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Emission implications of long-term climate targets

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Emission implications of long-term climate targets

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Abstract

This paper presents a set of multi-gas emission pathways compatible with different levels of ambition of avoiding long-term climate change, expressed in terms of long-term temperature targets, such as the EU 2°C target, and the certainty of achieving these. Also the effect of different assumptions on the resulting emission pathways, such as different baselines, technological improvement rates, or delay of global action is analysed. For achieving the EU target with a certainty of more than 50%, greenhouse gas concentrations need to be stabilised at 450 CO₂ equivalent or lower, requiring global emissions to peak within the next two decades, followed by substantial overall reductions by as much as 30 to 50% in 2050 compared to 1990 levels. The total emission reductions and the abatement costs strongly depend on the emissions growth in the baseline scenario and the further improvements of the abatement potential and reduction costs for all greenhouse gases in the future.

1. Introduction

The aim of this study is to explore allowable emissions levels of the set of the six greenhouse gases covered under the Kyoto Protocol on the long and short term compatible with any long-term climate policy targets to avoid dangerous climate change. In order to determine allowable levels of greenhouse gas emissions we have to back-calculate from acceptable levels of climate change to emissions. This is not simple. Not only is there the question to solve “what is an acceptable level of climate change (if any)?”, but also because there are major uncertainties in the cause-effect chain - the relationship between levels of greenhouse gas emissions and the impacts related to the human-induced climate change. Thus, we take a pragmatic route: The point of departure of our analysis will be the long-term climate targets of the European Union [1], i.e. a maximum temperature increase of 2°C over pre-industrial levels. It should be kept in mind though that, 2°C cannot be regarded as ‘safe’ as shown by many reviews of the scientific literature [2-4]. For example, the risk of heatwaves like the European heatwave of 2003 (and the resulting unusually large numbers of heat-related deaths) doubled due to human-induced climate change [5, 6].

We then develop multi-gas abatement pathways and analyze their associated risks to overshoot a climate target, such as 2°C [7, 8]. Such a risk assessment takes conceptually account of the main uncertainties in the climate system. Most studies on the implications of a multi-gas reduction strategy are of more recent date [see e.g. 9]. An important reason is that consistent information on

reduction potential for the non-CO₂ gases has been lacking. Available studies exploring the impacts of including non-CO₂ gases in the analysis of the Kyoto Protocol nevertheless find that major cost reductions can be obtained through the relatively cheap abatement options for some of the non-CO₂ gases and the increase in flexibility [10, 9]. Multi-gas studies on long-term stabilization targets indicate similar conclusions (e.g. Tol [11], Manne and Richels [12], van Vuuren et al. [13], den Elzen et al. [14]), or indicate important advantages in terms of avoiding climate impacts [15-17]. Other studies have explored the methodological issues of a multi-gas approach, such as which type of climate targets (for instance, concentration or temperature targets), can best be set for such a diverse group of gases (see Manne and Richels [12], Richels et al. [18], Fuglestedt et al. [19] and O'Neill [20]).

Obviously, it is much more complicated to define emission scenarios for stabilising CO₂ equivalent concentrations than CO₂ only, because these can be reached by various combinations of gasses, that also have different contributions to the radiate budget over time. So far there are roughly five ways of accounting the non-CO₂ emissions, by (i) simple scenario assumptions (e.g IPCC Third Assessment Report using a common non-intervention scenario (SRES A1B) for non-CO₂ emissions [21]); (ii) ‘scaling’, concentrations or radiative forcing are proportionally scaled with CO₂, for example, about 23% of CO₂ forcing as in Raper et al. [22]), or a certain CO₂ equivalent concentration level like 100ppm, to be added to a CO₂-concentration stabilisation target [23]; (iii) accounting for source-specific reduction potentials for all gases, as in the post-SRES scenarios [24, 25], (iv) differently elaborated ways based on cost-optimisation over

the greenhouse gas emissions [13] and/or over time [12] and (v) meta-approaches that make use of the multi-gas characteristics in existing scenarios derived by any of the previous approaches [26].

Here we focus on a cost-optimization variant, which closely reflects the political reality of pre-set caps on aggregated emissions and individual cost-optimising actors that decide in regard to the mix of reductions across the different greenhouse gases. The analysis focuses on two questions for climate-change policy-making:

1. What are emission pathways compatible with different levels of ambition of avoiding long-term climate change, expressed in terms of long-term temperature targets, such as the EU 2°C target, and the certainty of achieving these?

