are based on the outcomes of different post-2012 regimes. The figure also depicts the reduction ranges for Annex I countries as reported in IPCC Box 13.7

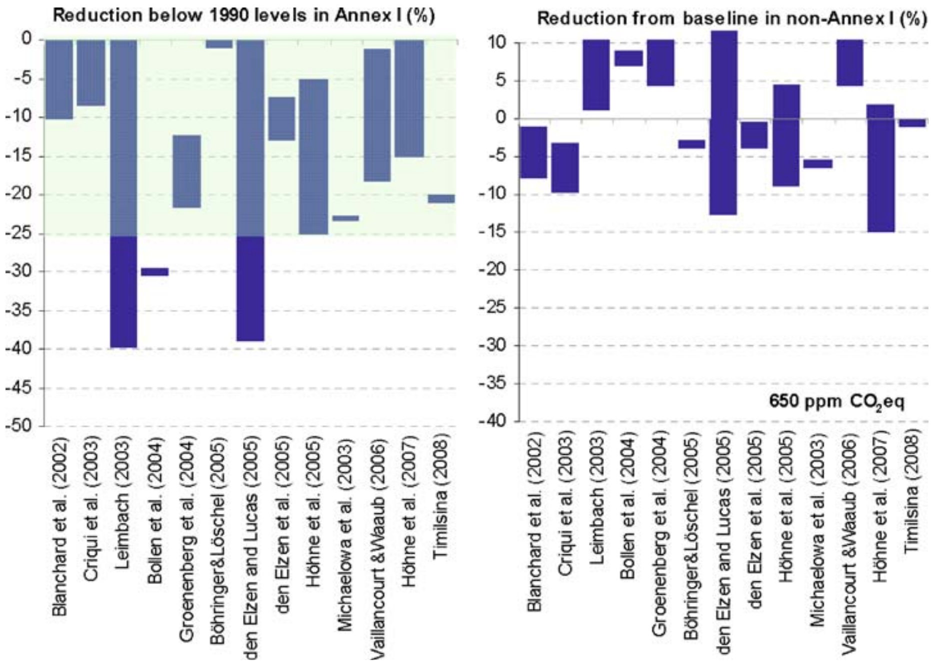


Fig. 1 (continued)

Most studies in Table 2 focussed on CO_2 only, instead of all GHGs. Criqui et al. (2003) and Höhne et al. (2003) were among the first to calculate emission allowances for all GHGs, i.e. CO_2-equivalent emissions, including the anthropogenic emissions of six Kyoto greenhouse gases (fossil CO_2, CH_4, N_2O, HFCs, PFCs and SF_6 (using the 100-year GWPs of IPCC 2001)). These studies, as did all earlier studies, excluded LULUCF CO_2 emissions, as these were too uncertain. Criqui et al. (2003) presented reduction targets for two C&C variants (convergence years 2050 and 2100) and three Multi-Stage variants for regions, and focused on stabilising GHG concentration targets at 550 and 650 ppm CO_2-eq (see also den Elzen et al. 2006). Den Elzen and Lucas (2005) extended this analysis, using ten very different emission allocation schemes, varying from grandfathering to a convergence in per capita emissions before 2015, leading to a wide range of reductions in Annex I countries, below 1990 levels. Another follow-up study, den Elzen et al. (2005b), focused on less regimes, but also presented abatement costs.

Höhne et al. (2003) focussed on a wide range of post-2012 regimes (all variants of those mentioned in Table 3) for a global emission target in 2020 (roughly corresponding with 550 ppm CO_2-eq), and was the first to present the reduction targets for individual countries.[1] The reductions for Annex I countries in 2020 are, in general, more stringent than those in Criqui et al. (2003), due to their assumed lower

[1]They used baseline scenarios for population, GDP and emissions at the level of countries, based on applying the regional downscaling method for the IPCC SRES emission scenarios from the four IPCC SRES regions to countries.

Table 3 Short description of the various post-2012 regimes for differentiation of future commitments (allocation schemes)

Approach	Abbreviation	Operational rule for allocation of emission allowances
Multi-Stage approach	MS	An incremental but rule-based approach, which assumes a gradual increase in the number of parties taking on mitigation commitments and in their level of commitment as they move through several stages according to participation and differentiation rules (Berk and den Elzen 2001; den Elzen 2002).
Historical responsibility (Brazilian Proposal)	HR	Reduction targets based on countries' contribution to temperature increase (UNFCCC 1997; den Elzen et al. 2005a).
Ability to Pay	AP	Emission reduction allocation and participation based on per capita income thresholds (Jacoby et al. 1999).
Contraction & Convergence (C&C)	CC	Emission targets based on a convergence of per capita emission levels of all countries under a contraction of the global emission profile (Meyer 2000).
Emission Intensity	EI	Emission reductions related to improvements in the emission per unit GDP output (Baumert et al. 1999).
Triptych	TY	Emission allowances based on various differentiation rules to different sectors for all Parties (Phylipsen et al. 1998).

2010 emissions in Annex I countries (the starting point of the calculations), from stronger Kyoto reduction assumptions. Höhne et al. (2003) assumed that all Annex I countries (including USA) implement the Kyoto targets, except for the former Soviet Union (FSU) and Eastern European States, which start from their baseline emissions (far below the Kyoto target). Criqui et al. (2003), however, assumed that all Annex I countries meet the Kyoto targets (this is for FSU and Eastern European States well above their baseline), except for the USA, which are assumed to meet their national target (about 25% above 1990 levels in stead of −7% below 1990 emissions under Kyoto in 2010).

