THE BENEFITS OF GREENHOUSE GAS EMISSION REDUCTION: AN APPLICATION OF *FUND*

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Abstract

The avoided damages of climate change are estimated for a range of emission reduction policies from a range of business as usual scenarios. In the emission abatement scenarios, concentrations of greenhouse gases overshoot before falling to a stable level. The peak concentrations are used to characterise the stabilisation scenario. Similarly, the peak impacts are used to evaluate the scenarios. This is in line with avoiding "dangerous interference with the climate system". Results are shown for both cost-effective and "realistic" emission reduction policies. Avoided climate change impacts increase with emission abatement, but the additionally avoided impacts fall as abatement gets more stringent. The most serious climate change impacts can be avoided with only modest emission reduction. Very stringent emission reduction may even increase climate change impacts, because of the removal of the sulphur veil and because emission abatement costs may slow economic growth and increase vulnerability. A comparison of the net present value of the costs of emission reduction with the net present value of the avoided damage also point towards more modest emission abatement. These findings are robust to variations in scenarios and parameters.

Keywords

Avoided impacts of climate change, emission reduction, climate policy

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1. Introduction

The ultimate objective of the United Nations Framework Convention on Climate Change is to "stabilise atmospheric concentrations of greenhouse gases" in order to avoid "dangerous interference with the climate system", which is usually understood as unacceptable impacts of climate change. This is a worthy goal. However, it is unlikely that there will ever be agreement on what are unacceptable impacts. Indeed, Arrow's (1951) impossibility theorem prevents this. A scientific analysis can only estimate the impacts of climate change that would be avoided through greenhouse gas emission reduction. Although the UNFCCC dates back to 1992, only a few quantitative analyses of avoided impacts of climate change have been published, and none with a comprehensive model of welfare impacts. This paper fills this gap.

Avoided impacts are an essential part of climate change policy analysis, unless one accepts an external ultimate target and seeks to reach this at minimum cost (as in, e.g., Manne and Richels, 1999). The method of tolerable windows is one option for policy analysis, but most of its implementations have focussed on greenhouse gas concentrations and temperatures rather than on impacts (e.g., Petschel-Held et al., 1999).[1] Cost-benefit analysis of greenhouse gas emission reduction does estimate avoided impacts. However, in a cost-benefit analysis, the marginal costs of emission reduction are balanced with the marginal costs of climate change (e.g., Nordhaus, 1993, Tol, 1999d). Cost-benefit studies therefore report the marginal damage costs of climate change, rather than the total avoided damage. See Tol (2005) for a review of the marginal damage cost literature.

Corfee-Morlot and Agrawala (2004) recently edited a book titled "The benefits of climate change policies". Although this volume contains many useful insights into climate change impacts, it does not provide an estimate of the damages avoided by emission reduction. The recent collection of climate change impact papers edited by Parry (2004) is also silent on avoided impacts. Nicholls and Lowe (2004) do estimate avoided impacts of sea level rise. They find that mitigation can substantially reduce flood impacts, but also point to the slow response of the sea level to global warming and, hence, mitigation. Tol (forthcoming, d) also estimates avoided sea level rise impacts, including, in contrast to Nicholls and Lowe (2004), the costs of emission reduction. Tol (forthcoming, d) shows that the effect of the costs of emission reduction on vulnerability to sea level rise is minor. In contrast, Tol and Dowlatabadi (2001) show that this effect is large for infectious diseases.

This paper is the first to provide a comprehensive estimate of the climate change impacts avoided by greenhouse gas emission reduction. The model used has several advantages. It includes many climate change impacts: agriculture, forestry, water resources, sea level rise, energy consumption, human health, and ecosystems. The sectoral impacts are modelled in an internally consistent way. Vulnerability varies with development. Impacts are expressed in many indicators, as well as in a single, consistent superindicator: welfare-equivalent income loss. The model has also disadvantages. It relies on reduced-form impact models. Climate scenarios are crude. Interactions between impacts are not well-captured. Therefore, the results presented below should be interpreted with caution.

In Section 2, I present the model used. In Section 3, various stabilisation scenarios are analysed. Stabilisation is achieved at the lowest possible cost, so as to minimise the effects of greenhouse gas emission reduction on vulnerability to climate change. Cost-effectiveness is not very realistic, though. Therefore, in Section 4, the avoided damages of more realistic (and more costly) policy scenario are investigated as well. In Section 5, sensitivity analyses are reported. Section 6 concludes.

2. The model

This paper uses version 2.8 of the *Climate Framework for Uncertainty, Negotiation and Distribution* (*FUND*). Version 2.8 of *FUND* corresponds to version 1.6, described and applied by Tol (1999a-e, 2001, 2002a, 2003), except for the impact module, which is described by Tol (2002b,c) and updated by Link and Tol (2004). A further difference is that the current version

[1] See Toth *et al.* (2000) for an apparently aborted attempt to extend the tolerable windows approach to climate change impacts

of the model distinguishes 16 instead of 9 regions. Finally, the model considers emission reduction of methane and nitrous oxide as well as carbon dioxide, as described by Tol (forthcoming, c).[2]

Essentially, *FUND* consists of a set of exogenous scenarios and endogenous perturbations. The model distinguishes 16 major regions of the world, viz. the United States of America, Canada, Western Europe, Japan and South Korea, Australia and New Zealand, Central and Eastern Europe, the former Soviet Union, the Middle East, Central America, South America, South Asia, Southeast Asia, China, North Africa, Sub-Saharan Africa, and Small Island States. The model runs from 1950 to 2300 in time steps of one year. The prime reason for starting in 1950 is to initialize the climate change impact module. In *FUND*, the impacts of climate change are assumed to depend on the impact of the previous year, this way reflecting the process of adjustment to climate change. Because the initial values to be used for the year 1950 cannot be approximated very well, both physical and monetized impacts of climate change tend to be misrepresented in the first few decades of the model runs. The 22nd and 23rd centuries are included to account for the fact that key impacts of a weakening or a shutdown of the thermohaline circulation would be disregarded if the time horizon of the simulations were shorter. Previous versions of the model stopped at 2200.

The period of 1950-1990 is used for the calibration of the model, which is based on the *IMAGE* 100-year database (Batjes & Goldewijk, 1994). The period 1990-2000 is based on observations (WRI, 2000). The climate scenarios for the period 2010-2100 are based on the EMF14 Standardized Scenario, which lies somewhere in between IS92a and IS92f (Leggett *et al.*, 1992). The 2000-2010 is interpolated. The period 2100-2300 extrapolated.

The scenarios concern the rate of population growth, economic growth, autonomous energy efficiency improvements, the rate of decarbonization of the energy use (autonomous carbon efficiency improvements), and emissions of carbon dioxide from land use change, methane and nitrous oxide.

The scenarios of economic and population growth are perturbed by the impact of climatic change. Population decreases with increasing climate change related deaths that result from changes in heat stress, cold stress, malaria, and tropical cyclones. Heat and cold stress are assumed to have an effect only on the elderly, non-reproductive population. In contrast, the other sources of mortality also affect the number of births. Heat stress only affects the urban population. The share of the urban population among the total population is based on the World Resources Databases (WRI, 2000). It is extrapolated based on the statistical relationship between urbanization and per-capita income, which are estimated from a cross-section of countries in 1995. Climate-induced migration between the regions of the world also causes the population sizes to change. Immigrants are assumed to assimilate immediately and completely with the respective host population.