2. What is the effect of different assumptions, such as different baselines and technological improvement rates of abatement potential and costs on the emission pathways, and their resulting emissions reductions and abatement costs?

In the next section, the overall method is presented that has been used for this analysis of linking global emission pathways with climate targets. Section 3 presents the results of the analysis for various concentration stabilisation targets, and analyses the impact of some of the major uncertainties. Section 4 presents the global abatement costs. The final section draws up several conclusions.

2. Method for the development of emission pathways with cost-effective multi-gas mixes

In order to assess the emission implications of different stabilization levels, this study presents new multi-gas emission pathways for the scenario period 2000-2400, that were derived by a method for a cost-effective mitigation of emissions. This method calculates the cost-optimal mixes of greenhouse gas emission reductions for a given global emission pathway under a least costs approach. The emission pathway is determined iteratively to match prescribed climate targets of any level, as described in detail below. It should be kept in mind though that this approach does not derive cost-effective pathways over the whole scenario period per se, but focuses on a cost-effective split among different greenhouse gas reductions for given emission limitations on GWP-weighted and aggregated emissions. For example, based on the current model version with static cost assumptions, we cannot make definitive judgments on how a delay in global action will affect overall mitigation costs. However, the model framework allows very well analyzing the existing policy framework with preset caps on GWP-weighted overall emissions under the assumption of cost-minimizing national strategies. The emissions that

have been adapted to meet the pre-defined stabilization targets include those of all major greenhouse gases (fossil CO₂, CH₄, N₂O, HFCs, PFCs, SF₆), ozone precursors (VOC, CO, NO_x) and sulphur aerosols (SO₂).

For our method we use the policy decision support tool FAIR 2.0 [27] in combination with another climate policy tool SiMCaP [26].

The FAIR ('Framework to Assess International Regimes for the differentiation of commitments') 2.0 model developed at the RIVM (the Netherlands) (www.rivm.nl/fair) is a policy decision-support-tool, which aims to assess the environmental and abatement costs implications of climate regimes for differentiation of post-2012 commitments [28, 27]. For the calculation of the emission pathways only the (multi-gas) abatement costs model of FAIR is used. This model distributes the difference between baseline and global emission pathway, over the different regions, gases and sources following a least-cost approach, taking full advantage of the flexible Kyoto Mechanisms (emissions trading) [14]. For this purpose, it makes use of (time-dependent) Marginal Abatement Cost (MAC) curves¹ for the different regions, gases and sources (as described below). The FAIR model also uses baseline scenarios, i.e. potential greenhouse gas emissions in the absence of climate policies, from the integrated assessment model IMAGE² and the energy model TIMER³.

The SiMCaP ('Simple Model for Climate Policy Assessment') model, developed at the ETH Zurich (Switzerland) (www.simcap.org), calculates global emission path-ways compatible with long-term climate targets [26]. The global climate calculations make use of the simple climate model MAGICC 4.1 [31-33]. More specifically, the pathfinder module of SiMCaP makes use of an iterative procedure to find emission paths that correspond to a predefined arbitrary climate target⁴.

The integration of both models, the 'FAIRSiMCaP' 1.0 model, enables to combine the strengths of both models, i.e.: (i) to calculate the cost-optimal mixes of greenhouse gases reductions for a global emissions profile under a least costs approach (FAIR); (ii) to find the global emissions profile that is compatible with any arbitrary climate target (SiMCaP). The combination of both models

¹ MAC curves that reflect the costs of abating the last ton of CO₂-equivalent emissions and, in this way, describe the potential and costs of the different abatement options considered are used here.

² The IMAGE 2.2 model is an integrated assessment model, consisting of a set of integrated models that together describe important elements of the long-term dynamics of global environmental change, such as agriculture and energy use, atmospheric emissions of greenhouse gases and air pollutants, climate change, land-use change and environmental impacts [29].

³ The global energy model TIMER 1.0, as part IMAGE, describes the primary and secondary demand and production of energy and the related emissions of greenhouse gasses and regional air pollutants [30].

⁴ For further details, e.g. assumptions in regard to natural forcing, see Meinshausen et al. [26].

allows to calculate global emission pathways with cost-effective gas-mixes compatible for every pre-

defined arbitrary climate target.

