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Stylized Emission Path

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Background note on a stylized emission path

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Summary

This background note provides details of a stylized greenhouse gas (GHG) emission path created in preparation of the UNDP Human Development Report 2007. Under this emission path, global greenhouse gas emissions are assumed to be halved by 2050 compared to their 1990 levels. 'More likely than not' (>50%) such an emission path would result in a global mean temperature increase above pre-industrial levels of less than 2°C. Such a temperature level is not a 'safe level' however. Ice sheet disintegration and rising sea levels, severe impacts on ecosystems, human health and food production can not be ruled out for temperature levels below 2°C. It is chosen here as a rough guideline for an emission pathway as 2°C is often considered as a policy target. Industrialized nations, i.e. the countries listed in Annex-I of the United Nations Framework Convention on Climate Change (UNFCCC), are assumed to reduce their emissions by 30% by 2020 and 80% by 2050 – relative to 1990 emission levels. Consequently, the remainder of the global emission budget is available for developing countries, i.e. Non-Annex I countries. Under this stylized emission path, non-Annex I GHG emissions are rising up to about 170% of their 1990 levels by 2020, before falling to about 85% of their 1990 levels by 2050. Two-thirds of the world's 21st century carbon budget is hence assumed to stem from Non-Annex I countries under this stylized emission path. The climate response under this emission pathway is comparable to the medium pathway analyzed by the Stern Review, namely a temporary peaking of CO_2equivalance concentrations (radiative forcing) at roughly 500ppm towards the middle of the century with a decline to 450ppm and below towards the end of this century. Using the simple climate model MAGICC as in IPCC AR-4, temperatures for most of the 19 AOGCM model emulations are projected to stay below 2°C although under high carbon cycle feedback settings, the upper temperature (1-sigma) uncertainty is 2.5°C above pre-industrial.

Table of Contents

1. Introduction

An increase in global population and the rightful fulfilment of development aspirations would entail ever rising greenhouse gas emissions over the coming decades – if historic patterns are followed to provide increased access to energy services. High emissions in turn would imply higher human-induced climate change, which in turn would hinder aspirations for sufficient water resources, food production, disease control and ecosystem services in many regions of the world over the course of the 21st century. In the longer term, this would threaten the fulfilment of the Millennium Development Goals. Thus, the challenge ahead is to combine development aspirations with a lower carbon future. In fact, sustained development might not be possible without climate change mitigation as a warming climate could imply tremendous impacts on many economies.

Recent climate policy targets agreed by some governments include those of the twenty-seven member states of the EU, which envisage emission reductions of 30% for industrialized countries by 2020 and 60-80% by 2050 compared to 1990 levels (see European Council conclusions, March 2007, available at http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/93135.pdf).

This note illustrates a stylized multi-gas emission pathway for the four world regions OECD (OECD 1990 members), REF (Economies in Transition), ASIA and ALM (Afrika and Latin America), consistent with the four SRES world regions used in the IPCC Special Report on Emission Scenarios (Nakicenovic and Swart 2000). The main characteristics of the default pathway are:

- *Industrialized country* GHG emissions (OECD and REF) are reduced (compared to their 1990 emissions),
  - by 30% by 2020 and
  - by 80% by 2050
- *Global* GHG emissions are reduced to 50% of their 1990 emission levels by 2050.
- *Developing* country emissions are following the median of 54 SRES and post-SRES emission scenarios up to 2020 with reductions thereafter so that the global emission level by 2050 is halved.
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Furthermore, three sensitivity pathways were calculated. Firstly, industrialized country emission reductions are assumed to be less, namely 70% by 2050. Developing country emissions are assumed to be lower in order to maintain the 50% global emission level by 2050. Secondly, industrialized country emissions reductions are assumed to be more than 80%, namely 90% by 2050. Again, developing country emissions are adjusted so that global emissions levels stayed at 50% in 2050. Thirdly, a sensitivity case is provided where industrialized country emissions follow the default pathway, but developing country emissions are allowed to increase up to 2035, with total global CO_2 emission levels reaching a maximum of 36.6Gt CO_2eq/yr (=10GtC/yr). While the first two sensitivity cases affect the evolution of global emissions only marginally, the latter would result in a significant increase of global emissions with correspondingly higher concentrations, and higher global mean temperature implications.

2. Method

This section illustrates the design of the stylized multi-gas emission pathway. The considered emissions encompass the most important greenhouse gas, carbon dioxide, as well as methane, nitrous oxide, hydroflourocarbons (HFCs), perflourocarbons (PFCs) and sulphur hexafluoride (SF6), as controlled under the Kyoto Protocol. In addition, tropospheric ozone precursors (volatile organic compounds, carbon monoxide), and aerosol (SOx, NOx) emissions are derived using the Equal Quantile Walk (EQW) method. The EQW method uses a set of 54 SRES and harmonized post-SRES multi-gas scenarios and picks different gases' emissions in each year at the same percentile for a particular region. For example, if fossil CO_2 emissions of OECD countries were assumed to be close to the 10% percentile of the 54 SRES and post-SRES scenarios in 2050, methane, nitrous oxide and other emissions for this year would be taken from the 10% percentile of those gases' emissions in the underlying database. For details, see Meinshausen et al. (2006).

For illustrative purposes, greenhouse gas emissions are aggregated by weighing them with their respective 'IPCC 1996' Global Warming Potentials – consistent with the reporting guidelines under the UNFCCC (IPCC 1996) [1]. Hence, the GHG emissions presented in this note comprise fossil and land use related CO_2, CH_4, N_2O, HFCs, PFCs, and SF6 in accordance with the basket of greenhouse gas emissions controlled under the Kyoto Protocol. Per capita emissions are derived using median regional population projections as detailed by Lutz et al. (2001).

The climate responses to these multi-gas emission pathways is calculated using the simple climate model MAGICC (see e.g. Wigley and Raper 2001), which is the primary simple climate model in the past IPCC Assessment Reports. Here, MAGICC 4.2 is used as described in the most recent IPCC Fourth Assessment Report, see section 10.5.3 and Figure 10.26 therein (Meehl, Stocker et al. 2007). Specifically, emulations of 19 coupled atmosphere-ocean climate models in combination with low, medium and high carbon cycle feedback settings were run for each emission pathway. Thus, these emulations do take into account carbon cycle feedback uncertainties – approximately spanning the range of the C4MIP carbon cycle model intercomparison (Friedlingstein, Cox et al. 2006). In total, 15 greenhouse gases, tropospheric ozone precursor, and aerosols are taken into account as well as natural forcings identically as used for and shown in shown in Figure 10.26 of the IPCC Fourth Assessment Report WG1 (Meehl, Stocker et al. 2007).

[1] For simplicity, all emissions are given in units of CO_2 or CO_2 equivalents in this note. For converting these CO_2eq numbers to the mass of carbon only, i.e. GtC/yr, simply divide by 3.667 (or multiply by the respective molecular weight, i.e. by 12 and divide by 44).

