Impact of the Kyoto Protocol on Stabilization of Carbon Dioxide Concentration

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Abstract

Although the impact of the Kyoto Protocol on CO_2 concentrations and temperature increase in 2012 *is insignificant, its implementation has considerable impact on the pathways that are available in the future to reach certain climate stabilization levels. We demonstrate this using a set of global emission paths that are constrained to maximum 3% change in emissions per year and a change in trend per year of maximum 0.5 percentage points. We translate these emission paths into CO_2 concentration and temperature paths using the MAGICC model with an average carbon cycle and a climate sensitivity of 3°C. We find that while the implementing the Kyoto Protocol until 2012 has only an effect of 2 ppmv on CO_2 concentration and several hundredth of degree Celsius in 2012, its implementation and reductions after 2012 enable reaching a maximum CO_2 concentration level by 2050 that is by the order of 20 ppmv or two tenth of a degree Celsius lower than not implementing the Kyoto Protocol. If it is implemented excluding the USA, the maximum levels would be 10 ppmv or one tenth of a degree Celsius lower. Not implementing the Kyoto Protocol and reducing global emissions after 2012, the CO_2 concentration level of 450 ppmv can only be reached, if global emission decline around 3% per year over several decades. Implementing the Protocol would relax this condition to around 2% per year. Delaying the start of global reductions until 2020 would increase the lowest reachable level further by around 40ppmv or 0.3°C.*

1 Introduction

The impacts of the Kyoto Protocol on CO_2 concentrations and global-average surface temperature are often described to be minimal. The basis for such statements can be twofold: Either the impact on CO_2 concentrations and global-average surface temperature are considered only in 2012 (e.g. Izrael 2004). Here the impact is indeed minimal (a few ppmv in concentration and a several hundredth of a degrees in temperature). Or the impact is considered as a comparison of the business as usual emissions with a scenario, where the targets of the Kyoto Protocol are reached in 2012, but where emissions continue to increase afterwards. Due to the increasing emissions in developing countries and the long time delay between the emissions and their effect on temperature increase, the effect of the Kyoto Protocol on CO_2 concentration and temperature increase is minimal under this point of view.

However, if the reductions under the Kyoto Protocol are considered in relation to stabilization of greenhouse gas concentrations and, hence, the substantial reduction of global greenhouse gas emissions after 2012, the impact of the Kyoto Protocol may be quite substantial. Or the impact of *not* meeting it may be quite substantial.

Earlier analyses provided emission pathways that lead to climate stabilization at different levels (e.g. Wigley et al. 1996, Kreileman and Berk 1997, Eickhout et al. 2003), but have not assessed the impact of the Kyoto Protocol targets on stabilization.

This paper analyses the possible emission pathways towards stabilization at certain levels of CO_2 concentration with particular attention to the Kyoto Protocol. It first provides an overview, which concentration levels seem unavoidable under the assumption that the Kyoto Protocol is implemented or not. It then illustrates the impact of meeting the Kyoto targets on the pathways that lead towards 450ppmv CO_2 concentration.

2 Method

From a given global CO_2 emission path until 2002 / 2010 / 2020, we calculate a number of arbitrary emission paths for the years thereafter. We translate the inertia in the energy system that causes the emissions into to following simple assumptions on the constraints on global CO_2 emissions:

- Global emissions cannot increase or decrease more than 3% from one year to the next.
- This annual increase or decrease (change from one year to the next) cannot change by more than 0.5 percentage points per year. For example, if emission have risen 2% from year t to year t+1, emissions can only rise by 1.5% to 2.5% from year t+1 to year t+2.

The choice of the values 3% and 0.5% are loosely based on the historical time series of global CO_2 emission, which grew on average by 1.5% per year in the last 30 years.

We assume that the global emissions *growth rate* peaks in a certain year and then declines and turns into a *reduction rate*. The *reduction rate* reaches a maximum, may stay stable and then declines to zero, i.e. stable *emissions*.

We then calculate the CO_2 concentration corresponding to these global emission paths. We use the MAGICC model Version 4.1 (Wigley and Raper, 2001) in its configuration used for the IPCC Third Assessment Report. It includes the Bern carbon cycle model with average parameters, including a temperature feedback on the carbon cycle. We scaled the emissions of CH_4, N_2O, NOx, NMVOC, CO, black and organic carbon, SO_2, CF_4, C_2F_6 from 1990 levels to decrease proportionally to CO_2. Other fluorinated gases are not included.