Besides these studies, there are also CO_2-only studies with macro-economic or energy-system models, which focus primarily on the C&C regime for global CO_2-only emissions targets, as was done by Bollen et al. (2004), Leimbach (2003), Persson et al. (2006) and WBGU (2003). These studies mainly vary the convergence year between 2025 and 2100, showing stringent reductions for Annex I countries for an early convergence. WBGU (2003) (identical to Nakicenovic and Riahi 2003) focuses on C&C 2050 and 2100 for 400 ppm CO_2 concentration stabilisation under the IPCC B1 and B2 baseline scenarios, and 450 ppm CO_2 under the IPCC A1T scenario. The first group of 400 ppm CO_2,corresponding with the lowest 450 ppm CO_2-eq target, and the lower baseline scenarios (B1 and B2), in particular, lead to low reductions targets for Annex I and non-Annex I countries (well above the IPCC AR4 range) (Fig. 1). Bollen et al. (2004) and Leimbach (2003) focus on global emission targets, in 2020, as high as 50–75% above 1990 levels (within 650 ppm CO_2-eq) and show high reduction targets for Annex I countries (30% to 40% below 1990 levels)—well below the IPCC AR4 range. In contrast, they have surplus emission allowances (emissions above the baseline) for non-Annex I countries. Compared to the other results, these studies seem outliers. Böhringer and Welsch (2006) used emission allocations from current emissions, based on equal-per-capita emission.

Groenenberg et al. (2004) has extended the Triptych approach for all GHGs and also presented an extensive sensitivity analysis, showing a wide range of reduction targets for Annex I and non-Annex I countries in 2020. As Kyoto targets were not considered, the reduction targets are somewhat higher, but still within the IPCC AR4 ranges. Den Elzen et al. (2008a) further improved the Triptych approach by, for example, a differentiated participation for developing countries that, together with accounting for the Kyoto targets (excluding the USA), lead to reduction targets which are somewhat lower than the IPCC AR4 reductions.

Böhringer and Löschel (2005) use another approach that differs from the rule-based allocation schemes used in all previous studies. They interviewed experts about their judgment on four key aspects of a possible Post-Kyoto scenario, until 2020: the targeted global emission reduction, USA participation, the inclusion of developing countries, and the allocation rule for abatement duties. In general, this approach leads to a high global emission limit by 2020 and rather low reduction targets for the Annex I and non-Annex I countries (Table 1 and Fig. 1).

Vaillancourt and Waaub (2006) proposed a dynamical multi-criterion method to compare various alternative allocation rules and found a compromise solution, although this led to global emissions as high as 50% above 1990 levels in 2020.

Höhne et al. (2005) updated the calculations of in their study of 2003, again for a wide range of regimes. For the lowest concentration category, a non-overshoot 400 ppm CO_2 concentration stabilisation (about 450 ppm CO_2-eq) is assumed. This, combined with the stronger Kyoto reduction assumptions (all Annex I countries including the USA implement Kyoto), leads to emission reductions in Annex I countries, up to 45% below 1990 levels in 2020, for 450 ppm CO_2-eq. In general, their reduction range exceeds the IPCC AR4 range on the lower end. Höhne et al. (2007) further updated the analysis with very similar reduction ranges, although they now assumed that the USA follows its national target, leading to a less ambitious range for Annex I countries. In Höhne et al. (2006) a variant of the per capita convergence (‘common but differentiated convergence’) is presented, in which the per capita emissions of all countries converge to a low level. The per capita emissions in non-Annex countries, however, start to converge later, but end up at the same level. This leads to slightly more ambitious 2020 I reduction targets for Annex I countries.

Den Elzen and Meinshausen (2006b) focused on Multi-Stage and C&C, and GHG concentration targets 400–550 ppm CO_2-eq. For 400 and 450 ppm CO_2-eq they assumed an overshoot in the concentration targets. This overshoot, combined with a lower baseline and less stringent Kyoto reduction assumption (all Annex I countries, except for the USA and Australia, implement their Kyoto targets by 2010), lead to less ambitious reduction targets for Annex I countries. Similar assumptions have been made in den Elzen et al. (2008b), presenting in detail the required abatement options and costs. As they excluded the 400 ppm scenario and used a lower baseline (update of IPCC B2), the reductions for Annex I and non-Annex I countries were less ambitious, although the USA still has to return to its 1990 levels by 2020. In den Elzen et al. (2007a) a variant of the Multi-Stage type regime, i.e. the 'South–North Dialogue' Proposal (Ott et al. 2004) was analysed. This proposal is based on the criteria of responsibility, capability and potential to mitigate, and include deep cuts in industrialised (Annex I) countries and differentiated mitigation commitments for developing countries.

Another very recent allocation study came from Baer et al. (2008), called the Greenhouse Development Rights Framework. This framework calculates national shares of the global mitigation requirement based on an indicator that combines capacity (per capita income over a $7,500 threshold) and responsibility (cumulative per capita emissions since 1990) in a way that is sensitive to intra-national income distribution. National allocations are then calculated by subtracting each country's share of the global mitigation requirement from its national baseline emissions trajectory. This approach leads to very high Annex I emission reductions of about −70% below 1990 levels in 2020.

The following findings can be drawn from Table 2 and Fig. 1:

- A wide range of studies cover the different stabilisation levels; most have studied 550 ppm CO_2-eq.
- The number of multi-gas studies that analysed the lowest concentration category, published at the time of writing the IPCC AR4, was limited, i.e. den Elzen and Meinshausen (2006b) and Höhne et al. (2005), but about four of these studies were in press at the time of writing the IPCC AR4 (see Table 1). In general, the studies of Höhne assume a lower global emission limit in 2020 (10%, 30% and 50% above 1990 levels for stabilisation at 450, 550 and 650 ppm CO_2-eq) and stronger Kyoto reduction assumptions (the USA follows Kyoto and FSU starts in 2010 with baseline emissions), whereas the studies of den Elzen assume a higher global emission limit (25%, 40% and 50% for stabilisation at 450, 550 and 650 ppm CO_2-eq by 2020) and lower Kyoto reduction targets (the USA follows national policy by 2010, and FSU starts in 2010 at their Kyoto targets). Therefore, the studies of Höhne et al. lead to more stringent reduction targets in the presented ranges for 2020, whereas those by den Elzen et al. lead to less stringent reduction targets for 2020. However, less stringent reductions in the short term require more stringent reductions in the long term, to reach the same long-term stabilisation level. Hence, the targets presented by Höhne for the long term, are less stringent than those presented by den Elzen.
- There is no argument for updating the ranges in Box 13.7 of the IPCC report based on the new studies published after its completion, as all studies show reductions that are in line with the reduction ranges in the box.
- As has been explained in the IPCC report, the reductions in Annex I and non-Annex I countries in the Box largely depend on the regime assumptions, the

global emissions target (and related to the concentration stabilisation target) and depend on the assumptions on the initial 2010 emission levels. This issue is also further analysed in the next chapter.