The tangible impacts are dead-weight losses to the economy. Consumption and investment are reduced without changing the savings rate. Thus, climate change reduces the long-term economic growth, although for the short term the consumption is particularly affected. Economic growth is also reduced by carbon dioxide abatement measures.

The energy intensity of the economy and the carbon intensity of the energy supply autonomously decrease over time. This process can be accelerated by abatement policies, an option not considered in this paper.

The endogenous parts of *FUND* consist of the atmospheric concentrations of carbon dioxide, methane and nitrous oxide, the global mean temperature, the impact of carbon dioxide

[2] A full list of papers and the source code of the model can be found at http://www.uni-hamburg.de/Wiss/FB/15/Sustainability/fund.html.

emission reductions on the economy and on emissions, and the impact of the damages to the economy and the population caused by climate change.

Methane and nitrous oxide are taken up in the atmosphere, and then geometrically depleted. The atmospheric concentration of carbon dioxide, measured in parts per million by volume, is represented by the five-box model of Maier-Reimer and Hasselmann (1987). Its parameters are taken from Hammitt *et al*. (1992). The model also contains sulphur emissions (Tol, forthcoming, c)

The radiative forcing of carbon dioxide, methane, nitrous oxide and sulphur aerosols is determined based on Shine *et al*. (1990). The global mean temperature T is governed by a geometric build-up to its equilibrium (determined by the radiative forcing RF), with a half-life of 50 years. In the base case, the global mean temperature rises in equilibrium by 2.5°C for a doubling of carbon dioxide equivalents. Regional temperature follows from multiplying the global mean temperature by a fixed factor, which corresponds to the spatial climate change pattern averaged over 14 GCMs (Mendelsohn *et al*., 2000). The global mean sea level is also geometric, with its equilibrium level determined by the temperature and a half-life of 50 years. Both temperature and sea level are calibrated to correspond to the best guess temperature and sea level for the IS92a scenario of Kattenberg *et al.* (1996).

The climate impact module is based on Tol (2002b,c). The following impact categories of climate change are considered: agriculture, forestry, sea level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, schistosomiasis, diarrhoea, energy consumption, water resources, and unmanaged ecosystems.

People can die prematurely due to temperature stress or vector-borne diseases, or they can migrate because of sea level rise. Like all impacts of climate change, these effects are monetized. The value of a statistical life is set to be 200 times the annual per capita income. The resulting value of a statistical life lies in the middle of the observed range of values in the literature (cf. Cline, 1992). The value of emigration is set to be 3 times the per capita income (Tol, 1995, 1996), the value of immigration is 40 per cent of the per capita income in the host region (Cline, 1992). Losses of dryland and wetlands due to sea level rise are modelled explicitly. The monetary value of a loss of one square kilometre of dryland was on average \$4 million in OECD countries in 1990 (cf. Fankhauser, 1994). Dryland value is assumed to be proportional to GDP per square kilometre. Wetland losses are valued at \$2 million per square kilometre on average in the OECD in 1990 (cf. Fankhauser, 1994). The wetland value is assumed to have logistic relation to per capita income. Coastal protection is based on cost-benefit analysis, including the value of additional wetland lost due to the construction of dikes and subsequent coastal squeeze.

Other impact categories, such as agriculture, forestry, energy, water, and ecosystems, are directly expressed in monetary values without an intermediate layer of impacts measured in their 'natural' units (cf. Tol, 2002b).

Climate change related damages can be attributed to either the rate of change (benchmarked at 0.04°C/yr) or the level of change (benchmarked at 1.0°C). Damages from the rate of temperature change slowly fade, reflecting adaptation (cf. Tol, 2002c).

Impacts of climate change on energy consumption, agriculture, and cardiovascular and respiratory diseases explicitly recognize that there is a climatic optimum which is determined by a variety of factors, including plant physiology and the behaviour of farmers. Impacts are positive or negative depending on whether the actual climate conditions are moving closer to or away from that optimum climate. Impacts are larger if the initial climate conditions are further away from the optimum climate. The optimum climate is of importance with regard to the potential impacts. The actual impacts lag behind the potential impacts, depending on the speed of adaptation. The impacts of not being fully adapted to new climate conditions are always negative (cf. Tol, 2002c).

The impacts of climate change on coastal zones, forestry, unmanaged ecosystems, water resources, diarrhoea malaria, dengue fever, and schistosomiasis are modelled as simple power functions. Impacts are either negative or positive, and do not change sign (cf. Tol, 2002c).

Vulnerability to climate change changes with population growth, economic growth, and technological progress. Some systems are expected to become more vulnerable, such as water resources (with population growth), heat-related disorders (with urbanization), and ecosystems and health (with higher per capita incomes). Other systems are projected to become less vulnerable, such as energy consumption (with technological progress), agriculture (with economic growth) and vector- and water-borne diseases (with improved health care) (cf. Tol, 2002c).

Carbon dioxide emissions are calculated on the basis of the Kaya identity. Abatement policy reduces emissions *permanently* (by changing the trajectories of carbon and energy intensities) as well as *transiently* (reducing current energy consumptions and carbon emissions). One may interpret the difference between permanent and transient emission reduction as affecting commercial technologies and capital stocks, respectively. The behaviour of the emission reduction module is similar to that of the models of Grubb *et al.* (1995), Ha-Duong *et al.* (1997) and Hasselmann *et al.* (1997). It is a reduced form way of modelling that part of the emission reduction fades away after the policy intervention is reversed, but that another part remains through technological lock-in.

The costs of emission reduction fall, through learning by doing, with cumulative emission reduction (Goulder and Mathai, 2000). Emission reduction is assumed to be relatively expensive for the region that has the lowest emission intensity. The calibration is such that a 10% emission reduction cut in 2003 would cost 1.57% (1.38%) of GDP of the least (most) carbon-intensive region, and a 80% (85%) emission reduction would completely ruin its economy. Emission reduction is relatively cheap for regions with high emission intensities. The thought is that emission reduction is cheap in countries that use a lot of energy and rely heavily on fossil fuels, while other countries use less energy and less fossil fuels and are therefore closer to the technological frontier of emission abatement. The model has been calibrated to the results reported in Hourcade *et al.* (1996); for relatively small emission reduction, the costs in *FUND* correspond closely to those reported by other top-down models, but for higher emission reduction, *FUND* finds higher costs, because *FUND* does not include backstop technologies, that is, a carbon-free energy supply that is available in unlimited quantities at fixed average costs. Tol (forthcoming, a) describes the details of the model.

The costs of methane and nitrous oxide emission reduction are based on the analysis of the USEPA (2003). The cost functions are quadratic and constant over time (Tol, forthcoming, c).

3. Stabilisation scenarios

Five alternative stabilisation scenarios are run. The scenarios are characterised by their peak concentration of carbon dioxide equivalent, which is varied from 450 ppm to 850 ppm in steps of 100 ppm. Ultimate stabilisation is at a lower level, as stabilisation requires that carbon dioxide emissions are driven to zero. Carbon dioxide emissions are reduced such that marginal emission reduction costs are equal for all regions; and such that marginal emission reduction costs increase with the discount rate. The marginal costs of methane and nitrous oxide emission reduction equal the marginal costs of carbon dioxide emission reduction, corrected for the global warming potential. This implementation is approximately cost-effective.

Figure 1 shows the atmospheric concentration of carbon dioxide and the corresponding global mean temperature. In the no control scenario, CO_2 concentrations peak at about 1350 ppm. The peak is lower and earlier under the stabilisation scenarios. The 2300 concentrations vary between 500 ppm and 335 ppm; concentrations are still falling gradually at the end of the simulation period. In the no control scenario, the global mean temperature peaks at 6.7°C above pre-industrial. In the stabilisation scenarios, the peak is lower and earlier; it varies between 3.9°C and 1.8°C. Temperatures continue to fall to 2300; in that year, the no control scenarios shows a temperature of 6.5°C, while the stabilisation scenarios vary between 2.9°C and 1.2°C.