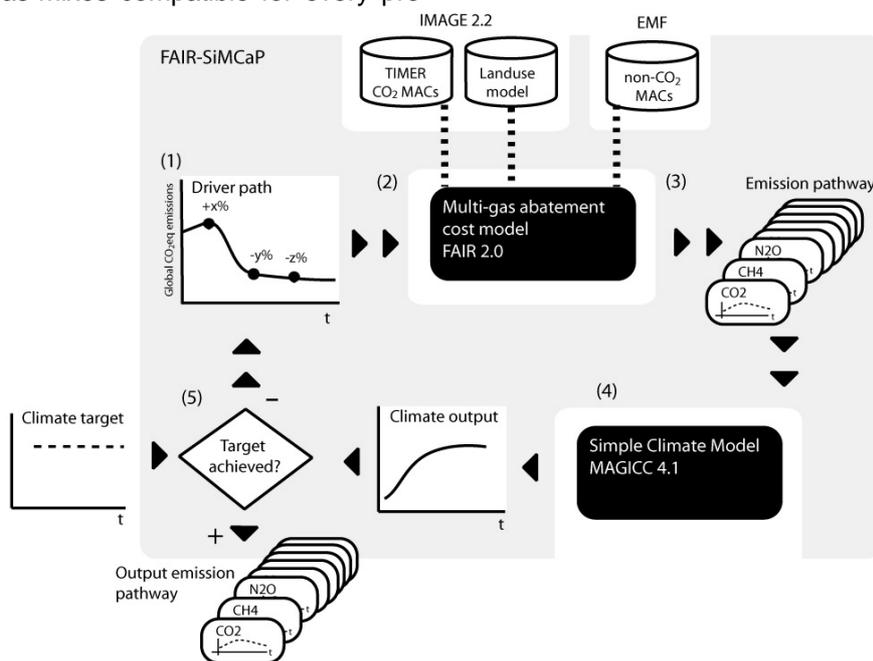


Figure 1 - FAIRSiMcaP model. The calculated global emission pathways were developed by using an iterative procedure as implemented in SiMcaP’s ‘pathfinder’ module using MAGICC to calculate the global climate indicators, the multi-gas abatement costs model of FAIR to allocate the emissions of the individual greenhouse gases and the IMAGE 2.2 and TIMER model for the baseline emissions scenarios and the MAC curves (see text for details).

More specifically, the FAIRSiMcaP calculations consist of four steps (Figure 1):

1. Using the SiMcaP model to construct a driver parameterized global CO₂-equivalent emission pathway, which is here defined by sections of linear decreasing or increasing emission reduction rates R_1 (initial 2010 value), R_X , R_Y and R_Z and years (X, Y and Z) at which the reduction rates change. This CO₂-equivalent emission pathway⁵ includes all anthropogenic emissions of greenhouse gases, except the LUCF CO₂ emissions (related to deforestation, and not sinks), as for those there are no MAC curves available. These LUCF CO₂ emissions are described by the baseline scenario.

2. The abatement costs model of FAIR is used to allocate the global emissions reduction objective (except LUCF CO₂ emissions), i.e. the difference between the baseline emissions and the global CO₂-equivalent emission pathway (see Figure 2) of step 1 using a least-cost approach (cost-optimal implementation of reduction measures), for the period 2000-2100⁶ over the six greenhouse gases using 100-year GWP indices and different sources

(e.g. for CO₂: 12; CH₄: 9; N₂O: 7). Figure 2 shows the contribution of the different greenhouse gases in the global emissions reduction in order to reach, for this case, the 450ppm CO₂-equivalent concentration level. It clearly shows that till 2025, there are potentially large incentives for sinks and non-CO₂ abatement options (cheap options), so the non-CO₂ reductions and sinks form a relatively large share in the total reductions. Later in the scenario period, the focus will be more on the CO₂ reductions, and the contribution of most gases becomes more proportional to their share in baseline emissions. So in this way, the emission pathways of the different greenhouse gases are constructed.

Different sets of baseline- and time-dependent MAC curves for different emission sources are used here. Response curves from the TIMER model are used for the energy CO₂ emissions [35], including technological developments, learning effects and system inertia⁷. For CO₂ sinks the MAC curves of by the IMAGE model are used [36]. For non-CO₂, exogenously determined MAC curves from EMF-21 [37-39] are used; these are based on detailed abatement options. As these curves were

⁵ The CO₂-equivalent emissions are calculated using the emissions of the six greenhouse gases combined with the 100 year Global Warming Potentials (GWPs) [34].

⁶ After 2100, the CO₂eq reductions rates are applied to each individual gas, except where non-reducible fractions (0.7) have been defined (N₂O, CH₄).