From all possible emission paths calculated as described above, we pick the ones that lead to a specified CO_2 concentration. For 450 ppmv, e.g., the concentration has to be below 450 ppmv before 2100 and 450±10 ppmv in 2150 and 2200.

We do not consider "overshoot" scenarios in this analysis based on the precautionary principle. Such scenarios would first result in concentrations well above the desired stabilization level and later approach it asymptotically from above. Some analysis suggest that there could be substantial changes in the carbon cycle in the latter half of the century leading to a slowed removal of CO_2 from the atmosphere (e.g. Cox et al. 2000). Overshoot scenarios would rely on the fast removal of CO_2 in the latter half of the century as it is implemented in the MAGICC model.

To calculate possible stabilization corridors, we use historical emissions until 2002 and start the emission paths from then onwards. 1990 emission levels are consistent with those provided in the IPCC Third Assessment Report (IPCC 2001) and the IPCC Special Report on Emission Scenarios (IPCC 2000). Emissions of 2002 are based on national estimates reported to the UNFCCC (www.unfccc.int) and where not available from the International Energy Agency (IEA 2002).

To calculate the impact of the Kyoto Protocol, we consider three cases: "Reference", "strong Kyoto" and "weak Kyoto". In the "strong Kyoto" case, all Annex I Parties are assumed to reach their Kyoto targets until 2010, including the USA, who announced not to ratify, and Australia, who announced not to ratify but to comply. Since emissions of economies in transition (Russia and Eastern European countries) are likely to be substantially below their Kyoto targets in 2010, these countries are assumed to reach the lower of their Kyoto targets and their reference emissions. All Non-Annex I Parties follow their reference emissions. In the case "strong Kyoto", the USA implements its national target for 2012 (an improvement of emission intensity, emissions per GDP, of 18% from 2002 to 2012), all other Annex I countries reach the lower of their Kyoto targets and the reference, all Non-Annex I countries follow their reference. In the case "Reference", all countries follow their reference emissions. For all regions reference emissions, are calculated applying the growth rates from the average over the six IPCC SRES scenarios to the current emissions of the countries. Table 1 provides the starting point for the calculations.

The case "strong Kyoto" can be seen as the upper bound of the effect of the Kyoto Protocol. It assumes full participation of the USA and that the "hot air" of the Eastern European countries will not be sold. It further assumes that CO_2 is reduced at the same percentage as the other greenhouse gases, while it seems likely that most cost effective short-term emission reductions can be achieved in emissions of N_2O and CH_4. It also does not include additional emission allowances from land use, land use change and forestry. The case "weak Kyoto" can be seen as more realistic, it still assumes that "hot air" is not sold, as the participating countries would reduce emissions domestically.

	Ref	Strong Kyoto	Weak Kyoto
	GtC	GtC	GtC
1990	7.12	7.12	7.12
2000	7.75	7.75	7.75
2002	8.05	8.05	8.05
2010	9.71	8.87	9.28
2020	11.67		

Table 1. CO_2 emissions under the different cases

From the resulting concentration levels, we also calculate the change in global mean surface temperature using the MAGICC model. The main uncertainty in this translation is the value of the climate sensitivity (the temperature increase for a doubling of CO_2 concentration), which lies between 1.5℃ to 4.5℃ (IPCC 2001). Recent work suggests a higher range of 2.0 to 5.1℃ with the highest likelihood at 3℃ (Kerr 2004). We used a climate sensitivity of 3℃ here.

Using this climate sensitivity and assumptions about the other greenhouse gases, others (Azar & Rhode 1997, IPCC 2001) have calculated that a scenario for 350 ppmv CO_2 concentration leads to an equilibrium temperature increase of 1.5℃ at a mean climate sensitivity, while the 450 ppmv scenario leads to an equilibrium temperature increase above 2℃ at a mean climate sensitivity.

The Council of Ministers of the European Union agreed that "global average temperatures should not exceed 2 degrees Celsius above pre-industrial levels…" (EC 1996). Keeping global mean temperature below 2℃ above pre-industrial level is therefore likely to require stabilization of CO_2 concentration below 450ppmv.