Table 1 shows the maximum market impacts for the 16 regions for the no control and the stabilisation scenarios.[3] Table 2 shows the same information for non-market impacts. Emission reduction clearly reduces peak impacts. Three things are noteworthy. Firstly, the largest gain in avoided impacts is from moving from the no control scenario to the peak at 850 ppm scenario. Deeper emission cuts avoid more damage, but the additionally avoided damage gets smaller and smaller. This is as would be expected. Secondly, in some cases, the maximum impact is insensitive to emission abatement. This is particularly true for non-market impacts in poor regions. Infectious diseases explain this. The main impacts would occur in the first decades of the 21st century, when people are poor enough to attract these afflictions. The climate of the first decades is hardly influenced by emission abatement, but infectious diseases are a major impact. Thirdly, damages *increase* for some regions between peak concentrations of 550 ppm and 450 ppm. One reason is that emission reduction becomes so costly that economic growth is slowed down, and vulnerability to climate change increases. Tol and Dowlatabadi (2001) first pointed out this possibility. Another reason is that, with a 450 ppm target, abatement is so stringent that sulphur emissions fall substantially as well, removing the sulphur veil, which would lead to regional warming.

Figure 2 shows the market and non-market impacts for Western Europe for the no control and the stabilisation scenarios. In the long run, market impacts are more or less equal for the stabilisation scenarios, because the global mean temperatures converge (cf. Figure 1). All stabilisation scenarios show considerably lower market impacts (roughly 1.5% of GDP) than the no control scenario. In the medium run, each stabilisation scenario avoids the peak in market damages seen in the no control scenario (almost 2.0% of GDP). The stabilisation scenarios vary by about 0.5% of GDP. In the short run, the stabilisation scenarios show slightly higher market impacts than the no control scenario because of the reduction in SO_2 emissions.

Different results emerge for the non-market impacts. Unlike market impacts, non-market impacts are always negative. Non-market impacts are smaller than market impacts. In the no control scenario, impacts go up first, then down, then up again. This is because non-market impacts are largely driven by the rate of warming, or rather its absolute value: cooling causes damage as much as warming. In the stabilisation scenarios, the maximum rate of warming is lower and earlier; the switch from cooling to warming is earlier as well, and cooling is faster for higher peak concentrations. In the stabilisation scenarios, the graphs are less smooth. This is because the rate of warming is partly driven by methane emission control; in the later years, emission control is constant for periods of 25 years, while methane has a lifetime of some 10 years only.

Figure 3 shows the market and non-market impacts for Sub-Saharan Africa for the no control scenario and the stabilisation scenarios. The market impacts look similar to those in Western Europe, but impacts are more negative; the stabilisation scenarios differ more in the long run; and the differences in the short-run are less pronounced as Africa has less sulphur to remove.

[3] Maximum or peak impacts are probably the best way to represent "dangerous interference".

The non-market impacts look very different. The main effect is not climate but development driven. Impacts fall from about 4.5% of GDP to a fraction of that, as Africans are assumed to rapidly grow rich enough to control diarrhoea and malaria. In fact, highest impacts are seen in the scenario that keeps CO_2 concentrations below 450 ppm, as mitigation crowds out public health care (cf. Tol, forthcoming, b).

Table 3 displays the net present value of the avoided damages (market and non-market). Emission reduction would save trillions of dollars in damages. Table 3 also displays the net present value of the consumption losses due to emission reduction. A comparison suggests that emission reduction may not be worthwhile (cf. Table 8).

4. Graduation scenarios

The previous section analyses the avoided impacts in approximately cost-effective stabilisation scenarios. Such scenarios are unlikely. Therefore, alternative scenarios are analysed here. They are based on graduation, like the scenarios analysed by Jacoby and others. Every region with an average per capita income of $X per year (default: $5,000; sensitivities: $2,500 and $10,000) reduces emissions by Y% per year (default: 0.5%; sensitivities: 0.25%, 1.0(0.5)2.5%).

Figure 4 shows the atmospheric concentration of carbon dioxide. With the appropriate combination of graduation income and annual emission reduction, almost any peak concentration can be reached. Two scenarios are singled out for further analysis: $5000 / 1.5% and $5000 / 2.5%. The first scenario reaches a peak CO_2 concentration of 658 ppm, which is very close to the peak CO_2 concentration (704 ppm) in the stabilisation scenarios of CO_2 *equivalent* at 850 ppm. The second scenario reaches a peak temperature increase of 3.8°C, which is close to the 3.9°C reached in the 850 ppm stabilisation scenario. The first scenario reaches a peak temperature of 4.3°C. The graduation and stabilisation scenarios reach approximately the same peak concentration, but in the stabilisation scenario, abatement starts low and then accelerates. As a result, the peak concentration is reached later in the graduation scenario, and warming is greater.

Figure 4 also shows the global mean temperature. Compared to Figure 1, temperatures reach higher peaks and fall less towards the end of the simulation period.

Table 4 shows the maximum market impacts for the 16 regions for the no control and the graduation scenarios. Table 5 shows the same information for non-market impacts. Again, emission reduction reduces impacts. However, market impacts in Table 4 (Table 5) are somewhat higher (lower) than the (non-)market impacts in Table 1 (Table 2) for comparable peak concentrations.

Figure 5 shows market impacts for Western Europe, Figure 6 for Sub-Saharan Africa. In Western Europe, market impacts by and large follow the warming pattern. The stabilisation scenario clings to the no control scenario, and then rapidly deviates. The graduation scenarios start diverging immediately but do so more gradually. In Sub-Saharan Africa, the graduation scenarios also cling to the no control scenario. This is because impacts on agriculture are important there, and the graduation scenarios take away some of the benefits of CO_2 fertilisation. Non-market impacts in poor regions are dominated by the development scenario, and hence largely independent of the emission reduction scenario. In rich regions, non-market impacts peak later in the graduation scenarios than in the stabilisation scenarios, as one would expect from the warming patterns. The peak is lower, because the rate of warming is lower in the graduation scenarios.

5. Sensitivity analysis

The results presented above rely on a single realisation of a single model for a single scenario. As the uncertainties about almost every aspect of climate change are large, this is undesirable. This section therefore presents a limited set of sensitivity analyses with regard to baseline scenarios, climate sensitivity and climate change impacts. The ratio of net present costs and benefits is of course also very sensitive to the discount rate, but a consumption discount rate of less than 3% is not in line with observed preferences and behaviour (Arrow *et al.*, 1996).

Table 6 shows the maximum market impacts for the 16 regions for the no control and the 650 ppm stabilisation scenarios. There are five variants of the no control scenario: the FUND scenario (used above) and the four base SRES scenarios (A1, A2, B1, B2) (Nakicenovic and Swart, 2000), here in their IMAGE incarnation (IMAGE Team, 2001). Table 7 repeats this for non-market impacts.

The no control FUND scenario has high peak market impacts compared to the SRES scenarios, with the exception of the A2 scenario, which has higher peak market impacts for developing countries. The A1 scenario has higher peak market impacts than the B2 scenario, which has higher peak market impacts than the B1 scenario. This order does not carry over to the stabilisation scenarios, because the higher emission scenarios require earlier and more stringent emission reduction to meet the concentration target. Nonetheless, because peak market impacts under the 650 ppm stabilisation scenario are low, the order of the avoided peak market impacts is the same as the order of the no control peak market impacts.