⁷ These MAC curves will change in near future due to the implementation of new abatement options (e.g. hydrogen, biomass combined with carbon capture) and improvements of the present implementation of some abatement options (e.g. renewables, biofuels).

constructed for 2010 only, increases in the abatement potentials due to technology process and removal of implementation barriers are assumed. Here, a relatively conservative value of an increasing potential (at constant costs) for all other non-CO₂ MAC curves of 0.4% per year is assumed [40, 36]. There are still some remaining agricultural emission sources of CH₄ and N₂O, where no MAC curves were available (e.g. for N₂O agricultural waste burning, indirect fertilizer, animal waste and domestic sewage). As it is unlikely that these sources remain unabated under ambitious climate targets, we assumed a linear reduction towards a maximum of 35% compared to the baseline levels within a period of 30 years (2040). These MAC curves are used in the default calculations, and described in detail in van Vuuren et al. [35, 36].⁸

3. Using the simple climate model MAGICC 4.1, the greenhouse gas concentrations, and global temperature and sea level rise are calculated.

4. Within the iterative procedure of the SiMCaP model, the parameterizations of the CO₂-equivalent emission pathway (step 1) are optimized (repeat step 1, 2 and 3) until the climate output and the prescribed target match sufficiently well.

These emission pathways have been developed for three underlying baseline scenarios:

1. IMA-B1: the IMAGE IPCC SRES B1 baseline [29] scenario with the LUCF CO₂ emissions of this scenario and with the default MAC curves. This scenario assumes continuing globalization and economic growth, and a focus on the social and environmental aspects of life. The baseline emissions are given in Figure 2;

2. CPI: the Common POLES IMAGE (CPI) baseline [13, 36] scenario with the LUCF CO₂ emissions of this scenario and with the default MAC curves. The CPI scenario assumes a continued process of globalisation, medium technology development and a strong dependence on fossil fuels. This corresponds to a medium-level emissions scenario when compared to the IPCC SRES emissions scenarios (Figure 2);

3. CPI-tech: the CPI baseline scenario with the LUCF CO₂ emissions of the IMA-B1 scenario (less

deforestation) and with MAC curves assuming additional technological improvements⁹.

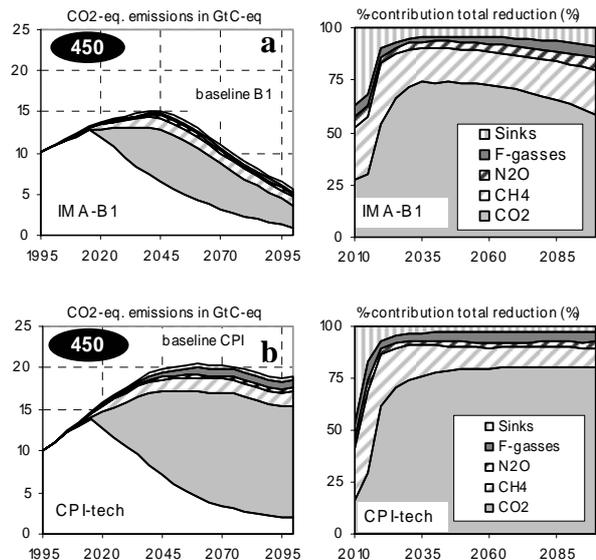


Figure 2 – Contribution of greenhouse gases in total emission reduction, under the emission pathways for a stabilization at 450ppm CO₂ equivalent concentration of the IMA-B1 (a) and CPI-tech scenario (b).

3. Emission pathways and their transient temperature implications

This section presents various global multi-gas emission pathways to stabilize at CO₂ equivalence levels of 550ppm (3.65W/m²), 500ppm (3.14W/m²), 450ppm (2.58W/m²) and 400ppm (1.95W/m²). The latter three pathways are assumed to peak at 525ppm (3.40W/m²), 500ppm (3.14W/m²) and 480ppm (2.92W/m²) before they return to their ultimate stabilization levels around 2150 (Figure 3). This peaking is partially reasoned by the already substantial present net forcing levels [7] and the attempt to avoid drastic sudden reductions in the presented emission pathways. These lower two stabilization pathways are within the range of the lower mitigation scenarios in the literature [25, 41, 42, 7]. Due to the inertia of the climate system, which tends to increase with higher climate sensitivities [43, 44], the peak of radiative forcing (3.14W/m²) before stabilization at 450ppm CO₂eq (2.58W/m²) does not translate into a comparable peak in global mean temperatures. However, for

