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research article

Cumulative CO_2 emissions: shifting international responsibilities for climate debt

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In contrast to many discussions based on annual emissions, this article presents calculations and projections of cumulative contributions to the stock of atmospheric CO_2 by the major players, China, Europe, India, Japan and the USA, for the period 1900–2080. Although relative contributions to the climate problem are changing dramatically, notably due to the rapid industrialization of China, long-term responsibilities for enhanced global warming have not been transparently quantified in the literature. The analysis shows that if current trends continue, by the middle of this century China will overtake the USA as the major cumulative contributor to atmospheric concentrations of CO_2. This has enormous implications for the debate on the ethical responsibilities of the major greenhouse gas emitters. Effective climate policy will require both the recognition of shared responsibility and an unprecedented degree of cooperation.

Keywords: China; climate policy; cumulative CO_2 emissions; developing countries; environmental debt; ethics; India; international comparison; negotiation

Contrairement aux nombreuses discussions fondées sur les émissions annuelles, ce papier présente les calculs et projections des contributions cumulées du stock de CO_2 atmosphérique des principaux acteurs, c'est-à-dire la Chine, l'Europe, l'Inde, le Japon et les Etats-Unis, pour la période 1900–2080. Bien que les contributions proportionnelles au problème climatique évoluent de manière dramatique, notamment dû à la rapide industrialisation de la Chine, les responsabilités à long terme sur l'aggravation du changement climatique n'ont pas été quantifiées de manière transparente dans le domaine d'étude. L'analyse montre que si les tendances actuelles continuent, d'ici le milieu de ce siècle la Chine dépassera les Etats-Unis en tant que plus grand contributeur aux concentrations cumulées de CO_2 atmosphérique. Ceci aurait des retombées très importantes quant au débat sur la responsabilité morale des plus gros émetteurs de gaz à effet de serre. Une politique climatique efficace demandera aussi bien une prise en compte du partage des responsabilités, qu'un degré de coopération sans précédent.

Mots clés: Chine; comparaison internationale; dette environnementale; émissions cumulées de CO_2; éthique; Inde; négociations; pays en développement; politique climatique

1. Introduction

Responsibility for the environmental debt imposed on future generations (Azar and Holmberg, 1995) has been central to the policy debate surrounding Kyoto and recent climate meetings. The climate policy debate inevitably involves ethical judgements and assignment of responsibilities.

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There is no doubt that the industrialized countries, notably Europe, the USA and Japan, carry the main historical responsibility for the human contribution to atmospheric greenhouse gas concentrations at present (den Elzen et al., 2005b; Srinivasan et al., 2008). Many developing countries have argued that they therefore should not be penalized for historical appropriation of the atmospheric commons by the rich countries (Najam et al., 2003). But relative contributions to the climate problem are changing dramatically, notably due to the rapid industrialization of China and, to a lesser extent, India. In 2007 China overtook the USA in total *annual* CO_2 emissions (Netherlands Environmental Assessment Agency, 2007).

Long-term responsibilities for the causes of global warming have, however, not been transparently quantified in the literature. Here we calculate and project *cumulative* CO_2 emissions for the main emitters for the period 1900–2080. Consideration of cumulative emissions is relevant to the formation of climate agreements because CO_2 has a long lifetime in the atmosphere.[1] Although other greenhouse gases contribute to climate change, we focus our attention on CO_2, as it is the most important contributor. It accounts for by far the largest part of the CO_2 equivalent emissions; for example, 77% in 2000 (Stern, 2007). Methane is the second largest contributor with 14% of CO_2 equivalent emissions in 2000, but has a considerably shorter lifetime in the atmosphere, namely 10 years (Ramaswamy et al., 2001). The focus on CO_2 emissions here, of course, does not mean that effective climate policy can neglect the other greenhouse gases.

Our projected *cumulative* CO_2 emissions show that by around 2050 China will overtake the USA as the major cumulative contributor to atmospheric concentrations of CO_2. The change in relative cumulative contributions will alter the ethical parameters of the debate on climate policy. In the near future the responsibility for the 'climate debt' will be shared by the largest emitters at this moment – Western Europe and the USA – and rapidly developing countries, such as India and especially China. Based on these projections, it is vital that China and India participate in future climate agreements.