3 Results

3.1 What are the emission corridors that lead to specific CO_2 stabilization levels?

As a first step we consider the emission corridors from 2002 onwards that lead to specific stabilization using the emission paths as described above. Figure 1 (left) provides the global CO_2 emission stabilization corridors for 400ppmv, 450 ppmv and 550 ppmv CO_2 concentration compared to the emission range of the IPCC SRES scenarios. The thick lines for each corridor are two exemplary paths, one increasing as fast as possible, one increasing as slow as possible. The shaded area is the envelope over all possible paths.

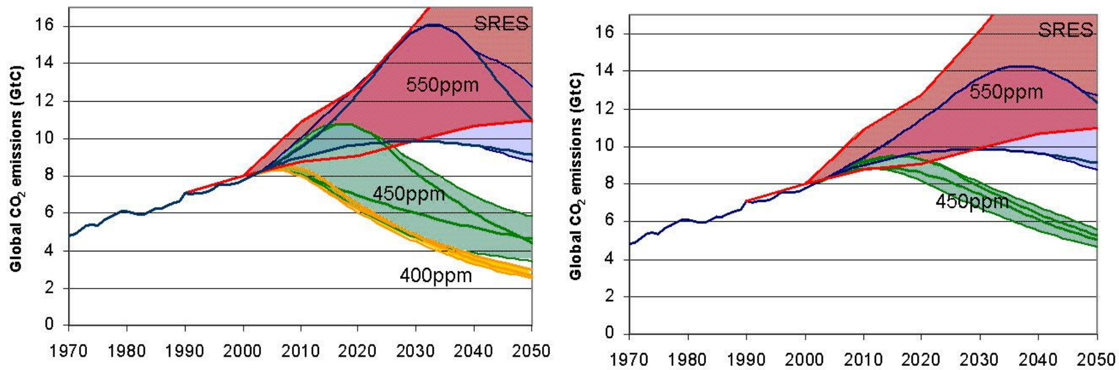

Figure 1. Global CO_2 emission corridors leading to 450 and 550 ppmv CO_2 concentration in comparison to the future emissions under the IPCC SRES scenarios at maximum 3% change and 0.5 percentage points trend change per year (left). Sensitivity for 2% / 0.25 (right)

With our methodology we find that for 400 ppmv global CO_2 emissions have to decline immediately and rapidly at 3% per year for several decades. Stabilization at 400 ppmv can only be reached, if the CO_2 concentration exceeds 400 ppmv slightly in the middle of the century. Otherwise no paths towards 400 ppmv would have been found. For 450 ppmv, global CO_2 emissions have to peak around 2020 and then decline rapidly. In 2020 most of the SRES range is above the 450ppmv range. For all paths, emissions in 2050 have to be well below 1990 levels. For 550 ppmv, emissions may increase and peak between 2030 and 2040 and then decline. The steep increase shown here for 2010 to 2030 has to be compensated by a steep decrease of -3% per year over several decades afterwards.

If only a 2% change in emissions per year and a trend change of 0.25 percentage point is allowed, stabilization corridors become much narrower (Figure 1 right). Under these conditions, staying below 400ppmv is not possible. The 450 corridor is much narrower, emissions peak between 2010 and 2020 and decline at –2% per year for several decades. The 550 corridor has its maximum at a lower point at 14 GtC around 2040. At annual change of 2% and trend change of 1 percentage point per decade, we do not find a path that leads to 450 ppmv.

3.2 Which CO_2 concentration levels are unavoidable?

We now consider the emission, concentration and temperature levels that are unavoidable, if emission reductions start at different points in time. The question is, what is the lowest CO_2 emission/concentration and temperature level that can still be reached using our constraints on global emission paths (maximum 3% change per year and not more than 0.5 percentage point change in trend per year). Figure 2 provides the results, where the emission reductions start in 2002, in 2010 under the assumption the Kyoto Protocol is or is not implemented or in 2020. The figure provides the annual change in global CO_2 emissions, global CO_2 emissions, CO_2 concentration and resulting temperature increase.

One can first compare the different emissions paths that are possible starting reductions from the reference in 2002, 2010 or 2020. Starting in 2002, global emission could peak before 2010 and then decline at 3% per year until the end of the century, CO_2 concentrations would still rise up to around 410 ppmv in 2040 and then start to decline. The temperature would rise until 2060 to 1.3°C above pre-industrial levels and then decline. Only if emissions decline faster than 3% per year over decades or a technology is found that sequesters CO_2 out of the atmosphere, stabilization below this level could be reached.