⁸ The information on non-CO₂ abatement options and their costs have been inventoried for EMF-21 for mainly 2010, over a limited cost range of 0 to 200 US\$/tCeq and not all sources. We have assumed a certain increase in the reduction potential and costs as a result of technological development and the reduction of implementation barriers. The rate, at which these trends will evolve, however, is highly uncertain. Under the current implementation the cheap parts of the non-CO₂ MACs tend to get exhausted before 2050 (Figure 2). This is reflected in the rapid drop in the share of the non-CO₂ gases in total reductions over time. It will be crucial to extend research on non-CO₂ emission reduction options beyond 2010 and on the sources, where no MAC curves are available. The presented results of this study may therefore change due to ongoing research in this area.

⁹ As current studies (e.g., [41, 42]) indicate that more technological improvements in abatement potential and reduction costs is possible than assumed in the CPI baseline, we have analyzed the impact of more optimistic assumptions. For this, we made the following, rather arbitrary, assumptions for this CPI tech scenario. For the MAC curves of energy CO₂ an additional technological improvement factor of 0.2%/year is assumed. For the MAC curves of the non-CO₂ gases, a technological improvement rate of 1%/year is assumed; instead of 0.2%/yr. For the sources of non-CO₂ gases, where no MAC curves were available, we now assume a maximum reduction of 80%, instead of 30% in 2040.

the presented 400ppm CO₂eq stabilization scenario, the initial peak at 480ppm CO₂eq seems to be decisive in regard to the question, whether

the 2°C or any other temperature threshold will be crossed (Figure 4).

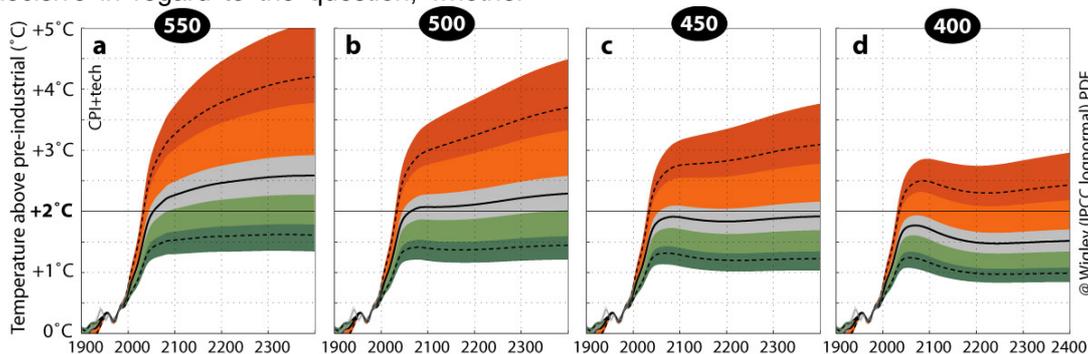


Figure 4 – The probabilistic temperature implications for the stabilization scenarios at (a) 550ppm, 500ppm (b), 450ppm, and (c) 400ppm CO₂ equivalent concentrations for the CPI tech baseline scenario based on the climate sensitivity PDF by Wigley and Raper (IPCC lognormal) [31]. Shown are the median (solid lines), and 90% confidence interval boundaries (dashed lines), as well as the 1%,10%,33%,66%,90%, and 99% percentiles (borders of shaded areas). The historic temperature record and its uncertainty is shown from 1900 to 2001 (grey shaded band) [45].