- As was also concluded by Sheehan, most of these studies use baseline emission scenarios, mostly the IPCC SRES scenarios, that are developed before 2003 and do not account for the recent rapid growth in emissions. More specifically, in all studies the reference cases are within the SRES marker scenario range, and hence subject to the critique outlined in Sheehan (2008). The impact of new baseline scenarios will be discussed in the next section.
- The studies that were analysed show that emissions in the group of non-Annex I countries deviate from the baseline roughly between 15% to 30% for 450 ppm CO_2-eq, between 0% to 20% for 550 ppm CO_2-eq and from 10% above to 10% below the baseline for 650 ppm CO_2-eq, in 2020. Quantitative estimates per regional group for non-Annex I countries are not possible, as all studies used different regional groupings.

3 Assessing the emission reductions in Annex I and non-Annex I

One particular issue of interest is: if Annex I countries reduce their domestic emissions to a certain extent, then how far do the emissions in non-Annex I countries have to be reduced, to achieve the stabilisation of the climate at a certain level? In the previous sections it is described which Annex I reductions have been calculated by the different studies, as well as what these studies assumed to be a "substantial deviation from the baseline" for non-Annex I countries. This section further analyses which factors are important in this trade-off and it assesses their influence, using simple calculations to quantify this influence. The analysis concentrates on 2020 as this is the timeframe of major interest in the negotiations. The most important factors in the reductions of greenhouse gas emissions in Annex I and non-Annex I countries, in order of descending influence, are:

1. *Baseline emissions*: These are particularly uncertain for non-Annex I countries, but so is the historical emission trend, which is not always the same in the models.
2. *The assumed global emission level in 2020 for a long-term concentration stabilisation target*: As the long-term concentration stabilisation level depends also on the cumulative emissions, a certain stabilisation level can only be translated into an emission *range* in 2020. This range is particularly large if one assumes that concentrations may temporarily overshoot the desired level.
3. *Land-use CO_2 emission projections*: Current land-use related CO_2 emissions and projections are particularly uncertain and, mostly, they are not or only indirectly considered in the studies cited above.

Below, a brief description is given of the assumptions for the first two points, followed by an analysis of each of these points, in Section 3.3.

3.1 Baseline

Current and historical emission levels vary by a few percentage points, depending on the data source, but all data sources report an increase in global emissions. Table 4

Table 4 GHG emissions (excluding LULUCF CO_2 and international transport emissions) for the Annex I and non-Annex I countries as a group and the world, for the period 1990–2006 (upper) and 2020 projection (lower)

	Emission (million tonnes CO_2-eq)			Change compared to 1990 levels		
	Annex I	Non-Annex I	World	Annex I (%)	Non-Annex I (%)	World (%)
1990	18,531	12,847	31,378	0	0	0
1995	18,123	14,294	32,417	−2	11	3
2000	17,986	16,866	34,852	−3	31	11
2005	18,414	20,609	39,023	−1	60	24
2006	18,460	21,548	40,008	0	68	25
2020 scenario[a]						
IPCC A1 2001	23,558	34,732	57,616	27	170	84
IPCC A2 2001	23,110	29,752	52,434	25	132	67
IPCC B1 2001	19,334	28,435	47,222	4	121	50
IPCC B2 2001	20,520	31,234	51,114	11	143	63
IPCC A1F 2001	24,066	35,126	58,521	30	173	87
IPCC A1T 2001	33,408	23,034	55,812	24	160	78
CPI 2003	21,108	31,779	52,243	14	147	66
Update IPCC B2	22,345	27,530	49,370	21	114	57
Sheehan (2008)[b]	22,215	40,575	61,726	20	216	97

Source: GHG emissions for the period 1990–2005: IEA (2008); CO_2 emissions in 2006: BP (2007) and non-$CO_2$and process CO_2 emissions in 2006: using the trend of 2004–2005.

[a]IPCC: IMAGE implementation of IPCC SRES 2001 scenarios (IMAGE-team 2001); CPI: common POLES-IMAGE baseline (van Vuuren et al. 2003, 2006); Update IPCC B2: updated IMAGE/TIMER implementation of the IPCC-SRES B2 scenario (van Vuuren et al. 2007)

[b]As the Sheehan baseline does not include the non-CO_2 GHG emissions, we have estimated these based on the IMAGE IPCC SRES A1b scenario.

gives the historical trend in the global GHG emissions (excluding land-use related CO_2 emissions and international transport emissions) for one very recent data source. In 2005, global CO_2-eq emissions were about 24% above 1990 emission levels (IEA 2008). The 2006 figures are based on a preliminary estimate by the Netherlands Environmental Assessment Agency, using recently published BP [British Petroleum (BP 2007)] energy data and cement production data. From 2005 to 2006, global CO_2 emissions from fossil fuel use increased by about 2.6%, which is less than the 3.3% increase the year before.[2] The 2.6% increase is mainly due to a 4.5% increase in global coal consumption. In the 1990–2006 period, global fossil-fuel related CO_2 emissions increased over 35%, which is an increase of 25% for the overall GHG emissions (excluding LULUCF CO_2 emissions), assuming an ongoing linear trend over the past 5 years, for the non-CO_2 GHG emissions in 2006.

Even if the Kyoto Protocol is implemented by those countries that have ratified it, it is very likely that global emissions will continue to rise until 2012, when a new international climate agreement can start to be effective. The approximate stabilisation of emissions by Annex I countries will be more than counterbalanced by an ongoing and strong rise in emissions in non-Annex I countries.