For non-market peak impacts, the situation is different. Without emission control, peak impacts in the developed regions follow the order of climate change (FUND > A2 > A1 > B2 > B1). However, for developing regions, the FUND, A1, A2 and B2 scenarios each may have the highest peak impacts, depending on the region. The reason is that economic growth and climate change together determine impacts. The B1 scenario has the lowest peak impacts. In the low income regions, emission reduction does not affect peak non-market impacts, regardless of the scenario. In the high income regions, avoided peak impacts follow the same order as the peak impacts without emission control. In the middle income regions, the pattern is mixed. Strikingly, peak non-market impacts may increase in the former Soviet Union because of the removal of the sulphur veil (A1 and A2) and in South Asia because of the costs of emission reduction (B1).

Table 8 displays the cost-benefit ratio of the net present value of avoided damages to emission reduction costs. Regardless of the no control scenario and the stabilisation target, emission reduction does not appear worthwhile, at least not to the amount tested..

Table 9 shows the maximum market impacts for the 16 regions for the no control (FUND) and the 650 ppm stabilisation scenarios. There are five variants: best guesses (used above), low (1.5°C) and high (4.5°C) climate sensitivity, and low (half) and high (double) impacts. Table 10 repeats this for non-market impacts.

Without emission control, the peak market impacts are as expected. Higher (lower) climate change lead to higher (lower) peak damages. Raising (lowering) climate sensitivity has a larger effect than raising (lowering) damages. Avoided market impacts follow the same pattern. The same holds for peak non-market impacts.

Table 11 shows the cost-benefit ratio of the net present avoided damage to emission reduction costs. With a high climate sensitivity or, to a lesser extent, high damages, the value of the avoided damages exceeds the costs of emission reduction to reach a 650 ppm peak carbon dioxide concentration for the poorer regions, Western Europe and the former Soviet Union. A target like this may be defended on the grounds of risk aversion and international equity.

6. Discussion and conclusion

This paper estimates the climate change impacts avoided by greenhouse gas emission reduction. It does so in a comprehensive, internally consistent manner, including not just reduced climate change but also the costs of emission abatement. The main results can be summarised as follows. Unabated climate change may lead to regional, annual welfare losses in excess of an equivalent loss of income by 10%. The most serious impacts can be avoided by relatively modest emission reduction. Less and less impacts are avoided as emission abatement gets more and more stringent. A comparison of the net present value of avoided damages and emission reduction costs confirms this. For the most stringent emission control, climate change impacts may increase because sulphur emission reduction would lead to regional warming and because emission reduction costs would enhance vulnerability. In developing countries, economic growth is at least as important to non-market damages as is climate change.

The results of this paper are not better than the underlying model. Valuation of non-market impacts, extension to other impacts, extreme climate scenarios, interactions between impacts, the evolution of vulnerability, and the modelling of adaptation remain major issues in need of improvement. Unfortunately, none of these issues can be easily solved (Smith *et al.*, 2001). Costs of emission reduction are here presented only in a very succinct manner.

The results shown here, regardless of their caveats, do have implications for climate policy. Less and less damage would be avoided as abatement would get more and more stringent and more and more costly. This implies that is much easier to justify modest emission reduction targets than it is to defend stringent targets. This conclusion is similar to that drawn by Nordhaus (1993) and other cost-benefit studies.

This conclusion is at odds with the more stringent climate policy target adopted by the EU (e.g., CEC, 2005). This implies that either that target is not justified, or the analysis here is incomplete or biased. Future research should shed further light on this matter.

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Table 1. Maximum climate change damage (%GDP) on market sectors for the no control scenario and five stabilisation scenarios for the 16 FUND regions.

Name	CO_2[a]	GMT[b]	USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
BaU	1352	6.7	0.94	0.65	1.89	0.49	1.33	2.65	9.80	2.42	2.40	0.66	2.34	2.24	9.61	6.66	3.08	8.38
850	704	3.9	0.14	-0.20	0.34	-0.18	-0.59	0.72	3.82	0.26	0.26	0.15	0.21	0.34	0.16	2.77	1.11	0.72
750	629	3.5	0.07	-0.25	0.20	-0.20	-0.70	0.53	3.24	0.02	0.06	0.08	0.03	0.15	-0.58	2.30	0.88	-0.06
650	554	3.0	0.02	-0.23	0.06	-0.22	-0.77	0.36	2.66	-0.19	-0.10	0.04	-0.12	0.06	-1.14	1.78	0.63	-0.71
550	479	2.5	-0.01	-0.21	-0.08	-0.19	-0.72	0.20	2.09	-0.35	-0.24	0.02	-0.24	-0.03	-1.54	1.15	0.34	-1.22
450	406	1.8	-0.02	-0.17	-0.11	-0.15	-0.62	0.05	1.46	-0.46	-0.30	0.01	-0.35	-0.10	-1.82	0.42	0.07	-1.72

[a] Maximum atmospheric concentration of carbon dioxide, in parts per million by volume.

[b] Maximum increase global mean surface air temperature since pre-industrial times, in degrees centigrade.

Table 2. Maximum climate change damage (%GDP) on non-market sectors for the no control scenario and five stabilisation scenarios for the 16 FUND regions.

Name	CO_2[a]	GMT[b]	USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
BaU	1352	6.7	0.31	0.23	0.26	0.26	0.23	0.18	1.22	0.18	0.22	0.23	0.09	0.19	0.21	0.53	4.66	0.15
850	704	3.9	0.25	0.18	0.21	0.22	0.18	0.13	1.22	0.11	0.14	0.15	0.07	0.11	0.14	0.53	4.66	0.15
750	629	3.5	0.24	0.17	0.20	0.21	0.17	0.12	1.22	0.09	0.13	0.14	0.07	0.10	0.13	0.53	4.66	0.15
650	554	3.0	0.23	0.16	0.19	0.19	0.15	0.10	1.22	0.09	0.12	0.13	0.07	0.08	0.10	0.53	4.66	0.15
550	479	2.5	0.21	0.14	0.17	0.18	0.14	0.08	1.22	0.07	0.12	0.13	0.07	0.07	0.09	0.53	4.67	0.15
450	406	1.8	0.18	0.12	0.15	0.16	0.11	0.06	1.73	0.07	0.13	0.33	0.57	0.04	0.06	0.56	4.92	0.17

[a] Maximum atmospheric concentration of carbon dioxide, in parts per million by volume.

[b] Maximum increase global mean surface air temperature since pre-industrial times, in degrees centigrade.