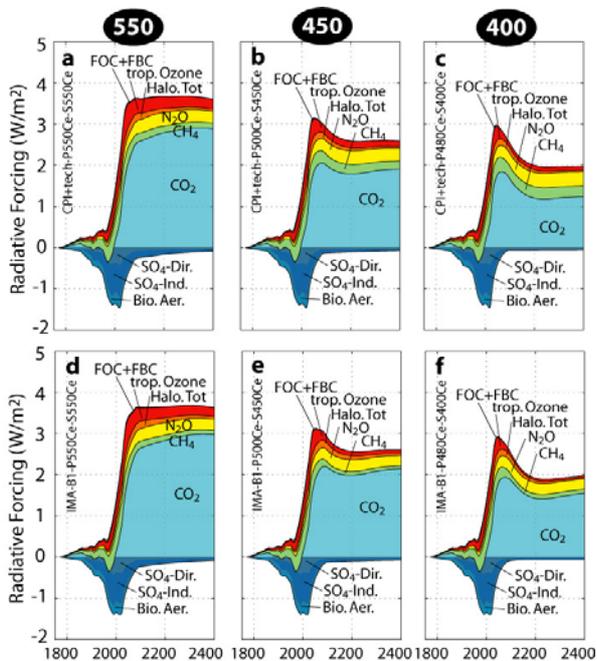


Figure 3 – The contribution to net radiative forcing by the different forcing agents under the three default emission pathways for a stabilization at (a,d) 550, (b,e) 450 and (c,f) 400 ppm CO₂ equivalent concentration after peaking at (b,e) 500 and (c,f) 475 ppm, respectively for the (a-c) CPI tech and (d-f) IMA B1 baseline scenarios. The upper line of the stacked area graph represents net human-induced radiative forcing. The net cooling due to the direct and indirect effect of SO_x aerosols and aerosols from biomass burning is depicted by the lower negative boundary, on top of which the positive forcing contributions are stacked (from bottom to top) by CO₂, CH₄, N₂O, fluorinated gases, tropospheric ozone and the

combined effect of fossil organic & black carbon.

Figure 4 gives the probabilistic temperature implications based on the climate sensitivity PDF of Wigley and Raper (IPCC lognormal) [31] for the emission pathways under the CPI-tech scenario. The results under the other scenarios are similar. The Figure shows that for a stabilization at 550ppm CO₂eq (corresponding approximately to a 475ppm CO₂ only stabilisation) the risk of overshooting 3°C is still about 33%. There is even a risk of about 10% to exceed 4°C. The probability that warming exceed 2°C is very high, more than 80%. Also for the long-term stabilisation at 500ppm CO₂eq (approximately 450ppm CO₂ stabilisation) the probability of exceeding 2°C is likely, more than 50%. Only for a stabilisation at 400ppm CO₂eq (approximately 350-375ppm CO₂ stabilisation) and, to a lesser extend, at 450ppm CO₂eq (about 400ppm CO₂ only stabilisation), the possibility that warming exceed 2°C is strongly reduced, to less than about 20-25 and 30-40%, respectively.

The emissions of the emission pathways for stabilization at 550, 450 and 400ppm CO₂eq concentrations for the three scenarios can be summarized by their GWP-weighted sum for illustrative purposes, as illustrated in Figure 5. Clearly, there are different pathways that can lead to the ultimate stabilisation level. Here, for all default pathways we assume that the emission reductions take place early in the scenario period and the global emissions peak around 2015, in order to avoid pathways that exceed an annual reduction of 2% per year (at least not over longer time periods). The reason is that a faster reduction might be difficult to achieve given the inertia in the energy system: electric power plants, for instance, have a technical lifetime of 30 years or more. Fast

reduction rates would require early replacement of existing plants, which is expensive.

For all stabilisation scenarios, the global reduction rates remain below 2%/year for the whole scenario period, except for the pathways at 400ppm CO₂eq with maximum reduction rates of 2.5-3%/yr over 20 years.

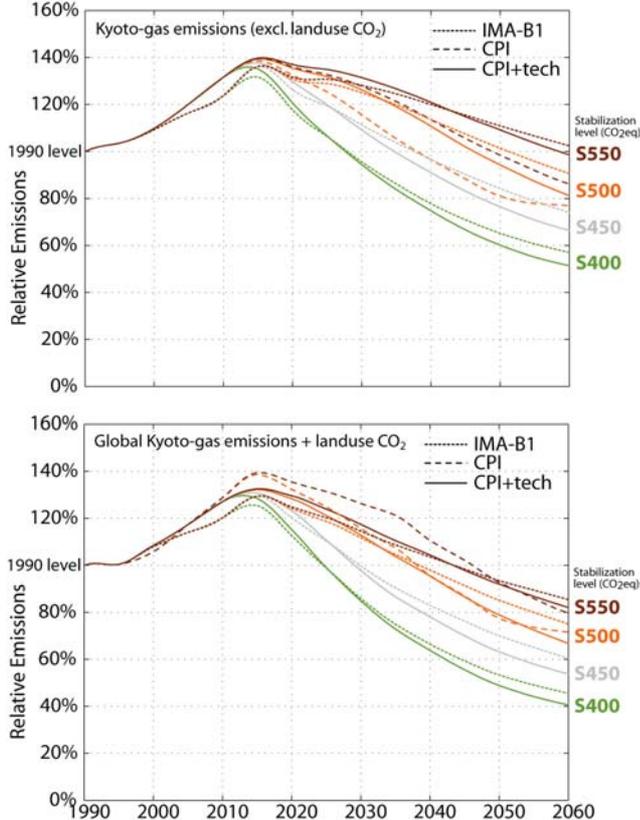


Figure 5 - Global emissions excluding and including LUCF CO₂ emissions for the stabilization scenarios at 550, 500, 450 and 400 ppm CO₂ equivalent concentrations for the three scenarios (CPI, CPI tech and IMA-B1)¹⁰.