[2]http://www.mnp.nl/en/dossiers/Climatechange/moreinfo/Chinanowno1inCO2emissionsUSAinsecondposition.html.

Table 4 also shows the projections of future emissions from various sources. The standard set of emission scenarios, IMAGE implementation (IMAGE-team 2001) of the IPCC special report on emission scenarios (Nakicenovic et al. 2000) was prepared already in 2001 and, therefore, does not reflect the recent changes in emissions.[3] Still, its large range covers most of the scenarios that were produced afterwards. Already in 2020, the spread will be high: global emissions could be as low as 50% below, or as high as 92% above 1990 level, according to the recent projection of Sheehan (2008) (for a discussion of this scenario, see van Vuuren and Riahi 2008). The impact of the various baselines on the reductions in Annex I and non-Annex I countries, will be analysed in Section 3.3.

3.2 Global emission level in 2020 necessary for a long-term concentration stabilisation target

A second, very important assumption is the global emission level in 2020, necessary for a long-term concentration stabilisation target. The long-term stabilisation level depends also on the cumulative emissions. A long-term stabilisation level can only be translated into an emission *range* in 2020. This range is particularly large if one assumes that concentrations may temporarily overshoot the desired level. In earlier studies, this emission level is lower, as they assumed that reductions would start earlier and would not be postponed, in the way they are in the current trends.

Höhne et al. (2005) were rather optimistic about the Kyoto implementation and early action by developing countries and did not allow for overshooting. They, therefore, used very low global emission levels of 10% and 30%, compared to 1990 levels in 2020, for 450 and also 550 ppm CO_2-eq, based on stabilisation paths from various sources that were available at that time. Given that today's global GHG emission level (excluding LULUCF CO_2) is already 25% above 1990, and that it will further increase until 2010, the chosen values are very ambitious and reaching +10% may have become unrealistic.

Den Elzen and Meinshausen (2006a, b) also presented emission pathways to stabilise CO_2-eq concentrations at 550 and 450 ppm. The 450 ppm pathway allows overshooting, i.e., concentrations peak before stabilising at lower levels, rising to 500 ppm CO_2-eq, before dropping to the 450 ppm CO_2-eq, later on. Allowing an overshoot also relaxes the global emission targets in the short term (2020), but increases the necessary effort afterwards (up to 2050 and beyond), shifting the burden into the future. The GHG emissions (excluding LULUCF CO_2) may increase to 30%, compared to 1990 levels in 2020, for 450 ppm CO_2-eq.

To illustrate the impact of the first three elements (baseline, 2020 global emission level and land-use CO_2 emissions) on the emission reduction in Annex I and non-Annex I, we use the global emission targets of den Elzen et al. (2007b), presenting the global GHG emission pathways for the three concentration stabilisation levels, and their ranges (see Table 5). The numbers of this study are in line with den Elzen and Meinshausen (2006b) and another study of Meinshausen et al. (2006), using the EQW methodology, and are within the 2020 and 2050 ranges of the IPCC AR4 (Fisher

[3]The IMAGE IPCC SRES scenarios are used here, as this set is used by many allocation studies in Table 2, for reasons of consistency (one single model is used for all scenarios) and regional detailed information.

Table 5 Assumptions for global emission target (excl. LULUCF CO_2) in 2020 and 2050 (%-compared to 1990 emission levels) for the different multi-gas pathways for stabilising at 450, 550 and 650 ppm CO_2-eq concentration of this study and Höhne et al

CO_2-equivalent	This study (based on den Elzen et al. 2007b)		Höhne et al. (2005)
concentration	Central estimate (%)	Range[a] (%)	(%)
2020			
450 ppm (no overshoot)			+10
450 ppm (overshoot)	+25	[+15; +30]	
550 ppm	+40	[+30; +45]	+30
650 ppm	+50	[+40; +60]	+50
2050			
450 ppm (no overshoot)			−40
450 ppm (overshoot)	−35	[−45;−25]	
550 ppm	−5	[−10; 0]	−10
650 ppm	+35	[+20; +60]	+45

Numbers are rounded off to the nearest decimal or half-decimal.

[a]The uncertainty range presented here needs to be considered carefully in the context of the envelope. Choosing lower reductions in the beginning needs to be compensated by higher reductions later on and vice versa.

et al. 2007). These estimates do not account for possible higher carbon releases from the terrestrial biosphere (such as carbon cycle feedbacks, or continuing high deforestation).

3.3 Analysis

Figure 2 shows the trade-off between deviations from baseline in non-Annex I countries in 2020 (left to right) and the change in GHG emissions for Annex I countries, compared to 1990 (top to bottom) for the stabilisation levels, as shown in Table 5 for den Elzen et al. (2007b). The Annex I reduction range of the AWG of −25% to −40% is also shown.

Note that these reductions are assumed to occur independently by domestic reductions in Annex I and non-Annex I countries. If Annex I countries decide to achieve some of these reductions outside of the group (through CDM or any other future mechanisms), additional reductions have to occur in developing countries.

The calculations behind these figures are very straightforward. First, a simple calculation can be made of the total overall global allowable emissions to meet the various concentration stabilisation targets, by combining the global GHG emission targets of Table 5 with the global GHG emissions of Table 4. In the second step, the allowable emissions of the Annex I countries can be calculated, by combing the allowable emissions of the non-Annex I countries (calculated as the reduction from their baseline emissions, see Table 4) and the global allowable emissions of step 1.

Figure 2 provides the average outcome over separate calculations for each of the six IMAGE IPCC SRES scenarios (IMAGE-team 2001) (A1B, A1Fl, A1T, A2, B1, B2) (*the IPCC SRES average*), for 2020 and 2050 to capture a wide spread of possible future baseline emission developments.