3. Relative Emissions

The relative emissions of these stylized pathways are largely prescribed by the assumptions for 2020 and 2050, especially for the Annex-I emissions. As aforementioned, Annex I emissions decrease by 30% up to the year 2020 and by 80% up to the year 2050 compared to 1990 levels. For the sensitivity cases (see dashed lines in Figure 1), industrialized countries emission rates are adjusted after 2020, so that they match -70% and -90%, respectively, by 2050.

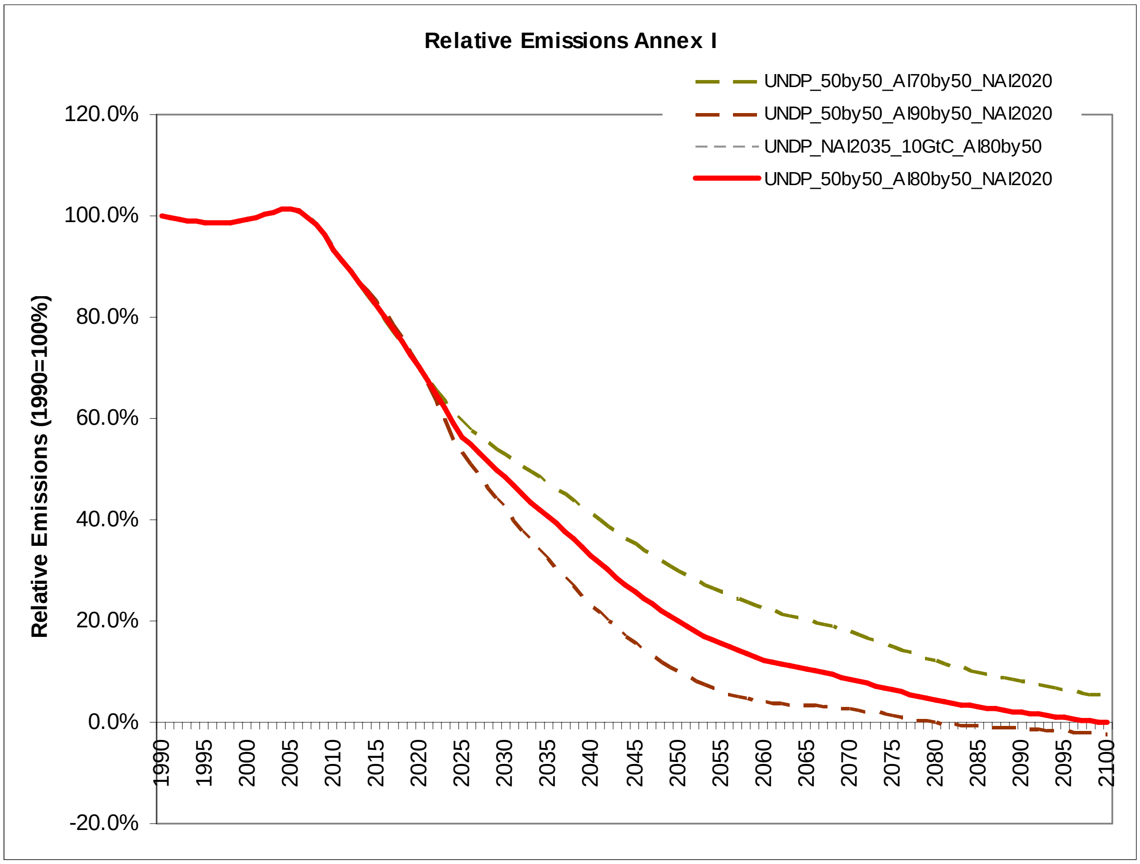


Figure 1 - Relative GHG emissions of industrialized countries under the default stylized emission pathway ('UNDP_50by50_AI80by50_NAI2020') with 30% reduction by 2020 and 80% reduction by 2050 (red solid line). Two sensitivity cases (dashed lines) show -70% and -90% reductions by 2050, respectively. The third sensitivity case with increased developing country emissions shares the same industrialized country emissions as the default pathway (solid line).

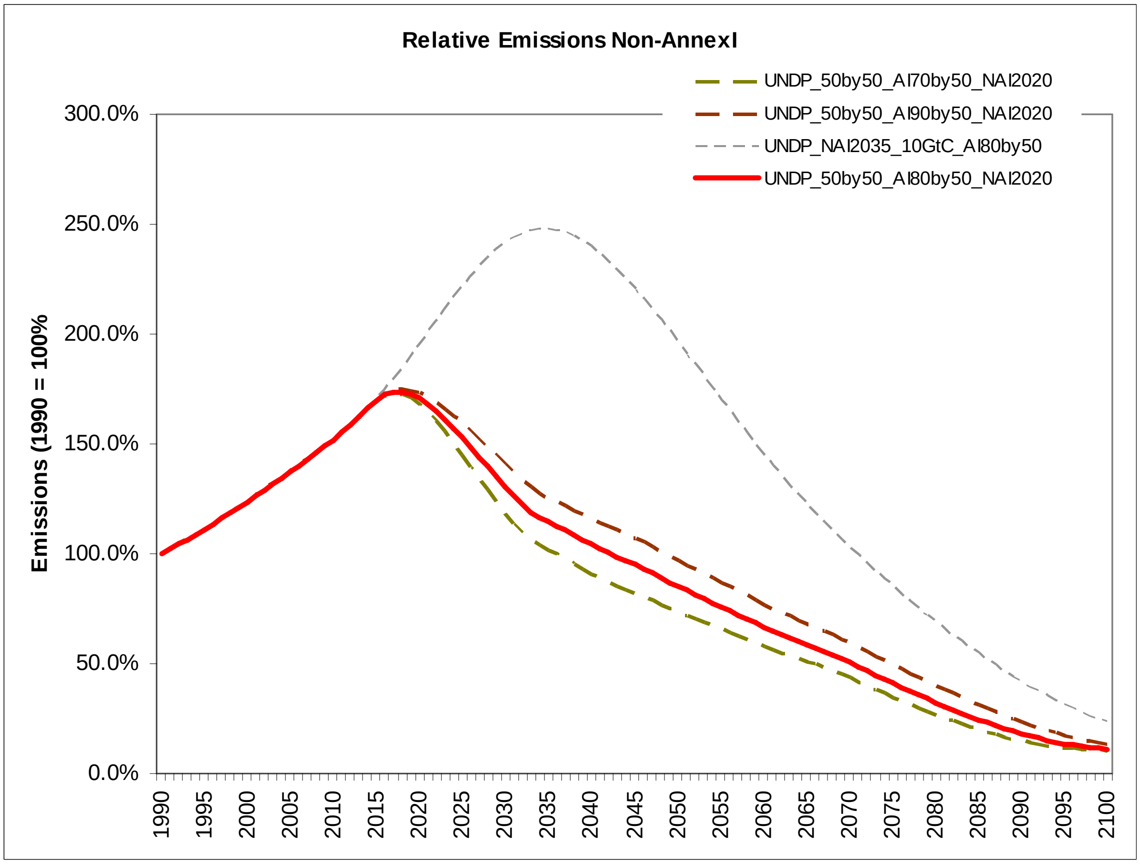


Figure 2 - Relative GHG emissions of developing / Non-Annex I countries under the default stylized emission pathway (red solid line). Two sensitivity cases (dashed lines) show the developing country emissions, if industrialized countries emit 70% (greenish dashed) and 90% (brownish dashed) less by 2050, respectively and under the assumption that developing countries' emissions are adjusted so that the global benchmark of halved emissions by 2050 is kept. The third sensitivity case with substantially increased developing country emissions lets emissions rise to roughly 250% of 1990 levels (thin grey dashed line).