2. Historical and projected cumulative CO_2 emissions

2.1. Methods

This article calculates and projects the contribution to anthropogenic climate change by focusing on a major cause of global warming, namely *cumulative* CO_2 emissions from fossil fuels. Changes in CO_2 concentration influence radiative forcing, which affects global-average surface temperature. This in turn influences weather patterns and sea level, with consequences for socio-economic systems, human health and well-being. Our indicator of c*umulative* CO_2 emissions relates to the start of the cause–effect chain and may be regarded as capturing the cause of the problem or, as an approximation, the degree of responsibility for human-induced climate change.[2]

Some studies suggest that in order to estimate responsibilities for climate change it is necessary to examine emissions on a per capita basis (e.g. Müller et al., 2007). Indeed, this is relevant information, since residents of countries with larger emissions per capita may be seen to have a larger responsibility for climate change than residents in countries with smaller per capita emissions. Nevertheless, emissions on a country level provide useful information for effective climate agreements, simply because the relevant political units in the negotiations for such agreements are countries.[3]

Our approach involves the calculation of both historical and projected levels of cumulative emissions for the major CO_2 emitters.[4] Up until 2004 we calculate the *cumulative* emissions of CO_2 from fossil fuels based on annual data between 1900 and 2004 from the Carbon Dioxide Information

TABLE 1 Reference projection of average annual growth in energy-related CO_2 emissions between 2004 and 2030

Country	% CO_2 growth
China	3.4
India	2.6
Japan	0.1
OECD Europe	0.3
USA	1.1
World	1.8

Source: EIA (2007).

Analysis Center (CDIAC), which is the primary climate-change data and information analysis centre of the USA Department of Energy. The CDIAC data of 1950 up to 2004 is based on carbon emission estimates from the United Nations (2006), derived from actual fossil fuel production and trade. The pre-1950 data is estimated by CDIAC using historical energy statistics (Marland and Rotty, 1984; Boden et al., 1995; Andres et al., 1999; Marland et al., 2007). Emission data for the individual countries included in our analysis are available from 1900 onwards, which is therefore the start date for computing cumulative emissions.[5] Even though fossil-fuel-related CO_2 emission estimates are the most reliable emission estimates (den Elzen et al., 2005a), it should be noted that there remains some uncertainty about historical emissions for each country.

We use projections of CO_2 emissions growth for the period 2004–2030 by the USA Energy Information Administration (EIA), which has made projections of annual energy-related carbon dioxide emissions per country (EIA, 2007).[6] These projections assume a constant growth rate of *annual* CO_2 emissions under a business-as-usual scenario and therefore exclude impacts of possible future climate policy agreements.[7] We include the following countries: China, India, Japan, the USA and Western Europe (as defined by CDIAC). Our forecast of *cumulative* CO_2 emissions between 2005 and 2030 is based on the reference scenario of the EIA (Table 1), while our forecast for the subsequent period, 2030–2080, is based on extrapolation of the associated constant annual CO_2 growth rates. The growth rate of CO_2 as projected by EIA for China may be seen as a conservative estimate (Auffhammer and Carson, 2008).

2.2. Results

The past developments of *cumulative* CO_2 emissions per country between 1901 and 2004 as well as projections until 2080 are shown in Figure 1. The figure shows that currently the USA has the highest level of *cumulative* CO_2 emissions, followed by Western Europe, China, Japan and India. However, this ranking changes dramatically in the coming decades. In 2031 India will have emitted more CO_2 than Japan. In 2021 China will have larger *cumulative* CO_2 emissions than Western Europe, and in 2052 China will surpass the USA as the largest cumulative emitter. India is expected to have a larger total of cumulative emissions than Western Europe shortly after 2080.

Two other observations are relevant for the climate policy dialogue. First, the shares in total energy-related cumulative contributions to CO_2 emissions for these countries from 1900 to 2008