To exemplify the figure, an example is given for the average over the six IPCC SRES scenarios. Figure 2a shows that the emission reductions for Annex I countries, as a group, of 25% relative to 1990 in 2020 (top range of the green shaded area),

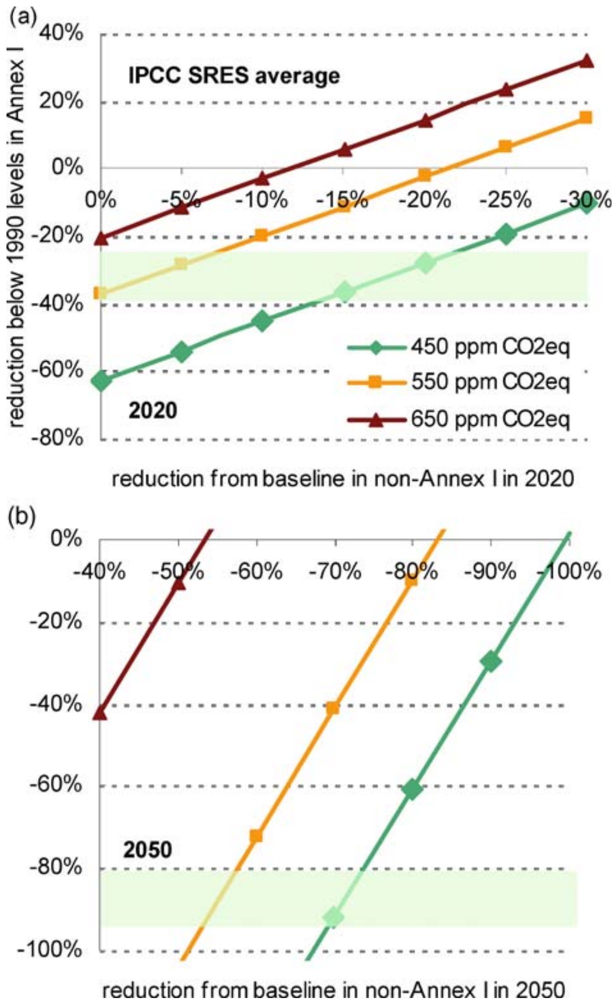


Fig. 2 The trade-off in reductions in 2020 (**a**) and 2050 (**b**), in Annex I and non-Annex I countries as a group, for three concentration stabilisation levels. The *numbers* represent the averaged outcome over separate calculations for each of the six IPCC SRES baselines (IPCC SRES average). The figure also depicts the reduction ranges for Annex I countries for 450 ppm CO_2-eq as reported in IPCC Box 13.7

and deviation from the baseline by non-Annex I countries, as a group, of around 7% is consistent with a 550 ppm CO_2-eq stabilisation level (intersection of the middle yellow line for 550 ppm with the top range of the green shaded area). For meeting 450 ppm CO_2-eq stabilisation, the non-Annex I countries' deviation, compared to the baseline, becomes around 22% (intersection of the bottom green line for 450 ppm with the top range of the green shaded area). If non-Annex I countries do not deviate from the baseline, then even if Annex I countries cut their emissions by about 40% in 2020, stabilisation of only slightly less than 550 ppm CO_2-eq is possible. Figure 2b also shows the results for 2050, for example, showing that for 550 ppm CO_2-eq a 80% emission reduction in Annex I countries corresponds with about 55% reduction from the baseline for non-Annex I countries. Note that this is viable only for the average of the IPCC SRES baseline scenarios. The outcome for individual IPCC SRES scenarios is different (see below).

3.3.1 Baseline emissions

The outcomes of the calculations heavily depend on the assumed baseline scenario (see also Section 3.1), as can be seen in Fig. 3. It shows the same picture for only one stabilisation level at a time (using the central estimate as shown in Table 5), but for various baseline scenarios (the IPCC scenarios and their updates as mentioned in Table 2 and the baseline of Sheehan), i.e. the average of the IPCC SRES baseline, as well as the minimum and maximum outcome, the common POLES-IMAGE (CPI) baseline (van Vuuren et al. 2003, 2006) and the update of IPCC B2 (van Vuuren et al. 2007). The figure shows that if Annex I countries as a group reduces with 30% below 1990 level, non-Annex I need to reduce about 10–25% below baseline for meeting 450 ppm CO_2-eq under the IPCC SRES emission scenarios. For the baseline of Sheehan (2008), which reports much higher growth in emissions in non-Annex I countries compared to the growth under the IPCC scenarios, the reduction becomes as high as 35% for non-Annex I (Table 4).

For all stabilisation levels, the choice of the baseline has significant implications for the required reductions in Annex I and non-Annex I countries. For example, 450 ppm CO_2-eq and 40% reduction of emissions in Annex I countries (top left figure, lower border of the green shaded area) would not require any deviation from the lowest baseline (minimum of the IPCC SRES), but a 20% deviation from the highest baseline for developing countries (maximum of the IPCC SRES). For the baseline of Sheehan this would even mean a deviation as high as 30%. In this scenario, the very high emission growth in non-Annex I countries, leads to much higher reductions in the Annex I and non-Annex I countries as the figure shows. Much less emission space is left for the Annex I countries when we fix the reduction below baseline in non-Annex I, or much higher deviation from the baseline in the non-Annex I countries is necessary when we fix the reduction for the Annex I countries.

3.3.2 The assumed global emission level in 2020 for a long-term concentration stabilisation target

So far, the central estimates have been assumed for the global emission limits in 2020. The uncertainty ranges of the global emission limits of 2020 have been used (see Table 5), and the effects of using the minimum and maximum have been analysed (see Fig. 4). For example, the figure shows that for 450 ppm CO_2-eq and a 40% emission reduction for Annex I countries would require a 7% to 22% deviation from the baseline, for a maximum and minimum global emission limit, compared to a 12% deviation for the default global limit.

3.3.3 Land-use CO_2 emission projections

The next important factor is the assumption of emissions from land use, land-use change and forestry (LULUCF).