Starting reductions in 2010 from reference (Kyoto not implemented), global emission could still peak before 2020 and then decline at 3% per year until the end of the century. CO_2 concentrations would still rise until 438 ppmv in 2050 and then start to decline. Temperature would increase to 1.6 until 2070 and then decline. Starting reductions in 2020 from reference, global emission could still peak before 2030 and then decline at 3% per year until the end of the century. CO_2 concentrations would rise until 475 ppmv in 2060 and then start to decline. Temperature would increase to 1.9 until 2080 and then decline. So, delaying reductions by a decade increases the lowest possible concentration level by 40ppmv (assuming an average carbon cycle) and temperature level by 0.3℃ (assuming a 3℃ climate sensitivity).

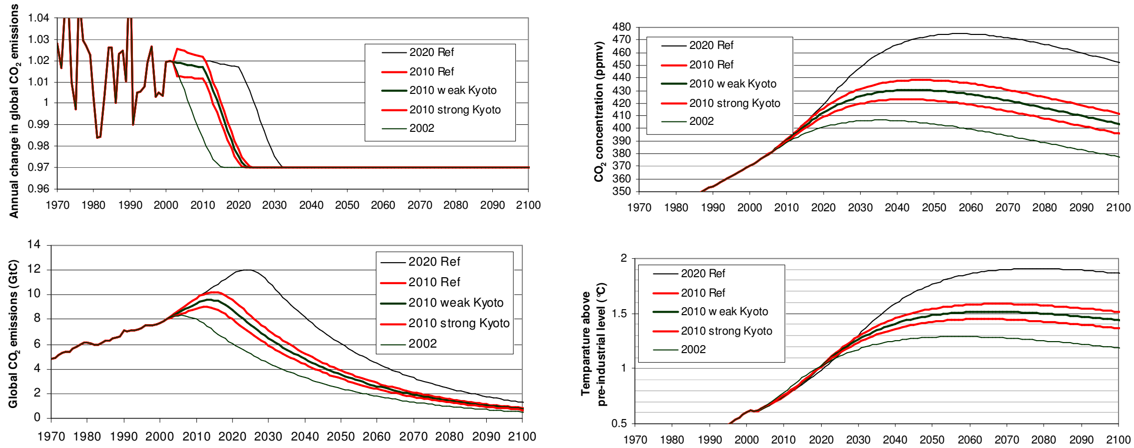

Figure 2. Lowest emission paths starting reductions from 2002, 2010 and 2020. Annual change in global CO_2 emissions (top left), global CO_2 emissions (bottom left), CO_2 concentration (top right) and temperature change (bottom right)

Looking only at the Kyoto cases, one can observe that reducing after 2010, not having implemented the Kyoto Protocol would lead to CO_2 concentration of 438 ppmv in 2050 and 1.6℃ in 2070. If assumed that all countries implement the Kyoto Protocol until 2010 (strong Kyoto), CO_2 concentration would rise to 423 ppmv in 2050 and 1.45℃ in 2070. The case "weak Kyoto" would lead to a CO_2 concentration of 430 ppmv in 2050 and 1.52℃ in 2070.

With maximum 2% change per year and not more than 0.25 percentage point change in trend per year, the maximum levels are around 20ppmv and 0.2℃ higher compared to 3% annual change and 0.5 percentage points change in trend.

We conclude that even with substantial global reduction efforts, concentration levels above 400 ppmv seem unavoidable, at least for a period of time. The implementation of the Kyoto Protocol can be an important step towards stabilization, if it is seen in the context of further substantial reductions after 2012. Its implementation can help avoid in the order of 10 ppmv (assuming an average carbon cycle) or one tenth of a degree Celsius (assuming a 3℃ climate sensitivity) in the long term, if fully implemented also by the USA around 20 ppmv or two tenth of a degree. Delaying global reductions even further to 2020 could lead to a maximum CO_2 concentration level about 40 ppmv or maximum temperature level of 0.3℃ higher.

3.3 What is the impact of implementing the Kyoto Protocol on emission paths towards 450ppmv?

Several CO_2 emission paths can lead to the same CO_2 concentration level, due to the long residence time of CO_2 in the atmosphere. Figure 3 provides the results of two emission paths towards 450ppmv CO_2 concentration assuming the Kyoto Protocol will be implemented or will not be implemented. Shown are the paths with maximum and with the minimum emissions in 2020 that still satisfy the 3%, 0.5% criterion.