Table 3. Net present costs (in trillion dollars) of emission reduction ("Em. red."), market impacts and non-market impacts for the 16 FUND regions and the five stabilisation scenarios; consumption discount rate: 3%.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
Em. red.	850	11.4	1.0	11.7	11.0	0.7	1.4	3.3	6.3	2.4	9.6	7.6	9.3	21.3	1.6	3.0	0.3
	750	8.8	0.8	5.0	5.0	0.7	1.4	4.0	6.3	2.1	7.5	7.6	8.4	19.5	1.6	3.2	0.4
	650	9.4	0.8	5.4	5.7	0.8	1.8	5.7	7.7	2.3	8.3	9.7	9.7	25.2	1.7	3.5	0.5
	550	15.0	1.3	9.0	9.0	1.2	2.7	9.3	11.8	3.5	12.7	14.7	14.8	43.7	3.0	5.8	0.7
	450	34.1	3.0	21.9	19.3	2.7	6.3	26.1	29.6	8.2	27.7	35.4	35.9	116.4	10.0	16.9	1.9
Market	850	0.6	0.0	1.3	-0.1	0.0	0.1	0.5	0.1	0.2	0.3	0.8	1.1	14.9	0.9	0.6	0.1
	750	0.6	0.0	1.5	-0.3	0.0	0.1	0.6	0.1	0.2	0.3	0.9	1.3	16.9	1.1	0.8	0.1
	650	0.7	0.0	1.7	-0.4	0.0	0.1	0.7	0.0	0.2	0.3	0.9	1.4	18.6	1.3	0.9	0.1
	550	0.7	0.0	2.0	-0.8	0.0	0.1	0.8	-0.2	0.2	0.3	1.0	1.5	19.7	1.5	1.0	0.2
	450	0.5	0.0	2.1	-1.5	0.0	0.1	1.0	-0.4	0.2	0.3	1.0	1.6	19.4	1.7	1.1	0.2
Non-market	850	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.3	0.0	0.0	0.0
	750	0.2	0.0	0.2	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.3	0.0	0.0	0.0
	650	0.3	0.0	0.3	0.3	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.4	0.0	0.0	0.0
	550	0.4	0.0	0.4	0.4	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.1	0.5	0.0	0.0	0.0
	450	0.6	0.0	0.6	0.6	0.0	0.0	-0.2	0.1	0.0	0.2	0.0	0.2	0.7	0.0	-0.1	0.0

Table 4. Maximum climate change damage (%GDP) on market sectors for the no control scenario and the graduation scenarios for the 16 FUND regions.

GI[a]	ER[b]	CO_2	USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
		1352	0.94	0.65	1.89	0.35	1.15	2.64	9.80	2.30	2.37	0.66	2.34	2.24	9.56	6.66	3.08	8.19
10000	0.50	934	0.44	0.13	0.85	0.05	0.22	1.53	6.23	1.11	1.22	0.34	1.30	1.22	4.39	4.20	2.16	4.10
5000	0.25	846	0.39	0.08	0.78	-0.03	0.01	1.27	5.34	0.82	0.96	0.28	1.01	0.98	3.28	3.38	1.90	3.16
5000	0.50	800	0.34	0.03	0.66	-0.05	-0.09	1.15	4.94	0.70	0.84	0.25	0.89	0.87	2.75	3.08	1.78	2.71
5000	1.00	720	0.25	-0.06	0.46	-0.09	-0.25	0.94	4.24	0.48	0.63	0.19	0.68	0.69	1.86	2.55	1.59	1.93
2500	0.50	682	0.25	-0.06	0.49	-0.13	-0.34	0.82	3.82	0.37	0.51	0.17	0.54	0.59	1.40	2.22	1.19	1.51
5000	1.50	658	0.19	-0.12	0.32	-0.12	-0.36	0.77	3.71	0.32	0.47	0.16	0.51	0.55	1.19	2.42	1.49	1.34
5000	2.00	611	0.14	-0.16	0.21	-0.14	-0.44	0.65	3.31	0.20	0.35	0.13	0.39	0.45	0.69	2.40	1.41	0.89
5000	2.50	577	0.10	-0.19	0.13	-0.15	-0.50	0.56	3.02	0.11	0.26	0.11	0.29	0.36	0.30	2.38	1.33	0.55

[a] Graduation income ($)

[b] Annual emission reduction (%)

Table 5. Maximum climate change damage (%GDP) on non-market sectors for the no control scenario and the graduation scenarios for the 16 FUND regions.

GI[a]	ER[b]	CO_2	USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
		1352	0.31	0.23	0.26	0.26	0.23	0.18	1.22	0.18	0.22	0.23	0.09	0.19	0.21	0.53	4.66	0.15
10000	0.50	934	0.26	0.19	0.22	0.22	0.19	0.15	1.22	0.15	0.18	0.19	0.08	0.16	0.18	0.53	4.66	0.15
5000	0.25	846	0.25	0.19	0.21	0.21	0.18	0.15	1.22	0.14	0.17	0.18	0.07	0.15	0.17	0.53	4.66	0.15
5000	0.50	800	0.24	0.18	0.21	0.21	0.18	0.14	1.22	0.13	0.16	0.17	0.07	0.14	0.16	0.53	4.66	0.15
5000	1.00	720	0.23	0.17	0.20	0.20	0.17	0.13	1.22	0.12	0.15	0.16	0.07	0.13	0.15	0.53	4.66	0.15
2500	0.50	682	0.22	0.16	0.19	0.19	0.16	0.13	1.22	0.12	0.15	0.15	0.07	0.13	0.15	0.53	4.66	0.15
5000	1.50	658	0.23	0.16	0.19	0.19	0.16	0.12	1.22	0.11	0.14	0.15	0.07	0.12	0.14	0.53	4.66	0.15
5000	2.00	611	0.22	0.16	0.18	0.19	0.15	0.12	1.22	0.11	0.13	0.14	0.07	0.11	0.13	0.53	4.66	0.15
5000	2.50	577	0.22	0.15	0.18	0.18	0.15	0.11	1.22	0.10	0.12	0.13	0.07	0.10	0.13	0.53	4.66	0.15

[a] Graduation income ($)

[b] Annual emission reduction (%)

Table 6. Maximum climate change damage (%GDP) on market sectors for the no control scenario and 650 ppm stabilisation scenario for the 16 FUND regions for the FUND and the four SRES scenarios.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
FUND	BaU	0.94	0.65	1.89	0.49	1.33	2.65	9.80	2.42	2.40	0.66	2.34	2.24	9.61	6.66	3.08	8.38
	650	0.02	-0.23	0.06	-0.22	-0.77	0.36	2.66	-0.19	-0.10	0.04	-0.12	0.06	-1.14	1.78	0.63	-0.71
	diff	0.92	0.88	1.83	0.71	2.10	2.29	7.14	2.61	2.50	0.62	2.46	2.18	10.76	4.88	2.45	9.09
A1	BaU	0.30	0.13	0.53	0.24	0.68	1.12	4.48	0.93	1.15	0.24	0.82	0.73	3.57	2.40	1.10	4.10
	650	0.02	-0.17	-0.03	-0.16	-0.57	0.42	2.62	-0.05	-0.04	0.05	-0.01	0.12	-0.69	0.94	0.29	-0.42
	diff	0.28	0.30	0.55	0.40	1.25	0.70	1.86	0.98	1.19	0.19	0.83	0.61	4.26	1.46	0.81	4.52
A2	BaU	0.59	0.45	1.15	0.61	1.77	2.58	8.58	3.33	3.34	0.61	2.79	2.11	14.25	5.82	2.87	12.93
	650	0.01	-0.22	-0.02	-0.21	-0.71	0.32	2.55	-0.16	-0.11	0.03	-0.10	0.07	-1.19	1.39	0.44	-0.71
	diff	0.57	0.66	1.17	0.82	2.48	2.25	6.03	3.50	3.45	0.58	2.89	2.05	15.44	4.44	2.42	13.64
B1	BaU	0.09	-0.16	0.06	-0.05	-0.28	0.53	2.93	0.19	0.23	0.09	0.17	0.24	0.40	1.11	0.36	0.60
	650	0.05	-0.22	-0.02	-0.20	-0.71	0.44	2.67	-0.02	0.01	0.07	0.02	0.16	-0.66	1.01	0.29	-0.27
	diff	0.04	0.06	0.09	0.14	0.43	0.09	0.26	0.21	0.22	0.02	0.16	0.07	1.05	0.10	0.08	0.87
B2	BaU	0.53	0.33	1.02	0.41	1.19	1.74	5.77	2.23	2.23	0.44	1.99	1.66	9.37	4.18	2.05	7.98
	650	0.04	-0.23	0.12	-0.22	-0.78	0.40	2.71	-0.16	-0.10	0.04	-0.10	0.10	-1.26	1.21	0.41	-0.72
	diff	0.48	0.56	0.90	0.62	1.97	1.35	3.06	2.39	2.33	0.40	2.09	1.56	10.63	2.96	1.63	8.70