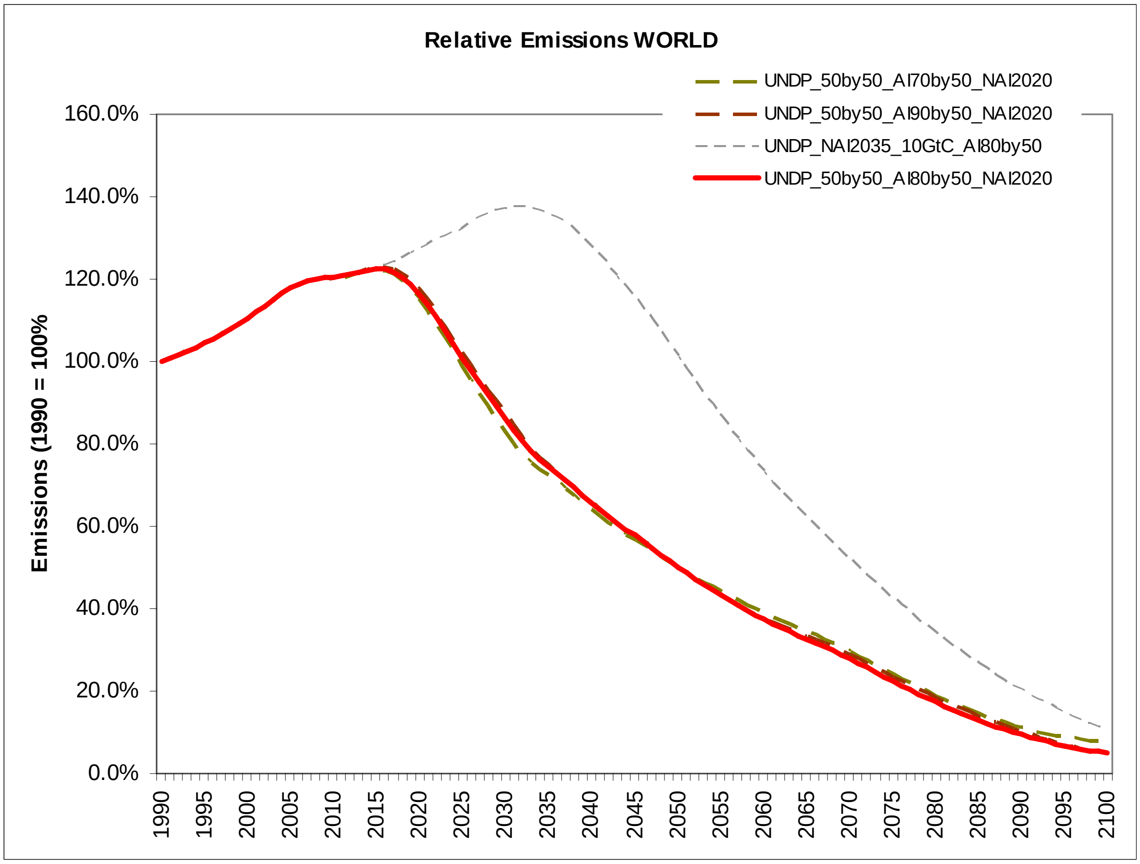


Figure 3 - Global GHG emissions under the default pathway and the considered sensitivity cases.

4. The Carbon Budget

The cumulative global emissions for the 50 years from year 2000 (i.e. 2000 to 2049) under the default pathway are 1.7 Tt CO_2eq (=1700 Gt CO_2eq = 1’700’000 Mt CO_2eq). Over the 21st century, the GHG emissions sum up to 2.15 Tt CO_2eq (=2’150 Gt CO_2eq), which means on average 21.5 Gt CO_2eq emissions per year. Current (2006) global emission levels are twice that, roughly 43Gt CO_2eq/yr, implying that after 50 years of current emission levels, emissions have to suddenly cease, if the global carbon budget for the 21st century is not to be exceeded.

Roughly two-thirds of the global carbon budget will be ‘consumed’ in developing countries under this stylized emission pathway. This is roughly constant for a 50 or 100 year time-horizon, and whether the aggregated GHG emissions or only total CO_2 emissions are analyzed. Of the four SRES regions, ALM and OECD will be allocated roughly equivalent parts of (slightly more than) a quarter, while the largest part is allocated to the country group ASIA (see Figure 4 to Figure 7).

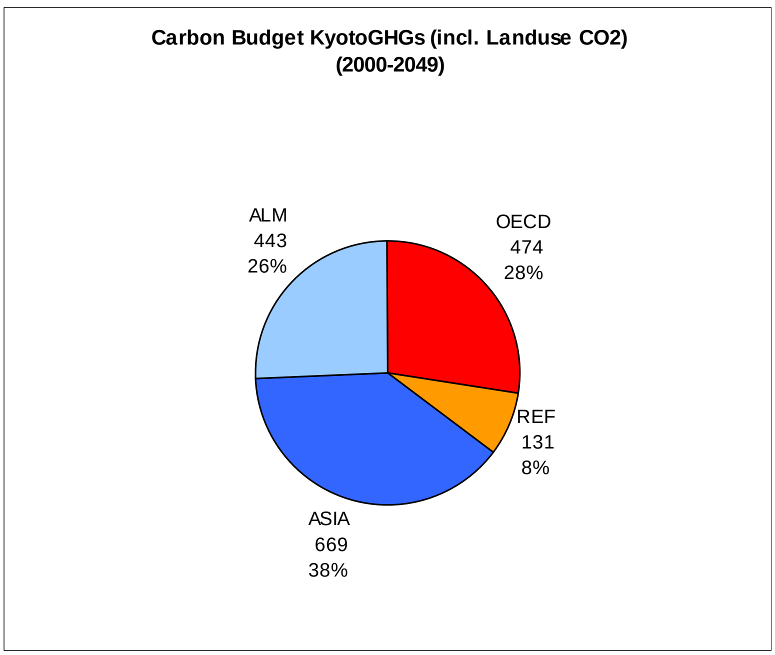


Figure 4 - Global GHG emission budget shares for the first half of the 21st century under the default pathway. Reddish colors indicate industralized (Annex I) country groups OECD and REF, while bluish colors indicate developing (Non-Annex I) country groups ASIA and ALM. Stated absolute budget numbers (e.g. 474 for OECD) are given in Gt CO_2eq.