If we delay the peaking of the global emissions until 2020, this needs to be compensated by steeper reductions hereafter. Now only for the 550ppm CO₂eq for the B1 and CPI tech scenario there will be pathways, which do not exceed the 2%/yr limit. For 400 and 450ppm CO₂eq, all three baseline scenarios lead to maximum yearly reduction rates above 3.5 and 2.5 %, respectively, for at least 20 years if emission reductions were delayed. For 500ppm CO₂eq, this rate reaches 2.5% for 15 years under the delayed scenario.

Under the three default scenario for stabilization at 550ppm CO₂eq, Kyoto-gas emissions (including LUCF CO₂) would approximately have to return to their 1990 levels by 2050. We also see that higher near-term emissions need to be compensated by lower future emissions (compare CPI and CPI-tech

¹⁰ For the CPI scenario the current assumptions about abatement potential and costs result in no emission pathways for 450 and 400 ppm CO₂ equivalent concentrations.

with B1). For stabilization at 500ppm CO₂eq, global Kyoto-gas emissions would need 10 to 20% below 1990 levels in 2050. The reduction requirements become as high as 50-60% and 30-40% below 1990 levels in 2050 to reach the 400ppm and 450ppm CO₂eq target, respectively (see Figure 5). In general, when we compare the reductions for the different concentration levels, we find about 15-20% additional reductions by 2050 are needed for every 50ppm lower stabilisation level.

Analysing the emission reductions of the Kyoto gases without LUCF CO₂ emissions, but still assuming that the LUCF CO₂ emissions decrease as specified, we see that the global Kyoto gas emission reductions are less: 35-45% and 15-25% below 1990 levels by 2050 to reach 400ppm and 450ppm CO₂eq target.

Figure 6 shows the global fossil CO₂ emissions. The reductions for the fossil CO₂ emissions are in general somewhat higher than the reductions of all Kyoto gas emissions for the lower concentration targets (400 and 450ppm CO₂eq), as we assume less abatement potential for the non-CO₂ gases in particular from agricultural and land-use related sources. The reduction requirements for the fossil CO₂ emissions are the highest for the CPI scenario, as this scenario assumes higher LUCF CO₂ emissions than the other two scenarios (B1, CPI-tech).

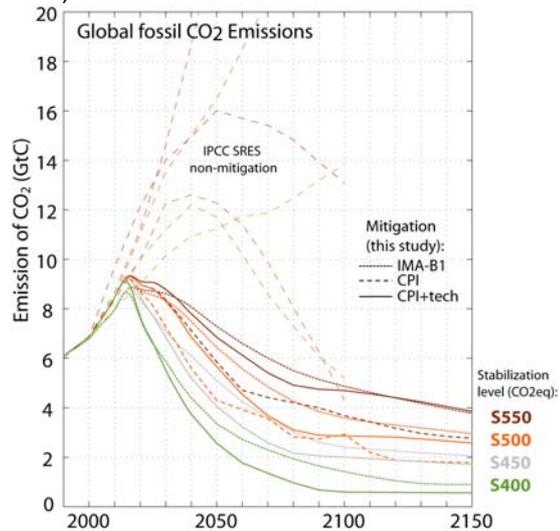


Figure 6 - Global fossil CO₂ emissions, otherwise as figure 5. In addition, global fossil CO₂ emissions of the six illustrative non-mitigation IPCC SRES scenarios [46] are shown.

4. Global emission abatement costs

In its Third Assessment Report (TAR) [47] the IPCC presents estimates for macro-economic costs of stabilisation of the CO₂ concentration and these estimates also cover a considerable range. For stabilisation of the CO₂ concentration at 450ppm (comparable to 500-525ppm CO₂eq.), GDP

reductions for 2050 are in the order of 2.5-3.0% (the range associated with scenario A1b and B2).