Table 7. Maximum climate change damage (%GDP) on non-market sectors for the no control scenario and 650 ppm stabilisation scenario for the 16 FUND regions for the FUND and the four SRES scenarios.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
FUND	BaU	0.31	0.23	0.26	0.26	0.23	0.18	1.22	0.18	0.22	0.23	0.09	0.19	0.21	0.53	4.66	0.15
	650	0.23	0.16	0.19	0.19	0.15	0.10	1.22	0.09	0.12	0.13	0.07	0.08	0.10	0.53	4.66	0.15
	diff	0.08	0.07	0.07	0.07	0.07	0.08	0.00	0.09	0.09	0.10	0.03	0.11	0.11	0.00	0.00	0.00
A1	BaU	0.26	0.20	0.23	0.23	0.20	0.19	1.47	0.20	0.21	0.21	0.16	0.25	0.21	0.53	4.61	0.16
	650	0.23	0.16	0.19	0.20	0.16	0.13	1.49	0.15	0.14	0.15	0.10	0.17	0.16	0.53	4.61	0.16
	diff	0.03	0.04	0.03	0.03	0.04	0.05	-0.01	0.06	0.06	0.06	0.06	0.08	0.05	0.00	0.00	0.00
A2	BaU	0.27	0.20	0.23	0.23	0.20	0.16	1.70	0.15	0.16	0.17	0.09	0.16	0.17	0.53	4.68	0.15
	650	0.23	0.14	0.18	0.19	0.14	0.09	1.71	0.08	0.12	0.13	0.07	0.09	0.10	0.53	4.69	0.15
	diff	0.04	0.06	0.05	0.04	0.06	0.07	-0.01	0.07	0.03	0.04	0.02	0.07	0.07	0.00	0.00	0.00
B1	BaU	0.24	0.16	0.19	0.20	0.15	0.13	1.52	0.14	0.14	0.15	0.08	0.16	0.15	0.53	4.61	0.16
	650	0.23	0.15	0.19	0.19	0.15	0.12	1.52	0.13	0.13	0.14	0.09	0.14	0.14	0.53	4.61	0.16
	diff	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	-0.01	0.01	0.01	0.00	0.00	0.00
B2	BaU	0.26	0.17	0.21	0.21	0.17	0.16	1.58	0.14	0.15	0.16	0.09	0.15	0.15	0.54	4.73	0.16
	650	0.23	0.14	0.18	0.18	0.13	0.11	1.58	0.09	0.13	0.13	0.07	0.10	0.10	0.54	4.73	0.16
	diff	0.03	0.04	0.03	0.03	0.04	0.05	0.00	0.05	0.03	0.03	0.02	0.05	0.05	0.00	0.00	0.00

Table 8. Cost-benefit ratios for the 16 FUND regions, the five stabilisation targets and the five alternative baseline scenarios.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
Base	850	0.06	0.06	0.12	0.00	0.04	0.08	0.17	0.02	0.09	0.03	0.10	0.13	0.71	0.58	0.22	0.31
	750	0.09	0.08	0.35	0.00	0.04	0.08	0.16	0.02	0.12	0.05	0.12	0.16	0.88	0.70	0.24	0.35
	650	0.10	0.08	0.37	0.00	0.03	0.07	0.13	0.01	0.12	0.05	0.10	0.16	0.76	0.76	0.26	0.30
	550	0.07	0.05	0.27	0.00	0.01	0.05	0.09	0.00	0.08	0.04	0.07	0.11	0.46	0.49	0.18	0.21
	450	0.03	0.02	0.13	0.00	0.00	0.02	0.03	0.00	0.03	0.02	0.03	0.05	0.17	0.17	0.06	0.09
A1	850	0.06	0.05	0.13	0.09	0.02	0.05	0.09	0.05	0.03	0.03	0.04	0.05	0.19	0.23	0.12	0.09
	750	0.06	0.05	0.14	0.10	0.01	0.05	0.09	0.05	0.03	0.03	0.04	0.05	0.19	0.23	0.11	0.09
	650	0.08	0.07	0.17	0.11	0.00	0.06	0.09	0.05	0.02	0.04	0.04	0.06	0.22	0.26	0.13	0.10
	550	0.06	0.06	0.17	0.10	0.00	0.04	0.07	0.03	0.01	0.03	0.03	0.04	0.15	0.17	0.10	0.07
	450	0.03	0.03	0.08	0.03	0.00	0.02	0.03	0.01	0.00	0.01	0.01	0.02	0.05	0.06	0.05	0.03
A2	850	0.07	0.06	0.27	0.03	0.05	0.09	0.15	0.03	0.09	0.04	0.07	0.09	0.51	0.31	0.12	0.25
	750	0.04	0.03	0.08	0.00	0.03	0.06	0.15	0.03	0.08	0.02	0.07	0.07	0.53	0.33	0.14	0.29
	650	0.08	0.06	0.18	0.00	0.04	0.09	0.15	0.02	0.10	0.03	0.07	0.09	0.61	0.36	0.14	0.31
	550	0.06	0.04	0.24	0.00	0.02	0.06	0.10	0.00	0.06	0.02	0.04	0.06	0.35	0.26	0.10	0.21
	450	0.03	0.02	0.10	0.00	0.00	0.02	0.02	0.00	0.02	0.01	0.02	0.03	0.12	0.11	0.02	0.08
B1	850	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	750	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	650	0.02	0.01	0.03	0.00	0.01	0.03	0.05	0.01	0.03	0.01	0.02	0.02	0.09	0.07	0.03	0.07
	550	0.03	0.01	0.07	0.00	0.00	0.03	0.04	0.00	0.01	0.01	0.01	0.02	0.05	0.07	0.03	0.05
	450	0.01	0.00	0.03	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.01	0.02
B2	850	0.05	0.04	0.16	0.01	0.03	0.05	0.10	0.01	0.06	0.03	0.06	0.07	0.32	0.20	0.09	0.18
	750	0.05	0.05	0.22	0.00	0.03	0.05	0.10	0.00	0.07	0.03	0.05	0.07	0.29	0.20	0.09	0.17
	650	0.07	0.05	0.22	0.00	0.02	0.06	0.10	0.00	0.07	0.03	0.06	0.08	0.35	0.25	0.12	0.21
	550	0.06	0.04	0.19	0.00	0.00	0.05	0.07	0.00	0.06	0.03	0.04	0.06	0.26	0.21	0.10	0.15
	450	0.02	0.01	0.10	0.00	0.00	0.02	0.03	0.00	0.02	0.01	0.01	0.03	0.09	0.10	0.04	0.06