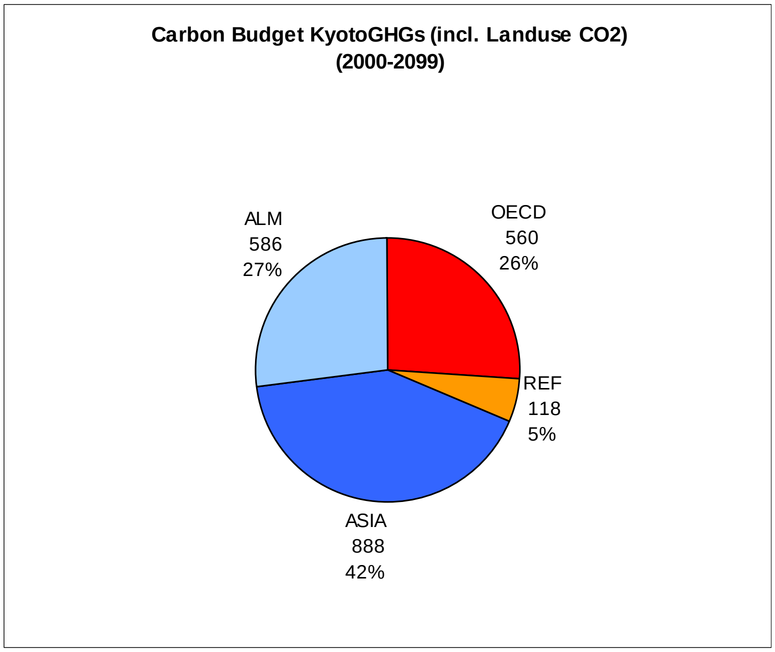


Figure 5 - Global GHG emission budget shares for the whole 21st century under the default pathway. See Figure 4.

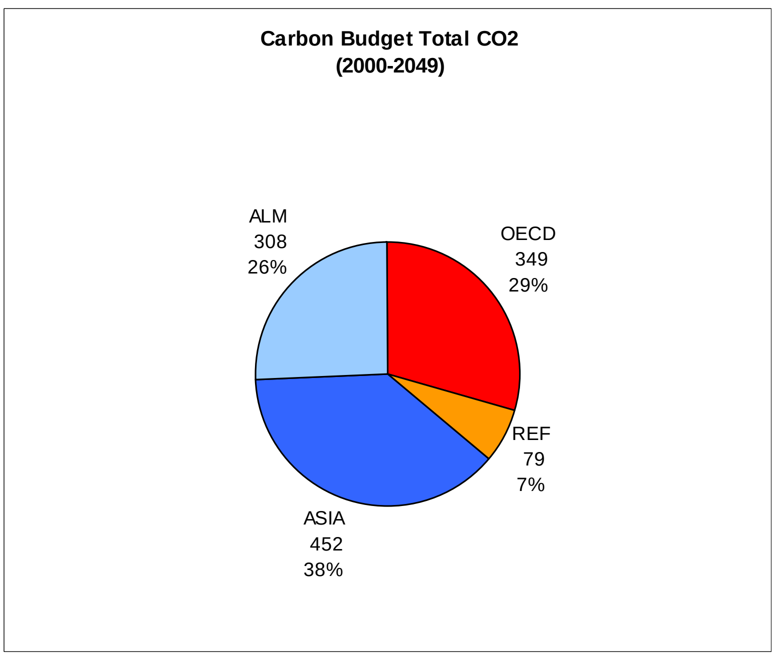


Figure 6 – Fossil and land use (total) CO_2 emission budget shares for the first half of the 21st century under the default pathway. Absolute budget numbers are indicated in Gt CO_2 (e.g. 349 Gt CO_2 for OECD countries).

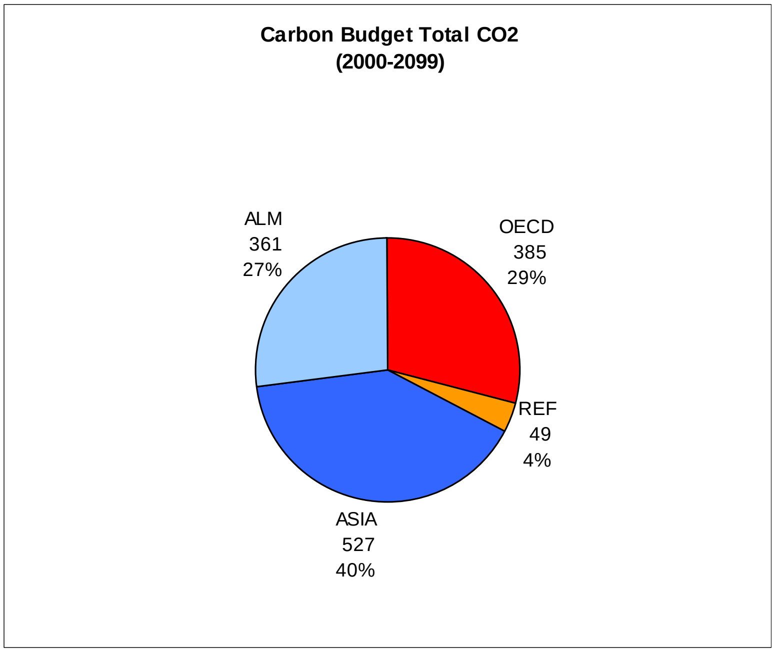


Figure 7 – Fossil and land use (total) CO_2 emission budget shares for the entire 21st century under the default pathway. See Figure 6.

5. Per-Capita Emissions

Absolute emissions will certainly be higher in developing countries than in industrialized countries for the 21st century. This is not surprising as developing countries' population are expected to grow from four to six times the population size of industrialized countries throughout the 21st century. On a per capita basis, developing countries emissions are therefore much lower in developing countries (Figure 8 and Figure 9).