The allocation studies by Höhne assume that CO_2 emissions from LULUCF need to decline at the same speed as emissions from all other sectors. However, while most baseline scenarios assume an increase in emissions in other sectors (in particular in the developing countries with the highest LULUCF emissions), all baseline scenarios assume that these emissions will decline over the course of the century. This is due

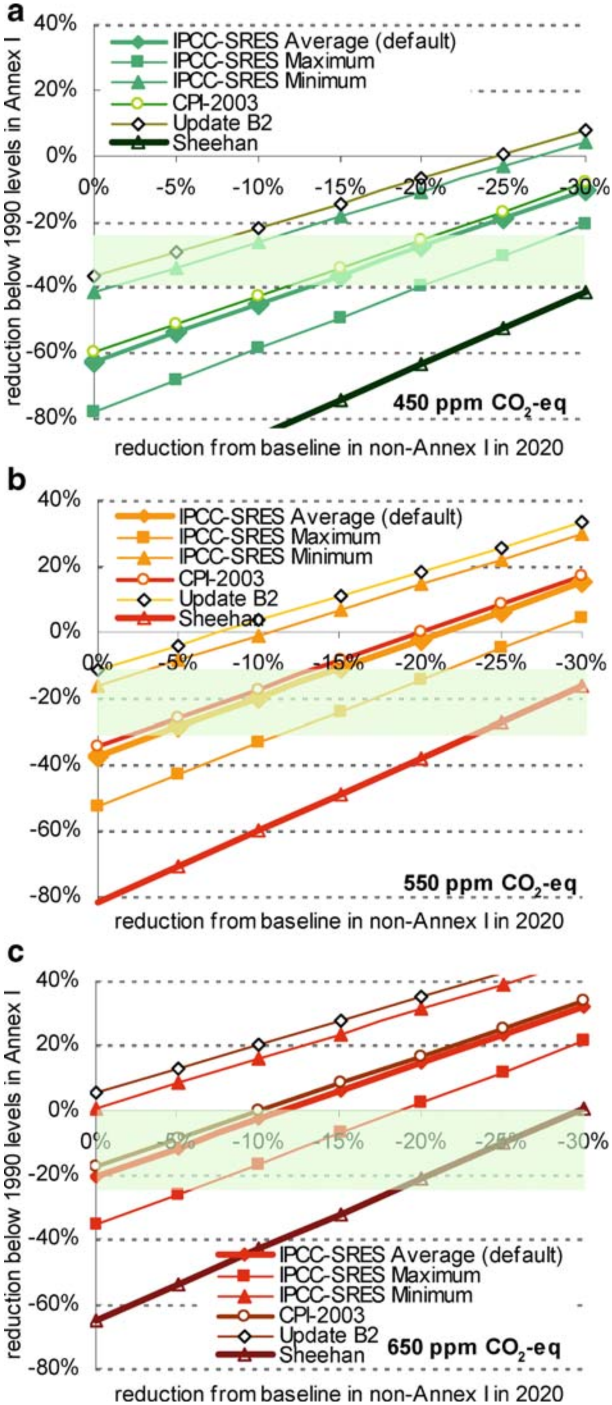


Fig. 3 The trade-off in reductions in 2020, in Annex I and non-Annex I countries as a group, for various baseline emissions (incl. baseline of Sheehan), for concentration stabilisation at 450 (**a**), 550 (**b**) and 650 (**c**) ppm CO_2-eq**.** The figure also depicts the reduction ranges for Annex I countries for the concentration stabilisation levels as reported in IPCC Box 13.7

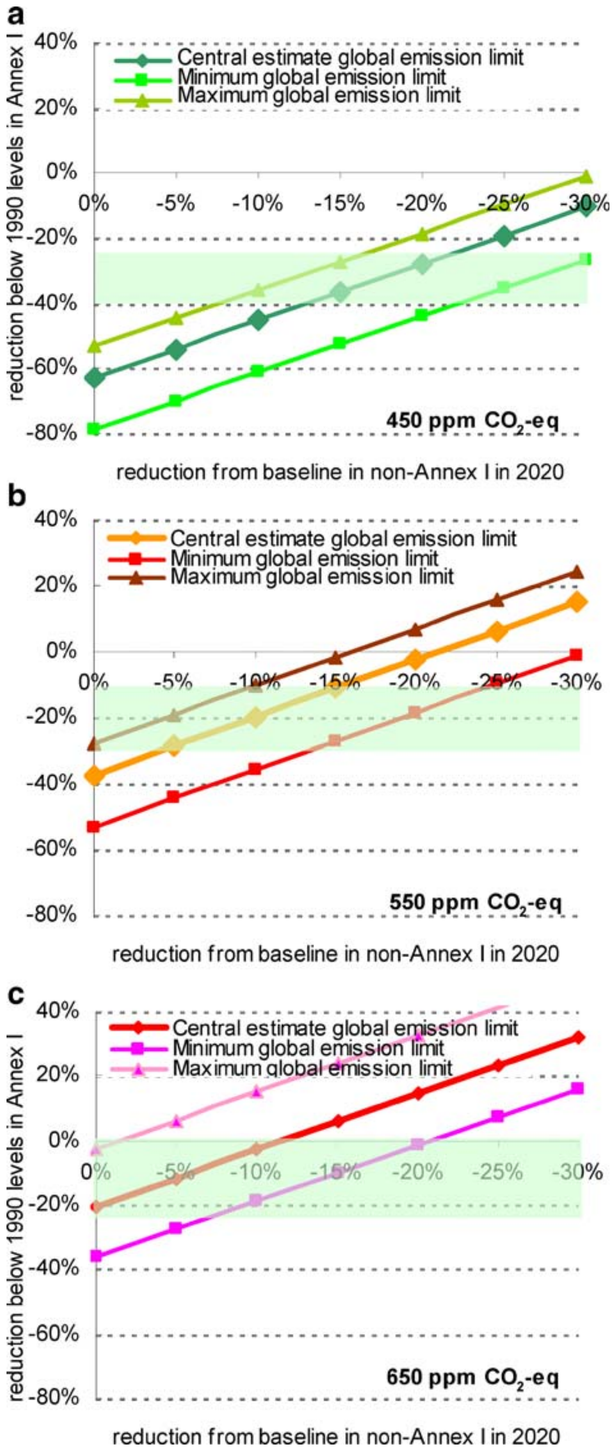


Fig. 4 The trade-off in reductions in 2020, in Annex I and non-Annex I countries as a group, for various global emission limits in 2020, for concentration stabilisation at 450 (**a**), 550 (**b**) and 650 (**c**) ppm CO_2-eq**.** The *numbers* represent the averaged outcome over separate calculations for each of the six IPCC SRES baselines. The figure also depicts the reduction ranges for Annex I countries for the concentration stabilisation levels as reported in IPCC Box 13.7