Table 9. Maximum climate change damage (%GDP) on market sectors for the no control scenario and 650 ppm stabilisation scenario for the 16 FUND regions for the base case, high and low climate sensitivity, and high and low damages.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
Base	BaU	0.94	0.65	1.89	0.49	1.33	2.65	9.80	2.42	2.40	0.66	2.34	2.24	9.61	6.66	3.08	8.38
	650	0.02	-0.23	0.06	-0.22	-0.77	0.36	2.66	-0.19	-0.10	0.04	-0.12	0.06	-1.14	1.78	0.63	-0.71
	diff	0.92	0.88	1.83	0.71	2.10	2.29	7.14	2.61	2.50	0.62	2.46	2.18	10.76	4.88	2.45	9.09
Low CS	BaU	0.13	-0.15	0.10	-0.46	-0.70	0.08	2.11	-0.25	-0.18	-0.05	-0.13	-0.05	-0.15	1.69	0.62	0.05
	650	-0.06	-0.18	-0.22	-0.27	-0.72	-0.24	0.61	-0.53	-0.44	-0.09	-0.46	-0.32	-1.93	0.16	-0.12	-1.69
	diff	0.18	0.04	0.31	-0.19	0.02	0.32	1.49	0.28	0.26	0.04	0.33	0.27	1.78	1.53	0.74	1.74
High CS	BaU	3.41	3.64	7.39	4.54	10.62	11.49	32.79	13.56	12.21	2.90	11.53	9.70	46.72	20.67	10.53	40.59
	650	0.53	0.10	1.43	0.57	0.72	2.59	9.05	2.30	2.21	0.80	1.95	2.13	5.86	6.50	2.92	6.24
	diff	2.88	3.54	5.96	3.97	9.90	8.90	23.73	11.26	10.00	2.10	9.58	7.57	40.86	14.17	7.61	34.35
Low dam	BaU	0.45	0.31	0.91	0.24	0.63	1.27	4.55	1.18	1.15	0.32	1.12	1.07	4.53	3.13	1.47	3.95
	650	0.01	-0.12	0.03	-0.11	-0.40	0.18	1.31	-0.10	-0.06	0.02	-0.06	0.03	-0.61	0.88	0.31	-0.38
	diff	0.45	0.43	0.88	0.35	1.03	1.09	3.24	1.28	1.21	0.30	1.19	1.05	5.14	2.25	1.16	4.32
High dam	BaU	1.82	1.24	3.64	0.94	2.53	5.07	18.18	4.70	4.61	1.27	4.49	4.30	18.14	12.54	5.89	15.78
	650	0.03	-0.47	0.13	-0.44	-1.58	0.70	5.23	-0.40	-0.22	0.08	-0.25	0.11	-2.43	3.53	1.25	-1.51
	diff	1.79	1.71	3.52	1.39	4.11	4.37	12.95	5.10	4.83	1.19	4.74	4.19	20.57	9.00	4.64	17.29

Table 10. Maximum climate change damage (%GDP) on non-market sectors for the no control scenario and 650 ppm stabilisation scenario for the 16 FUND regions for the base case, high and low climate sensitivity, and high and low damages.

		USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
Base	BaU	0.31	0.23	0.26	0.26	0.23	0.18	1.22	0.18	0.22	0.23	0.09	0.19	0.21	0.53	4.66	0.15
	650	0.23	0.16	0.19	0.19	0.15	0.10	1.22	0.09	0.12	0.13	0.07	0.08	0.10	0.53	4.66	0.15
	diff	0.08	0.07	0.07	0.07	0.07	0.08	0.00	0.09	0.09	0.10	0.03	0.11	0.11	0.00	0.00	0.00
Low CS	BaU	0.23	0.18	0.20	0.20	0.17	0.14	0.79	0.13	0.16	0.17	0.07	0.14	0.16	0.34	2.98	0.10
	650	0.16	0.12	0.14	0.14	0.11	0.07	0.79	0.06	0.08	0.08	0.04	0.06	0.07	0.34	2.99	0.10
	diff	0.07	0.06	0.06	0.06	0.06	0.07	0.00	0.07	0.08	0.08	0.02	0.08	0.09	0.00	0.00	0.00
High CS	BaU	0.43	0.29	0.35	0.34	0.29	0.25	2.11	0.23	0.30	0.31	0.13	0.26	0.28	0.90	7.99	0.27
	650	0.32	0.21	0.26	0.25	0.20	0.14	2.11	0.13	0.21	0.21	0.12	0.12	0.15	0.91	7.99	0.27
	diff	0.11	0.09	0.09	0.08	0.09	0.11	0.00	0.10	0.09	0.10	0.01	0.13	0.13	0.00	-0.01	0.00
Low dam	BaU	0.15	0.11	0.13	0.13	0.11	0.09	0.61	0.09	0.11	0.11	0.05	0.09	0.10	0.26	2.33	0.08
	650	0.11	0.08	0.09	0.10	0.08	0.05	0.61	0.04	0.06	0.06	0.03	0.04	0.05	0.26	2.33	0.08
	diff	0.04	0.03	0.04	0.03	0.04	0.04	0.00	0.04	0.04	0.05	0.01	0.05	0.05	0.00	0.00	0.00
High dam	BaU	0.61	0.45	0.52	0.52	0.45	0.36	2.46	0.34	0.42	0.45	0.19	0.37	0.42	1.05	9.31	0.31
	650	0.45	0.31	0.38	0.38	0.30	0.20	2.46	0.17	0.25	0.26	0.14	0.16	0.20	1.05	9.32	0.31
	diff	0.16	0.14	0.14	0.13	0.14	0.16	0.00	0.17	0.18	0.19	0.05	0.21	0.22	0.00	-0.01	0.00

Table 11. Cost-benefit ratio for the 650 stabilisation / FUND baseline scenarios for the best guess parameters, high and low climate sensitivity, and high and low impacts.

	USA	CAN	WEU	JPK	ANZ	EEU	FSU	MDE	CAM	SAM	SAS	SEA	CHI	NAF	SSA	SIS
Base	0.10	0.08	0.37	0.00	0.03	0.07	0.13	0.01	0.12	0.05	0.10	0.16	0.76	0.76	0.26	0.30
Low CS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.49	0.14	0.00
High CS	0.61	0.59	2.50	0.61	0.73	0.75	1.06	0.79	1.26	0.39	0.94	1.27	6.79	4.21	1.48	2.90
Low dam	0.07	0.06	0.31	0.00	0.02	0.06	0.12	0.00	0.10	0.04	0.09	0.14	0.72	0.72	0.24	0.29
High dam	0.28	0.23	1.24	0.00	0.06	0.25	0.48	0.00	0.39	0.15	0.37	0.58	2.88	2.87	0.96	1.15

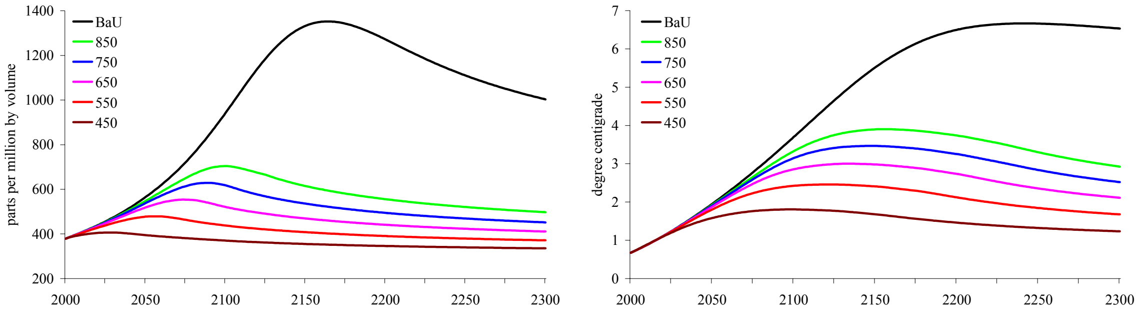

Figure 1. The atmospheric concentration of carbon dioxide (left panel) and the global mean temperature (right panel) according to the no control scenario (BaU) and the five stabilisation scenarios, characterised by their peak concentrations of 850, 750, 650, 550 and 450 ppm