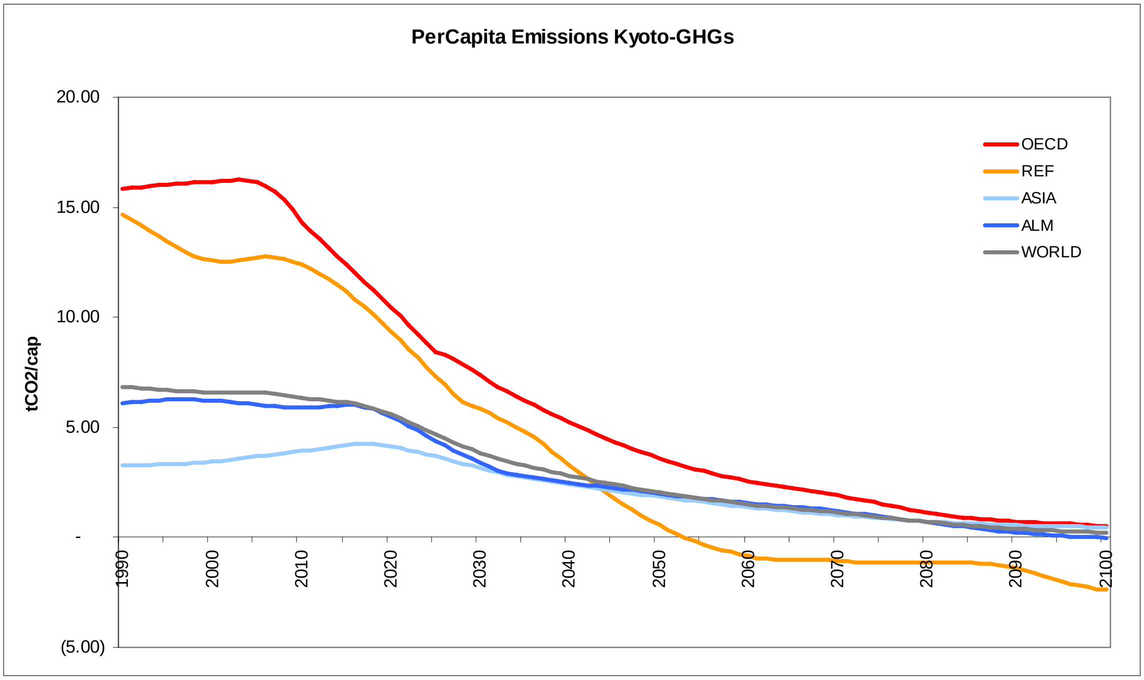


Figure 8 – Per capita GHG emissions under the default stylized emission pathway using regional emission share characteristics from 54 SRES and post-SRES scenarios and population projections based on Lutz et al. (2001). [2]

[2] The net negative emissions of countries with economies in transition ('REF') are expected due to CO2-uptakes up landuse related activities outweighing the very low fossil CO2 and other GHG emissions towards the end of the century. Compare Figure 9.

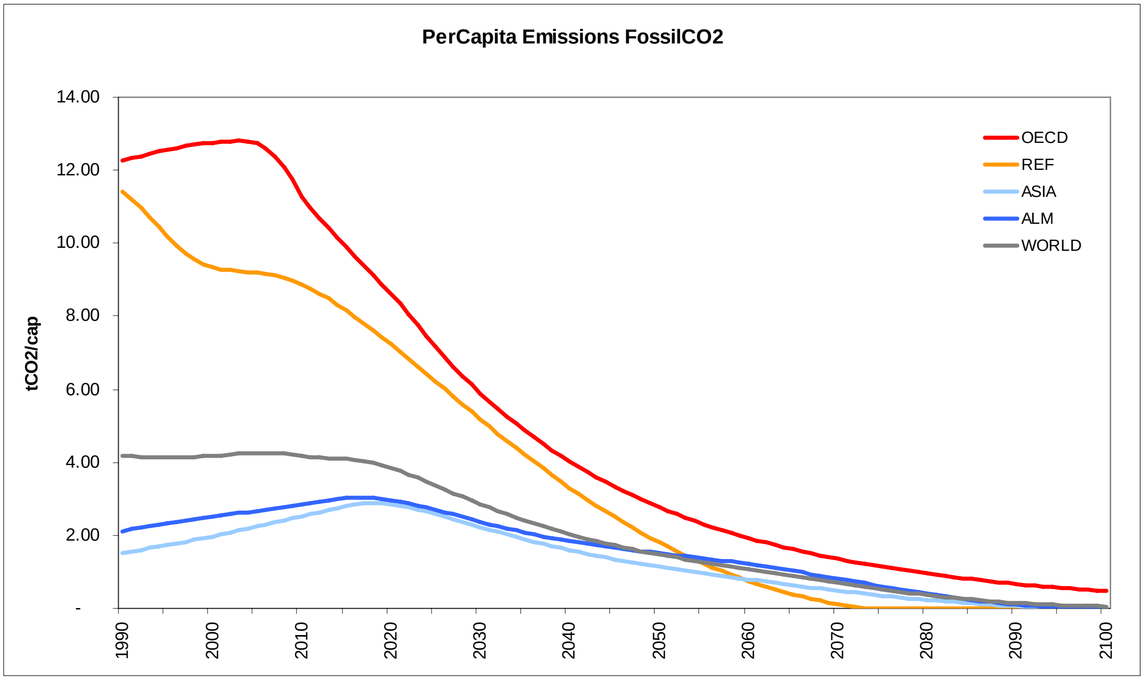


Figure 9 - As Figure 8, but for fossil CO_2 emissions only.

6. Climate Response

The CO_2 equivalence concentrations, which express the anthropogenically induced forcing due to all GHGs, tropospheric ozone and aerosols, will peak slightly above 500ppm CO_2eq around 2050. Subsequently, concentrations are expected to drop again, reaching about 450ppm CO_2eq by the end of the 21st century. Under high carbon cycle settings, and a high climate response, the concentrations might rise to around 540ppm and fall only to 500ppm towards the end of the century (see Figure 10). Beyond 2100, concentrations will further decrease, if emissions were kept at low levels.

Based on the multi-model climate emulations, the global mean surface temperatures under the stylized emission pathway can be expected to have a 50% or better probability of staying below 2°C. Although, for high carbon cycle feedbacks, a temperature increase of 2.5°C and higher can not be ruled out. Given that some of the potentially catastrophic climate impacts, like large scale ice-sheet disintegration, are dependent on the length of time that the warming exceeds a certain temperature level, this UNDP pathway has the benefit that temperatures could decrease towards the end of the century again, although only slightly. Under most pathways that aim for a stabilization at a certain greenhouse gas concentrations level, or which do not decrease concentrations fast enough, temperatures are unlikely to decrease - see for example Figure 10 and the medium STERN 500 pathway (Stern 2006). This medium STERN 500 pathway has a similar peaking level of atmospheric GHG concentrations compared to the default UNDP stylized pathway, i.e. 500ppm CO_2eq, but aims only for a slight decrease in concentrations in order to level off at 450ppm CO_2eq stabilization.

The sensitivity case of the UNDP stylized pathway with developing country emissions rising up to 2035 and global total CO_2 emissions up to 10GtC/yr would exceed a 2°C temperature with relatively high likelihood. The additional two sensitivity cases, with higher and lower industrialized country emissions by 2050 – and compensating adjustments for developing country emissions - share the same concentration and temperature response characteristics as the default UNDP stylized pathway. See Figure 10.