These GDP costs have to be seen in perspective, though. On the one hand, such long-term GDP abatement costs are approximately equivalent to a delay of only a couple of years in regard to the point in time, when the World might experience a twenty fold increase in its GDP around 2100 compared to present levels [48, 49]. On the other hand, avoided climate damages and ancillary benefits are not included in such cost estimates, although they might be comparable in scale. Here, we present some preliminary results¹¹ of the global abatement costs¹² as percentage of world GDP for the different CO₂ equivalent concentration levels (Figure 7). We see that the global costs increase as a result of increasingly tight concentration levels. All emission pathways show a rapidly increase of the costs till 2050, and then a decrease for most of the scenarios, except for pathway leading to 500ppm CO₂ eq. under the CPI baseline.

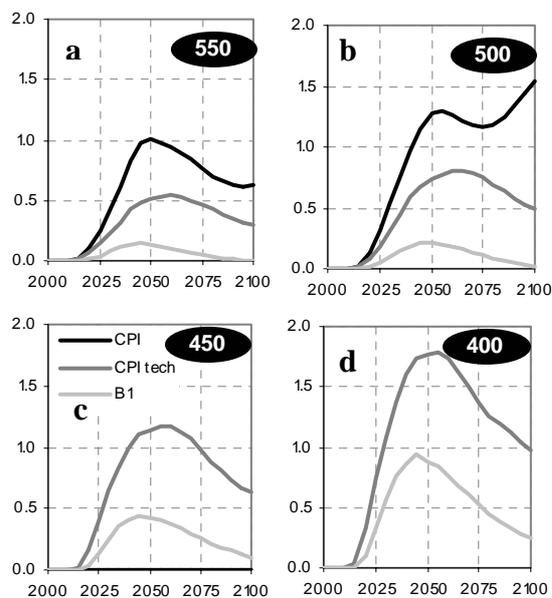


Figure 7 - Global abatement costs as % of GDP for the stabilization scenarios at (a) 550ppm, (b) 500ppm, (c) 450ppm and (d) 400ppm CO₂ equivalent concentrations for the three scenarios (CPI, CPI tech and IMA-B1).

The Figure also shows that the global abatement costs are even more influenced by the baseline emissions and the assumed technical change improvements of the abatement potentials

¹¹ The costs figures presented here should be seen as provisional, and may change due to ongoing research related to the abatement potential and reduction costs for all greenhouse gases.

¹² The costs calculated only represent the direct-cost effects based on MAC curves but not the various linkages and rebound effects via the economy or impacts of carbon leakage; i.e. there is no direct link with macro-economic indicators such as GDP losses or other measures of income of utility loss.

and costs, than the final concentration stabilisation level. More specifically, the baseline emissions directly determine the reductions that are required to reach the emission profile for stabilisation. In addition, the baseline assumptions also indirectly influence the abatement potential, in particular, assumptions related to costs of different technologies. Finally, the economic assumptions obviously influence the relative cost measures such as GDP losses or abatement costs as percentage of GDP. Another crucial uncertainty is the rate at which the potential and abatement costs for CO₂ and non-CO₂ emission reductions develops in time (compare the CPI and CPI tech baseline scenario – see section 2).

5. Conclusions

This study uses a method to derive multi-gas emission pathways by a method that calculates the cost-optimal mixes of greenhouse gases reductions for a given global emissions pathway. The study presents emission pathways for different CO₂ equivalent concentration stabilisation levels, i.e. 550, 500, 450 and 400 ppm CO₂ equivalent.

This analysis shows that an emission pathway leading to a 550ppm CO₂ equivalent stabilisation is unlikely to meet the climate target of limiting global mean temperature rise to 2°C above pre-industrial levels (EU 2°C target). In order to achieve this EU target with levels of certainty of more than 50%, greenhouse gas concentrations need to be stabilised below 450 CO₂ equivalent or lower, requiring global emissions to peak within the next two decades, followed by substantial overall reductions by as much as 30 to 60% (incl. LUCF CO₂ emissions) in 2050 compared to 1990 levels (450/400ppm CO₂eq). Further delay in peaking leads to delayed, but much steeper reductions.

The analysis shows that the global reductions, and thus the abatement costs, much depends on the emission growth in the baseline scenario, as well as further developments of the abatement potential and reduction costs for all greenhouse gases in the future due to technology progress and removal of implementation barriers. These two factors also highly influence the certainty of meeting more stringent climate targets. Lower baseline emissions also lead to a later peaking of the global emissions, and therefore more allowable emissions after peaking. However, the allowable delay in the peaking emissions is limited, less than 5-10 years delay, and in order to achieve the lower stabilisation levels it is still needed to stabilise the global emissions within the next two decades.

6. Acknowledgements

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