Table 6 Assumptions for global emission target (excl. LULUCF CO_2) in 2020 (%-compared to 1990 emission levels) for the different multi-gas pathways for stabilising at 450, 550 and 650 ppm CO_2-eq concentration for various assumptions on avoiding deforestation (affecting the LULUCF CO_2 emissions)

CO_2-equivalent concentration	Baseline deforestation (this study) Central estimate (%)	Avoiding deforestation 2020 (%)	Avoiding deforestation 2030 (%)
2020			
450 ppm	25	35	30
550 ppm	40	50	45
650 ppm	50	55	52

to the fact that, at a certain point, all forest is depleted (stopping the emission) and reforestation occurs (increasing the terrestrial carbon uptake).

The allocation studies by den Elzen assume that CO_2 emissions from LULUCF follow the baseline, so there will be no policy intervention against deforestation, and emissions will be ongoing until at least 2020, after which they will decline. This is also assumed in the calculations presented in the figures of this paper. The other allocation studies in Table 2 are not very clear about what they have assumed for the LULUCF emissions.

Separate policy interventions are currently discussed under the UNFCCC to avoid deforestation as early as possible. One could, therefore, assume that emissions from LULUCF, due to policy interventions against deforestation, are declining much faster than all other emissions. This means, in turn, that all other emissions could decrease slightly slower. To illustrate this influence of different intervention policies against deforestation, two cases have been tested (see Table 6). The first case is assuming a strong policy to avoid deforestation on the short-term, leading to zero emission by 2020, in the second case a medium policy is assumed, which leads to zero emission by 2030. The latter roughly corresponds with reducing the baseline LULUCF CO_2 emissions by 50% in 2020. Consequently, global emission levels of *all other sectors* could be higher (higher values in Table 6 compared to the central case).

Note that, again, the reductions in the sectors are treated independently, so they are not linked with the carbon market. If the avoiding of deforestation should be induced by the carbon market through a new emission credits transfer mechanism, then reduction targets of Annex I countries (buyers) would have to be more stringent.

Figure 5 shows the results in terms of reductions in Annex I countries below 1990 (top to bottom) and in non-Annex I countries below the baseline (left to right). Avoiding deforestation by 2020 eases the efforts of developing countries in all other sectors from −22% to −12% below baseline in 2020 for the 450 ppm CO_2-eq case.

3.3.4 Influence of all factors

What does the "substantial deviation from baseline" mean for non-Annex I countries in box 13.7? The answer depends on a number of factors, which are summarised in Fig. 6. It is assumed (a priori) that the group of Annex I countries reduce emissions

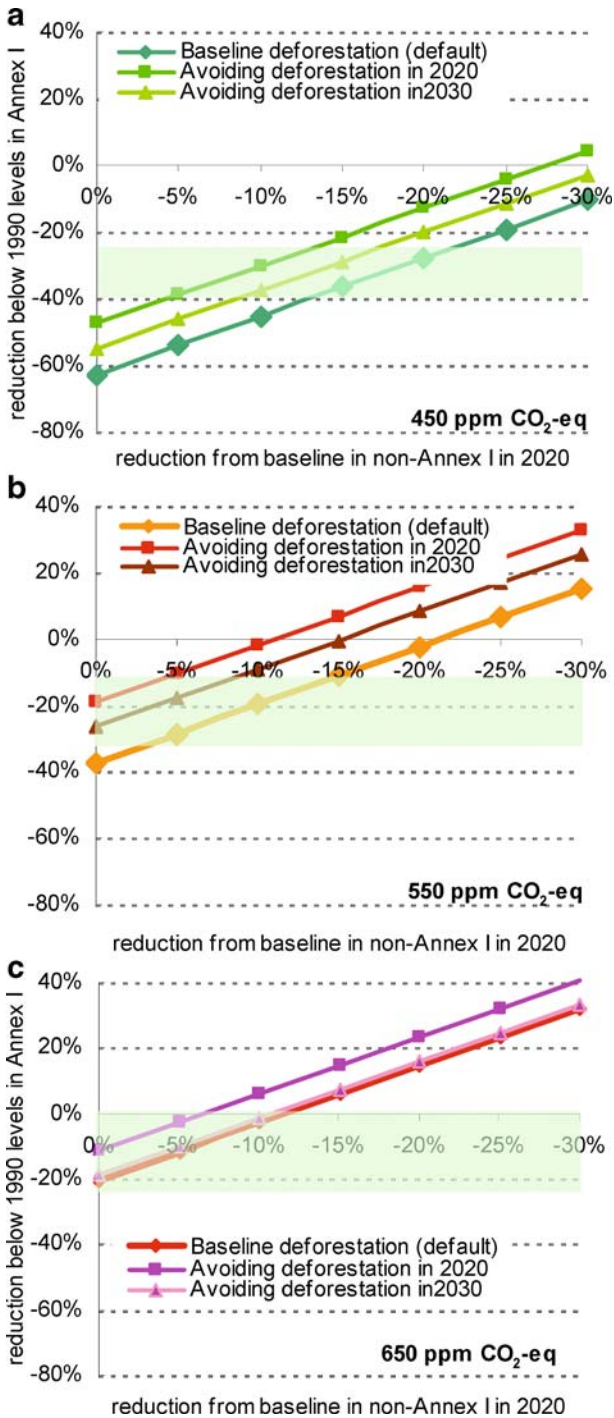
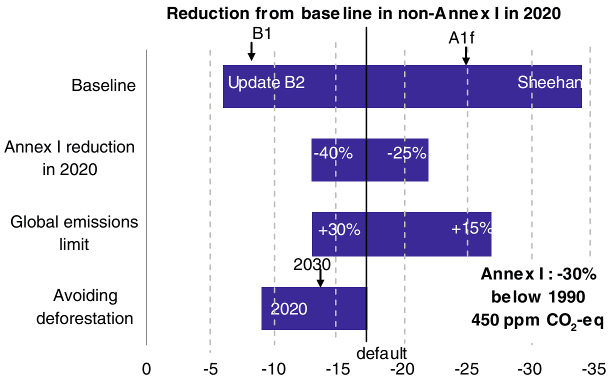