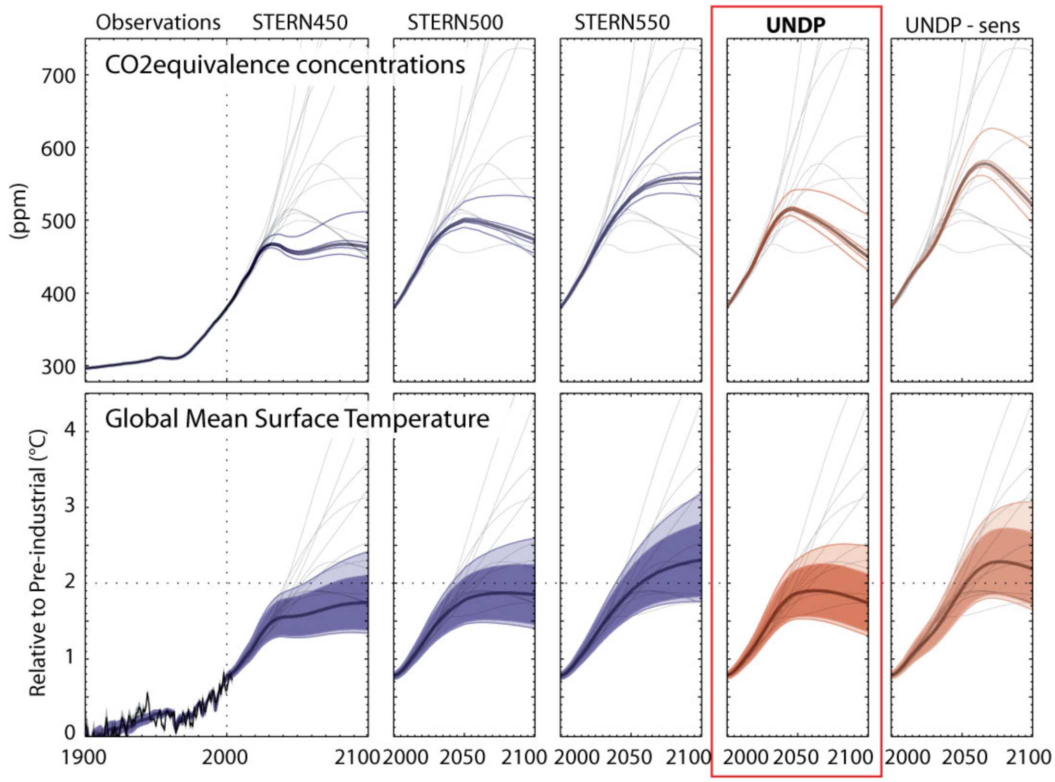


Figure 10 - The climate response towards the stylized UNDP emission pathway (red frame) compared to the three pathways presented in STERN (blue areas in left columns), a sensitivity case of the UNDP pathway with high developing country emissions (right column). Furthermore, the median of each pathway's response is shown in the background in addition to the median climate response evolutions due to SRES scenarios, which do not assume any climate mitigation initiatives (thin grey lines in background). The top row depicts the radiative forcing due to all anthropogenically induced greenhouse gases, tropospheric ozone and aerosols, expressed as CO_2 equivalent concentrations. The bottom row depicts global mean surface temperatures and their respective 1-sigma uncertainty ranges. The dark/center uncertainy ranges depict 1-sigma response uncertainties due to the different AOGCM emulations. The outer/paler uncertainty ranges are using high and low carbon cycle feedback settings as in IPCC AR-4 Figure 10.26. For the historic period, global mean temperature evolutions are shown according to Folland et al. (2001) and Jones et al. (2003).

7. Limitations

The limitations of the presented stylized emission pathway are on the one hand, that only emission levels are diagnosed, not the energy-system implications of achieving these emission levels. There is a growing body of literature on the technical, economic and energy-system implications of low emission pathways, which will be reviewed in the forthcoming WG3 report of the Fourth Assessment Report of the IPCC.

Furthermore, these stylized pathways use one specific method to partition the global emission levels, namely a series of assumptions on milestones (e.g. halved global emissions by 2050) and a derivation of multi-gas and regional emission levels using the characteristics of 54 SRES and post-SRES scenarios. Thus, no explicit ‘emission allocation’ regime has been applied, of which there are numerous proposals discussed in the literature, such as the ‘Brazilian proposal’ of historic responsibility, a Multi-Stage approach or others (den Elzen, Fuglestvedt et al. 2005; den Elzen, Berk et al. 2005; den Elzen and Lucas 2005). The EQW pathways only approximately reflect the partitioning of emissions as represented in the underlying database of emission scenarios, which in turn, apply a variety of techniques to determine future emission evolutions.

8. Conclusion

Addressing the intertwined issues of development and climate change requires a quantification of challenges ahead. This note attempts to provide a part of the puzzle by sketching a stylized emission pathway that would roughly be in line with preventing global mean temperature increases of more than 2°C. The challenge is to implement the institutional frameworks, develop and disseminate the appropriate technologies and spur the necessary behavioural changes in order to make both possible, development for those most in need of it and strong climate change mitigation. In the long-term, unabated climate change would be likely to undermine the achievement of the Millennium Development Goals.

Application of a specific allocation regime could of course change the regional emission shares – although given the overall decrease of global emissions required to achieve for example a 2°C target, the options are limited. The fact of limited options is highlighted by the sensitivity pathway, which allows developing country emissions rising towards 2035, but fails to stay below 2°C. In other words, climate targets which might prevent catastrophic climate change will not be achieved with the unabated growth of emissions – even if that growth takes place only in some regions.

9. Appendix A: Gas-by-gas and region-by-region emissions

For a comprehensive graphical overview of the gas-by-gas emissions and regional emission shares in comparison with those of 54 SRES and post-SRES scenarios, please see the attached documents “UNDP_DataOverview_absoluteEmissions.pdf” and “UNDP_DataOverview_percapitaEmissions.pdf”

10. Appendix B: Data tables

Please find complete data table with annual emission data for the stylized UNDP pathway and its sensitivity cases in the attached spreadsheets “DATA_UNDPpathways_percapita04-Apr-2007.xls” (per capita emissions) and “DATA_UNDPpathway_absolute04-Apr-2007.xls” (absolute emissions).

11. Appendix C: First set of additional figures, 5th April 2005

Merged Figure 1 – 3 with relative emissions.