We can observe, that in the reference case, only a small emission corridor remains to stabilize CO_2 concentrations at 450 ppmv (under our assumption for the emission paths that global emissions can decline 3% per year at maximum). With this model, we calculate that global emissions would then have to peak before 2020 and then have to decline faster than 2.5% per year for over a few decades to keep 450 ppmv within reach. 1990 levels have to be reached by 2040 at the latest. In 2050 emissions have to be at least 30% below 1990 level. If we had restricted the decline to maximum 2% per year, no path would have been found.

For the case where the Kyoto Protocol is assumed to be implemented the situation is more relaxed, but still very ambitious. The corridor to reach 450 ppmv is much wider. Either emissions continue to increase, peak shortly after 2020 at the latest and then decline at 3% per year for several decades or emissions decrease almost immediately after 2012 at a rate of only 1.5% per year for several decades. This is still ambitious but less strict than under the case where Kyoto is not implemented. The early reductions to reach the Kyoto targets are rewarded by less stringent reductions later in the century.

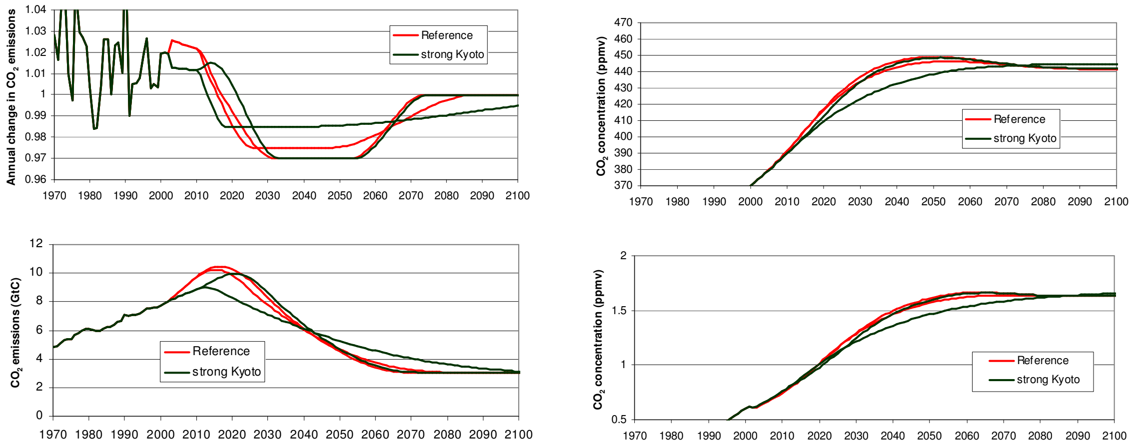

Figure 3. Corridors towards stabilization of CO_2 concentration at 450ppmv. Change in global CO_2 emissions per year (top left), annual global CO_2 emissions (bottom left), resulting CO_2 concentration (top right) and temperature increase (bottom right)

4 Conclusions

Although the impact of the Kyoto Protocol on CO_2 concentrations and temperature increase *in 2012* is insignificant, its implementation has considerable impact on the pathways that are available in the future to reach certain climate stabilization levels. We demonstrate this using a set of global emission paths that are constrained to maximum 3% change in emissions per year and a change in trend per year of maximum 0.5 percentage points. We translate these emission paths into CO_2 concentration and temperature paths using the MAGICC model with an average carbon cycle and a climate sensitivity of 3°C. We find that while the implementing the Kyoto Protocol until 2012 has only an effect of 2 ppmv on CO_2 concentration and several hundredth of degree Celsius in 2012, its implementation and reductions after 2012 enable reaching a maximum CO_2 concentration level by 2050 that is by the order of 20 ppmv or two tenth of a degree Celsius lower than not implementing the Kyoto Protocol. If it is implemented excluding the USA, the maximum levels would be 10 ppmv or one tenth of a degree Celsius lower. Not implementing the Kyoto Protocol and reducing global emissions after 2012, the CO_2 concentration level of 450 ppmv can only be reached, if global emission decline around 3% per year over several decades. Implementing the Protocol would relax this condition to around 2% per year. Delaying the start of global reductions until 2020 would increase the lowest reachable level further by around 40ppmv or 0.3°C.

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