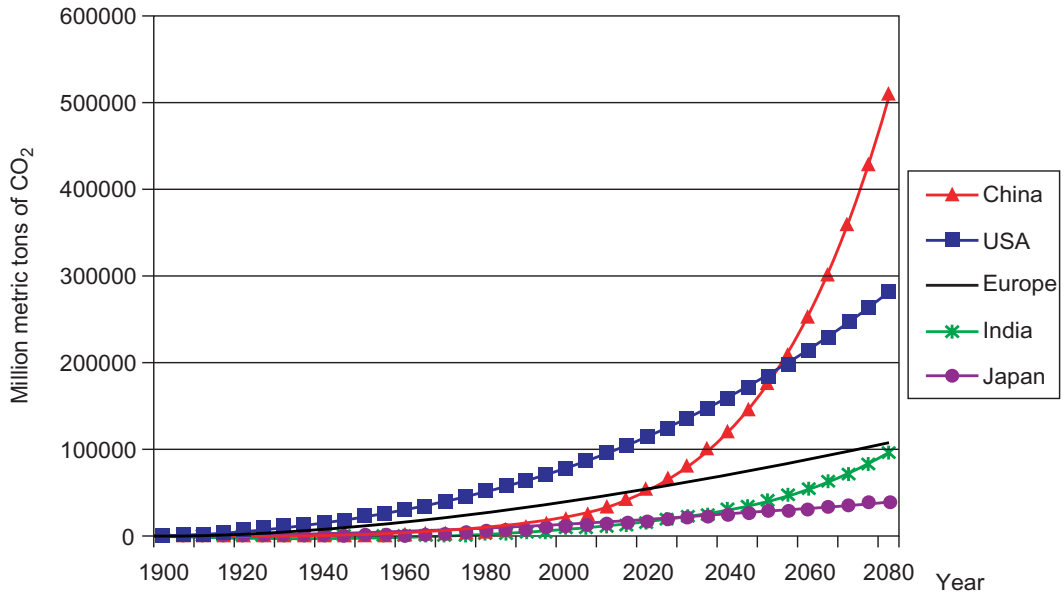

FIGURE 1 Historical and projected cumulative CO_2 emissions until 2080 using the EIA reference scenario.

are 48% for the USA, 24% for Western Europe, 16% for China, 7% for Japan, and 5% for India. In 2080 these shares will have changed to 49% for China, 27% for the USA, 10% for Western Europe, 9% for India, and 4% for Japan. The relative contribution of China to CO_2 emissions from the present to 2080 will be 57%, while the USA will contribute 23%. These figures highlight the potential shift in responsibilities for the cause of global climate change.[8]

The future paths of economic growth and oil prices assumed in the EIA reference scenario affect the projections of CO_2 emissions. To assess the sensitivity of the projections, the EIA has estimated future CO_2 emissions for low and high economic growth and oil price scenarios. These scenarios imply different *annual* CO_2 emission growth rates per country. Table 2 shows the years when the *cumulative* CO_2 emissions of China and India surpass the cumulative emissions of the industrialized countries for the different scenarios. The timing of changes in rankings of *cumulative* CO_2 emissions varies only slightly between the different scenarios, indicating the robustness of the conclusions drawn from Figure 1.

Our results may be sensitive to the starting year of the analysis. In order to examine this sensitivity, we compute and project *cumulative* CO_2 emissions from fossil fuels, beginning in 1950, and compare the results with those from the previous analysis using 1900 as a starting year. The choice of 1950 is particularly relevant because uncertainty about estimates of post-1950 CO_2 emissions per country is smaller than the uncertainty about estimates of pre-1950 emissions (Andres et al., 1999). Projections based on the reference scenario indicate that the cumulative emissions of India will surpass those of Japan in 2029 (2031 in previous analysis using 1900 as the starting date) and Western Europe in 2080 (shortly after 2080 in the previous analysis). China will surpass Western Europe in 2013 (2021 in the previous analysis) and the USA in 2047 (2052 in the previous analysis). In other words, the previous results are robust to changing the start year from 1900 to 1950.

TABLE 2 Timing of change in rankings of cumulative CO_2 emissions, per scenario

Projection scenario:	China > Europe	China > USA	India > Japan	India > Europe
Reference	2021	2052	2031	2086
High growth	2021	2047	2030	2080
Low growth	2021	2055	2032	2092
High oil price	2021	2053	2031	2087
Low oil price	2021	2054	2031	2087

2.3. Discussion

Our analysis deals with energy-related CO_2 emissions and excludes emissions from land-use changes. The latter are an important contributor to global CO_2 emissions and between 1990 and 2002 account for about 18% of global greenhouse gas emissions compared with 61% caused by energy-related emissions (Stern, 2007). Emissions caused by changes in land use are almost entirely driven by emissions from deforestation concentrated in a few countries, such as Indonesia and Brazil. Therefore, including emissions due to changes in land use would not alter our previous results very much. It would, though, increase the total CO_2 emissions of Asia and Latin America compared with Western countries, especially during the 1990s (Houghton, 2005).

Den Elzen et al. (2005a) show that adding CO_2 emissions due to land use to fossil-fuel-based CO_2 emissions increases the share of Asian countries in the overall contribution to temperature increase in 2000 by about 5% and reduces the OECD share by about 6%. Therefore it can be expected that consideration of emissions due to changes in land use will shift forward the estimated points in time at which India and China surpass Western Europe, and China surpasses the USA. However, the contribution of land-use change to emissions is projected to decrease rapidly in the coming decades, for Asian countries in particular, because of the rapid elimination of forests and the small areas of remaining forest (FAO, 2001). Furthermore, it should be noted that historical emissions from land-use change are highly uncertain compared with emissions caused by fossil fuels, resulting in large differences in land-use emissions across data sources (den Elzen et al., 2005a). Similarly, projections of future land-use emissions are very uncertain as well (Houghton, 2005). Instead, our results based on fossil fuel CO_2 may be regarded as representing relatively certain estimates.