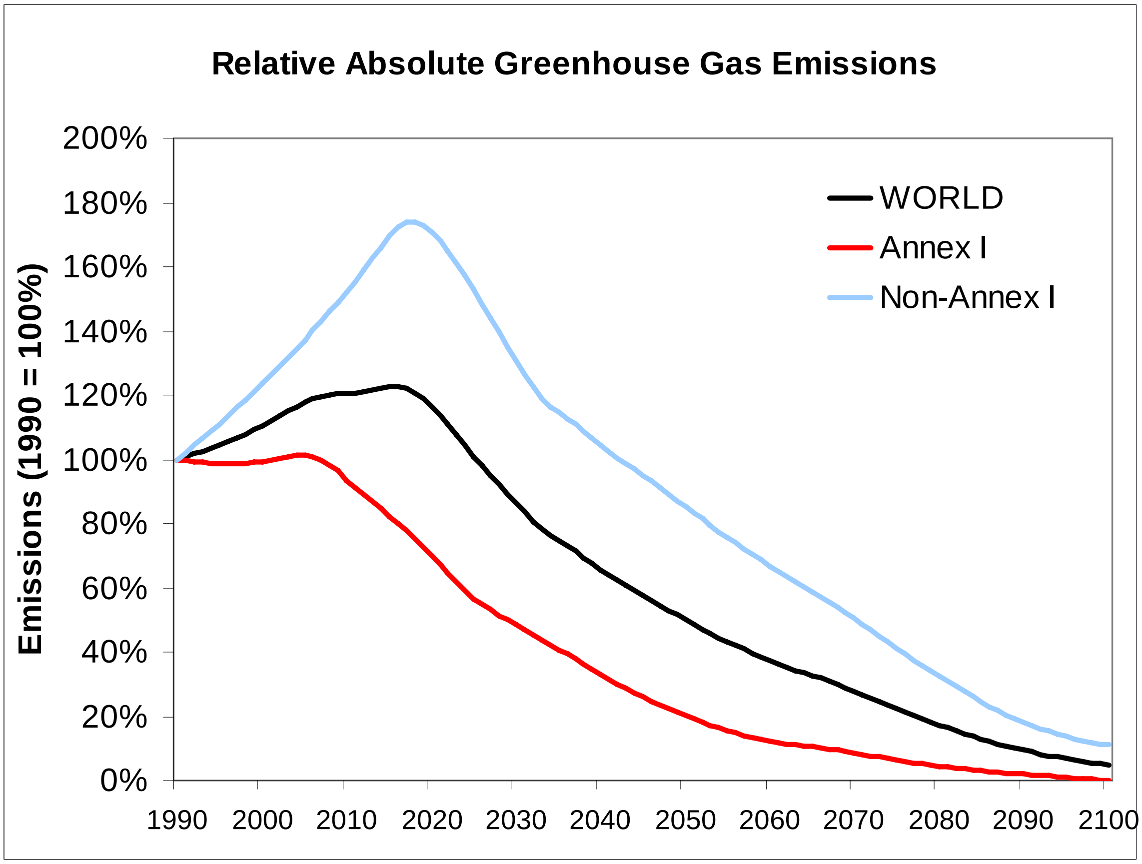


Figure 11 – Greenhouse gas emissions under the stylized emission pathway relative to 1990. The global emissions (black line) are assumed to be halved by 2050. Industrialized country (Annex I) emission are assumed to decrease by 30% by 2020 and by 80% by 2050 relative to 1990. Developing country emissions are assumed to increase up to 2020 with following reductions determined by the prescribed global emission levels.

Revised Figure 8 with industrialized (Annex I under UNFCCC) and developing (Non-Annex I) countries.

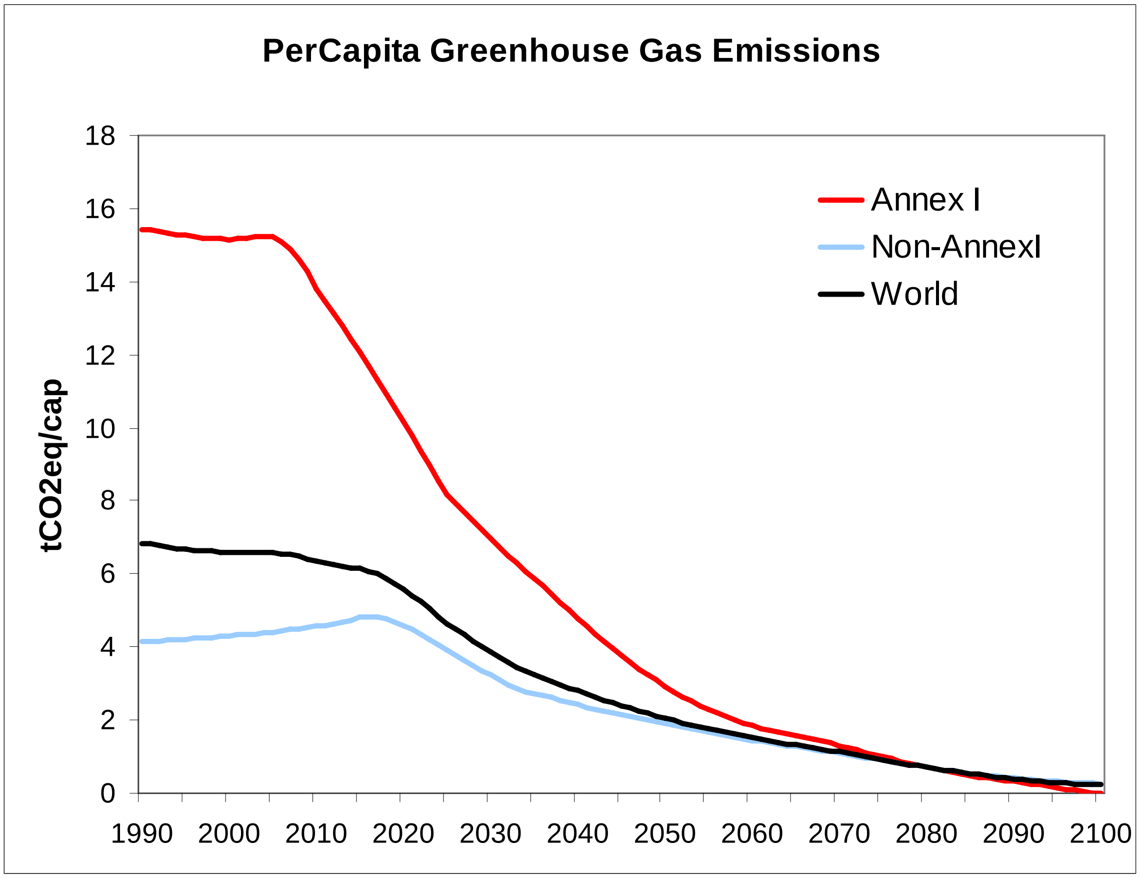


Figure 12 - Percapita greenhouse gas emissions under the default stylized emission pathway using regional emission share characteristics from 54 SRES and post-SRES scenarios and population projections based on Lutz et al. (2001).

12. Appendix D: Second set of additional on "Usage of carbon budget under business-as-usual emission paths", 25th May 2007

- Under non-mitigation SRES scenarios, the 400GtC carbon budget for total CO2 emissions is going to be "used up" by 2032-2042.

- Under non-mitigation SRES scenarios, a 600GtCe carbon budget for equivalent CO2 emissions (all Kyoto greenhouse gases) is going to be "used up" by 2035-2045.

See following figure.