Fig. 5 The trade-off in reductions in 2020, in Annex I and non-Annex I countries as a group, for various assumptions on avoiding deforestation, for concentration stabilisation at 450 (**a**), 550 (**b**) and 650 (**c**) ppm CO_2-eq**.** The *numbers* represent the averaged outcome over separate calculations for each of the six IPCC SRES baselines. The figure also depicts the reduction ranges for Annex I countries for the concentration stabilisation levels as reported in IPCC Box 13.7

Fig. 6 The impact in the reduction from the baseline in non-Annex I countries as a group in 2020 of all factors assuming a 30% reduction in Annex I countries, below 1990 levels (default)



by a certain percentage and then analyse which reductions from baseline will be required in the non-Annex I countries. In this case, a 30% emission reduction below the 1990 emissions level in the Annex I countries was assumed, as this is roughly in the middle of the AWG reduction range of 25% to 40%. The substantial deviation for reaching 450 ppm CO_2-eq is very roughly around 17% below the baseline, in 2020.

The most important factor is the assumption on the baseline. Varying the baseline and keeping all other parameters constant, the reduction in the non-Annex I countries is between −5% and −35% below the baseline, in 2020. The baseline by Sheehan is the most ambitious, because it assumes the largest growth in non-Annex I emissions. Varying the assumed reductions in Annex I countries, means that the reduction in the non-Annex I countries could vary between −13% and −22%. Varying the global emission level in 2020 to still be consistent with 450 ppm CO_2 eq, the reduction in non-Annex I countries could vary between −13% to −27%. Varying assumptions on avoiding deforestation, means that the reduction in the non-Annex I countries could vary between −9% and −17%.

4 Conclusions

This paper provides background information on Box 13.7 of the IPCC Forth Assessment Report, Working Group III, which shows reduction ranges for Annex I and non-Annex I countries, for 2020 and 2050, consistent with stabilising the climate at various levels. In this paper, the authors of the box give more details on the studies used to prepare the ranges and analyse whether new information, obtained after completion of the IPCC report, influences these ranges. This analysis includes all studies that were available to us. We did not make judgements on the way the studies allocated emission reductions across regions and countries.

A first question was how the ranges were derived and whether these new allocation studies would change the results.

The conclusion is that there is no argument for updating the ranges in Box 13.7 of the IPCC report. The new studies that were published after the publication of the IPCC report show reductions that are in line with the reduction ranges in the box. The more recent allocation studies, published after the IPCC report came out, were accounted for in the calculations of the presented reduction ranges. However, the studies themselves were not referred to in the IPCC report, due to the fact that they were still in press or submitted at the time of its publication.

The ranges given in the box and in this paper are assumed to be achieved domestically by both groups of countries. If Annex I countries plan to achieve a part of their emission targets outside of their territory, through credit transfer mechanisms such as the CDM, then first the ranges presented in the box and in this paper would have to be achieved and the credit transfers would have to occur in addition.

From the studies analysed, this paper specifies "substantial deviation" and "deviation" from baseline in the Box: emissions in the group of non-Annex I countries may deviate from the baseline roughly between 15% to 30% for 450 ppm CO_2-eq, 0% to 20% for 550 ppm CO_2-eq and from 10% above to 10% below the baseline for 650 ppm CO_2-eq, in 2020, in addition to the stated reductions for Annex I countries. Quantitative estimates per regional group for non-Annex I countries are not possible, as all studies used different regional groupings.

A second question is what are the important determinants for the "substantial deviation from the baseline" in non-Annex I countries. Simple and transparent calculations were used to illustrate the impact of different assumptions.

The substantial deviation from baseline in the non-Annex I countries for reaching 450 ppm CO_2 eq for the default settings in our calculations is around 17% below the baseline, in 2020. The most important factor for this value is the assumption on the baseline. The reduction in non-Annex I countries is between −5% and −35% below the baseline, in 2020, with the baseline of Sheehan lying leading to the lower end of this range. When the assumed reductions in Annex I countries vary, then the reduction in non-Annex I countries could vary between −13% and −22%. With varying the global emission levels in 2020, the reduction in non-Annex I countries could vary between −13% to −27%. Varying assumptions on avoiding deforestation, means that the reduction in non-Annex I countries could vary between −9% and −17%.

As was also concluded by Sheehan, most of the allocation studies use baseline emission scenarios, mostly the IPCC SRES scenarios, which were developed before 2003, and do not account for the recent rapid growth in emissions. This paper shows that if higher baselines are used, such as the one of Sheehan, then reductions in Annex I and/or non-Annex I countries have to be more ambitious.

The analysis by this paper reconfirms that stabilising the climate at safe levels is a serious challenge. The current slow pace in climate policy and steadily increasing global emissions mean that it is almost unfeasible to reach relatively low global emission levels, in 2020, as was assumed to be possible by some studies of 5 years ago (e.g. +10% above 1990 level compared to +26% today). Newer studies assume higher global emission levels in the short term, but also assume more stringent emission reductions in the longer term, to reach the same stabilisation levels. Amplified efforts are needed to be able to turn around the trend in global greenhouse gas emissions.

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