It is of interest to compare our results with other studies that have estimated the contributions of different regions to climate change. Höhne and Blok (2005) estimated relative contributions to climate change using *cumulative* fossil fuel CO_2 emissions for the OECD, Asia, Latin America, and Eastern Europe and the former Soviet Union in 1995 and 2050. Their results indicate that the OECD had the largest contribution to climate change in 1995 and that the relative contributions of Asian countries will increase in 2050 compared with the OECD. Den Elzen et al. (2005a) modelled regional contributions to increases in global mean surface temperature. They found that the OECD contributed about 40% and Asia 20% to temperature increase in 2000, using 1890 as the start date, and that Asia will be the largest contributor in 2100. These studies are based on emissions of regions or groups of countries and confirm that the relative share of emissions by Asian countries is rising, which is consistent with our findings. The results of our analysis indicate that the rapid

development of China, in particular, will have a considerable effect on the relative responsibility for cumulative energy-related emissions, which is very relevant information for climate policy.

3. Conclusions

The analysis in this article indicates that China, and to a lesser extent India, will become major contributors to the causes of climate change in the second half of this century. Sensitivity analyses show that these findings are robust to different scenarios of projections of CO_2 emission as well as different starting years of calculating cumulative emissions. In particular, the projections showing that China will be the largest cumulative emitter are of considerable importance for the climate policy debate.

Our analysis highlights that any climate agreement without China and India is bound to be ineffective in terms of stabilizing CO_2 concentrations in the long run. It is therefore essential that India and China participate in climate agreements. This is not to discount the ethical responsibility for climate change by the USA and other industrialized countries. One should also take into account that a considerable proportion of the goods produced in China, which contribute to its rapidly rising CO_2 emissions, are consumed in Western countries. Under a business-as-usual scenario, by 2050 the world's largest nations will have a shared responsibility for the climate problem. In the decades to come, they will be responsible for either solving or exacerbating the climate crisis. Effective climate policy will require both the recognition of shared responsibility and an unprecedented degree of cooperation.

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Notes

1. According to Montenegro et al. (2007), 'about 75% of CO_2 emissions have an average perturbation time of 1800 years and the remainder have a lifetime much longer than 5000 years'. Climate simulations of Matthews and Caldeira (2008) even suggest that 'any future anthropogenic emissions will commit the climate system to warming that is essentially irreversible on centennial timescales'.
2. We define responsibility as contributing to the cause of the climate problem, which is related to, but not strictly equal to, moral responsibility, as has been discussed by Müller et al. (2007), for example.
3. It is, moreover, difficult to come up with a cumulative measure of per capita emissions. Uncertainty about estimates would then increase because of additional uncertainty about national population projections.
4. Over time these emissions are gradually removed from the atmosphere. Considerable uncertainty is associated with the carbon cycle (see note 1). This removal is not considered in our calculations in order to keep the analysis transparent. If removal were to be modelled then the cumulative emissions of countries with relatively large emissions early in time, such as the USA and Western Europe, will be slightly smaller than countries that have relatively larger emissions later in time, such as India and China.
5. Given the enormous growth of the world economy and related CO_2 emissions in the 20th century, the exclusion of pre-1900 emissions is not likely to alter the later-reported results very much.
6. In our calculations we use the most recent EIA projections. Uncertainty is associated with projecting future emissions. Evidently, the calculations can be easily updated when revised projections become available.
7. Effects of possible emission reductions that may result from the Kyoto Protocol are not considered in the EIA projections, as their assessment is complicated by two factors. First, the treaty does not indicate the methods

(e.g. reduction in own country, CDM, JI, or sinks) by which the ratifying parties will reduce their emissions. Second, the participants have not agreed upon actions after 2012 (EIA, 2007). We do not expect that this is likely to influence our results considerably, because the relevant period (2005–2012) is quite short and the Protocol does not demand very stringent emission reductions. Moreover, China, India and the USA are not bound by the treaty.

8. As a comparison we have also calculated and projected cumulative CO_2 emissions for the African continent and the Middle East. The annual growth of emissions under the EIA reference scenario is 2.3% for both groups of countries. Results show that neither Africa nor the Middle East will overtake the USA or Western Europe in 2080 in cumulative emissions. Relative shares do change over time though. For example, cumulative emissions of the Middle East relative to the USA are 11% in 2004 and rise to 34% in 2080. For Africa this figure rises from 9% in 2004 to 25% in 2080.

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