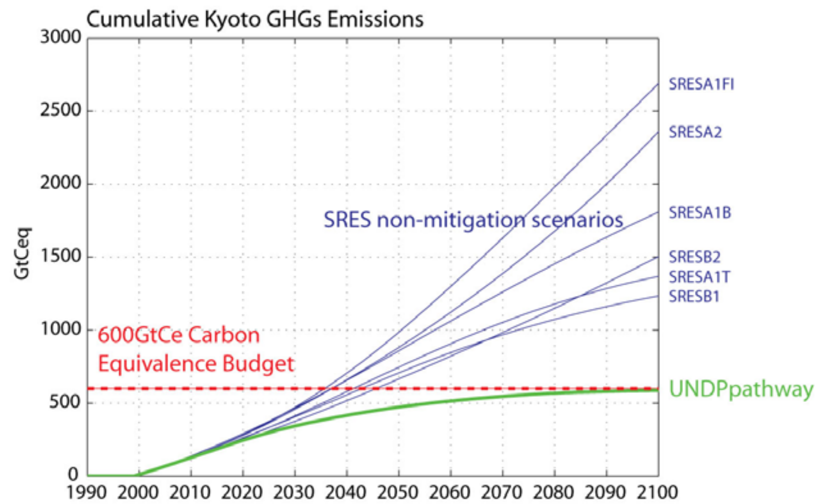
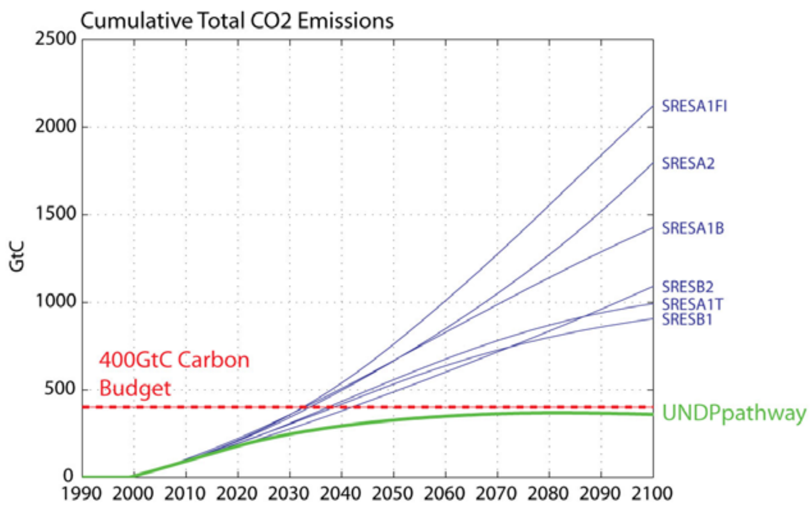
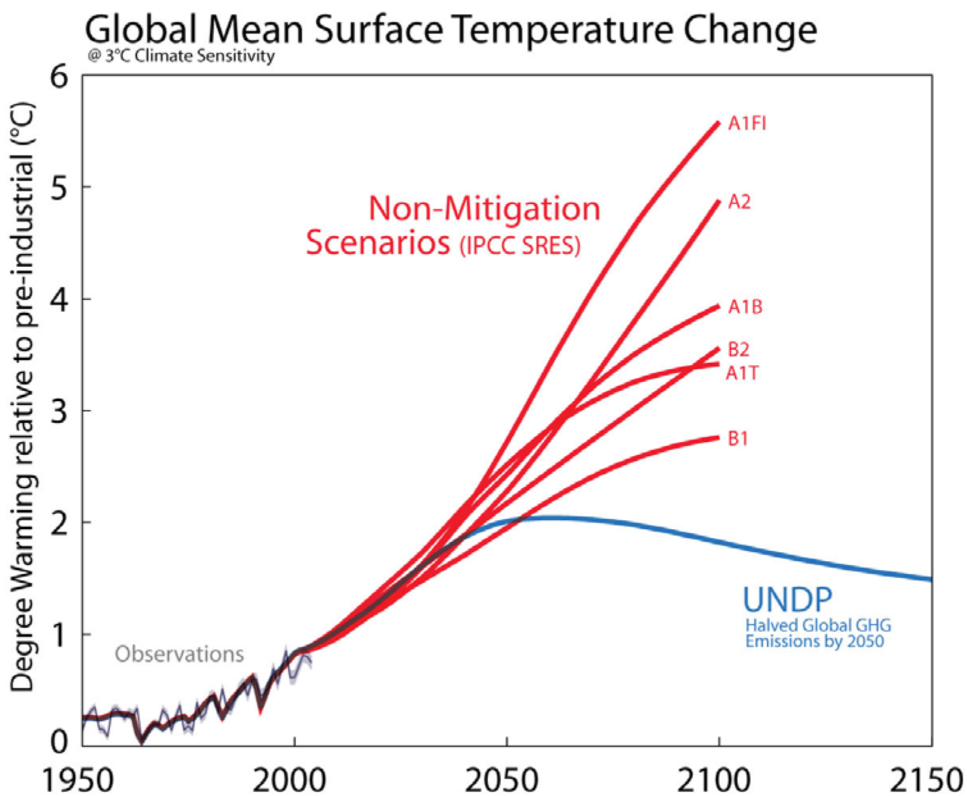


Figure 13 - Cumulative greenhouse gas (top) and total CO2 (bottom) emissions under 6 Illustrative non-mitigation SRES scenarios (bluish lines) and the UNDP pathway (green line) as well as a 400GtC total CO2 carbon budget and a 600 GtCe GHG budget (dashed red lines).



13. Appendix E: Third additional figure on "Temperature implications at 3°C climate sensitivity", 25th May 2007

As a cautionary note, the following figure has been submitted by email with the following text: "I do see the illustrative value in such a figure, although I do have - as explained on the phone - some hesitation as you might draw criticism from the scientific camp. I would leave the decision up to you, whether to put this figure in the report, although it would have to be prominently accompanied by some clear words of caution. For example, the middle range SRES projections based on the AOGCMs (i.e. the BIG models, which have on the whole a slightly lower eff. climate sensitivity) are substantially smaller for the higher emission scenarios: In the last decade of the 21st century, the A1FI scenario is estimated to reach 4.0 above 1980-1999, i.e. 4.5 above pre-industrial (see Table SPM 3 IPCC, WG1). Thus, the shown trajectory here with about 5.3 for 2090-2099 is quite a bit higher, although well within the range of the stated uncertainty by IPCC AR4 (2.4 to 6.4 above 1980-1999 and thus 2.9 to 6.9 above pre-industrial)."



Note: This graph is for illustrative purposes only as it does not reflect uncertainties in the climate system, but a fixed 3°C climate sensitivitiy (IPCC AR4 best guess) using "combined" constraint as in Meinshausen (2006) and the simple climate model MAGICC 4.2 (Wigley & Raper) as in IPCC AR4. Global mean temperature differences between paired non-mitigation and mitigation scenarios emerge approximately 2030, depending on the considered baseline scenario.

14. Acknowledgements

The author would like to thank Kevin Watkins and Bill Hare.

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