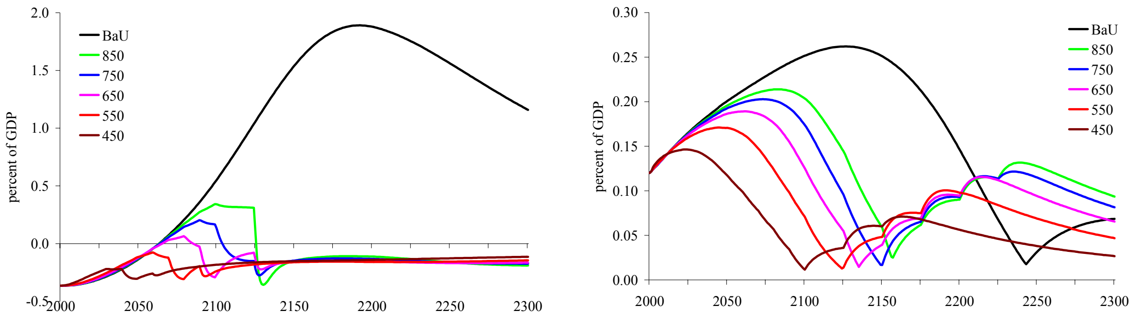

Figure 2. The monetised damages of climate change in Western Europe for the no control and the five stabilisation scenarios. Market impacts are displayed in the left panel, non-market damages in the right panel.

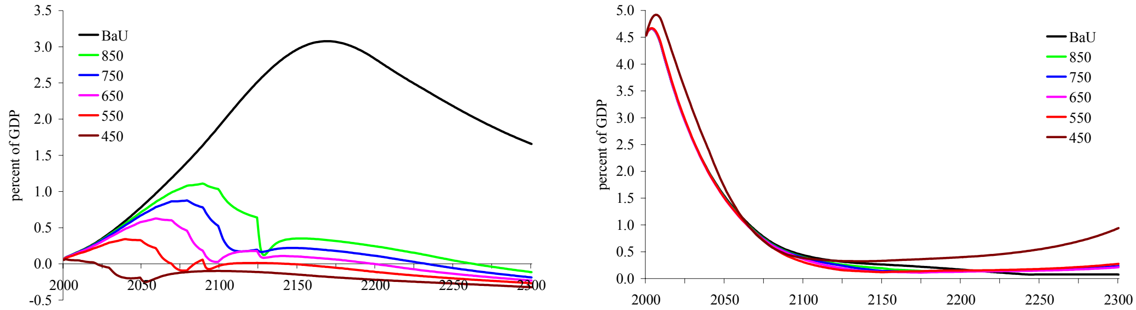

Figure 3. The monetised damages of climate change in Sub-Saharan Africa for the no control and the five stabilisation scenarios. Market impacts are displayed in the left panel, non-market damages in the right panel.

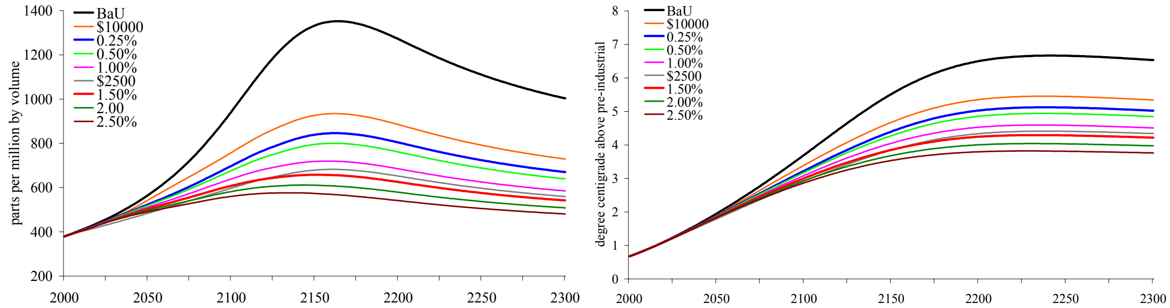

Figure 4. The atmospheric concentration of carbon dioxide (left panel) and the global mean temperature (right panel) according to the no control scenario (BaU) and the eight graduation scenarios, characterised by their annual emission reduction (0.25%, 0.50%, 1.00%, 1.50%, 2.00%, 2.50%; default 0.50%) and their graduation income ($2500, $5000, $10000; default $5000).

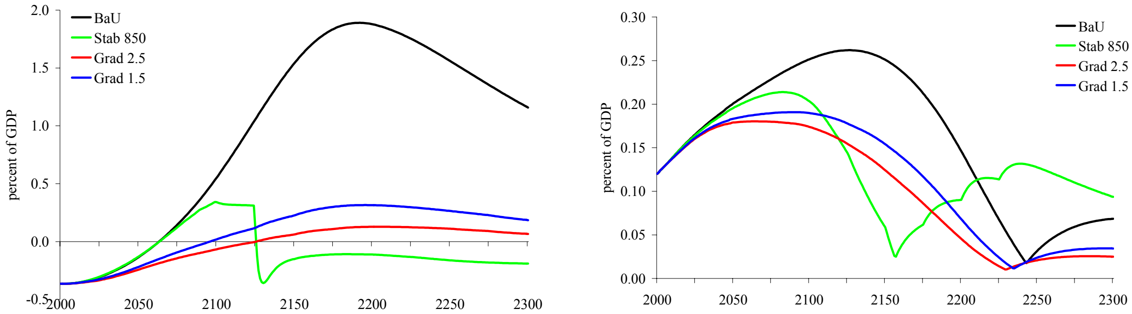

Figure 5. The monetised damages of climate change in Western Europe for the no control, the two selected graduation scenarios and the corresponding stabilisation scenario. Market impacts are displayed in the left panel, non-market damages in the right panel.

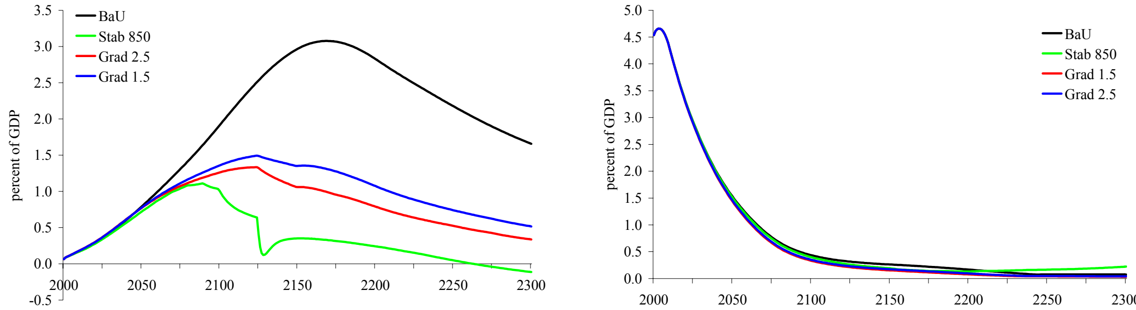

Figure 6. The monetised damages of climate change in Sub-Saharan Africa for the no control, the two selected graduation scenarios and the corresponding stabilisation scenario. Market impacts are displayed in the left panel, non-market damages in the right panel.

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Research Unit Sustainability and Global Change

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