Quantifying national responsibility for climate breakdown: an equality-based attribution approach for carbon dioxide emissions in excess of the planetary boundary

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Summary

Background This analysis proposes a novel method for quantifying national responsibility for damages related to climate change by looking at national contributions to cumulative CO_2 emissions in excess of the planetary boundary of 350 ppm atmospheric CO_2 concentration. This approach is rooted in the principle of equal per capita access to atmospheric commons.

Methods For this analysis, national fair shares of a safe global carbon budget consistent with the planetary boundary of 350 ppm were derived. These fair shares were then subtracted from countries' actual historical emissions (territorial emissions from 1850 to 1969, and consumption-based emissions from 1970 to 2015) to determine the extent to which each country has overshot or undershot its fair share. Through this approach, each country's share of responsibility for global emissions in excess of the planetary boundary was calculated.

Findings As of 2015, the USA was responsible for 40% of excess global CO_2 emissions. The European Union (EU-28) was responsible for 29%. The G8 nations (the USA, EU-28, Russia, Japan, and Canada) were together responsible for 85%. Countries classified by the UN Framework Convention on Climate Change as Annex I nations (ie, most industrialised countries) were responsible for 90% of excess emissions. The Global North was responsible for 92%. By contrast, most countries in the Global South were within their boundary fair shares, including India and China (although China will overshoot soon).

Interpretation These figures indicate that high-income countries have a greater degree of responsibility for climate damages than previous methods have implied. These results offer a just framework for attributing national responsibility for excess emissions, and a guide for determining national liability for damages related to climate change, consistent with the principles of planetary boundaries and equal access to atmospheric commons.

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Introduction

The UN Framework Convention on Climate Change (UNFCCC) includes the principle of "common but differentiated responsibilities and respective capabilities". This principle has been widely used to determine differential national responsibilities for mitigation efforts. But the principle of differentiated responsibilities can also be applied to allocating responsibility for climate change itself, and damages related to climate change, on the grounds that countries that have contributed more to global emissions are more responsible for related problems than those that have contributed less. The present analysis offers a novel method for doing so, in a manner that is consistent with the principles of planetary boundaries and equal access to atmospheric commons.

There are various existing approaches to measuring national responsibility for climate change. Negotiations and agreements under the UNFCCC are focused on current territorial emissions. Based on this approach, China's responsibility is more than double that of the USA, and India comes just behind the European Union (EU-28; table 1). When it comes to climate change, however, what matters is stocks of CO_2 in the atmosphere, not annual flows; so responsibility must be measured in terms of each country's contribution to cumulative historical emissions.[1,2] Using 1850 as the base year, the USA and the EU-28 are about twice as responsible as China, whereas India is responsible for only a small fraction of historical emissions (table 2). Tables 1 and 2 use the PRIMAP-Hist dataset,[3] excluding forestry and other land use.

Looking at countries' historical emissions alone is not adequate, however, given the differences in population size. For instance, China might have contributed substantially to cumulative emissions, but it also has a much larger population than other countries (eg, it is about four times the size of the USA). Any metric of responsibility should ideally take this discrepancy into account.[4] We can expect that doing so would show the national responsibility of the USA to be proportionally

Research in context

Evidence before this study

To date, there has been no robust attempt to quantify national responsibility for the ecological, social, and economic damages caused by excess global CO_2 emissions. The predominant approaches to conceptualising national responsibility for emissions focus on current annual territorial emissions, or in some cases cumulative territorial emissions, in a manner that does not account simultaneously for both the scale of national emissions and population size of countries. The literature on climate debt addresses this limitation by recognising the principle of equal per capita access to atmospheric commons, yet existing methods in the literature do not allow quantification of national responsibility for emissions in excess of a given safe global carbon budget. Furthermore, no existing methods have attempted to quantify responsibility for emissions in consumption-based terms, in a manner that accounts for international trade.

Added value of this study

This analysis addresses the limitations of existing research by developing a novel method for quantifying national responsibility for damages related to climate change, using consumption-based emissions data as much as possible. It proceeds from the principle that all countries should have equal access to atmospheric commons in per capita terms, which is defined here as a fair share of a safe global carbon budget consistent with the planetary boundary of 350 ppm atmospheric CO_2 concentration. Building on this principle allows the development of a just method for attributing national responsibility for global emissions in excess of the planetary boundary, and for conceptualising and quantifying climate debt.

Implications of all the available evidence

The findings of this analysis demonstrate that high-income countries have a substantially higher degree of responsibility for climate damages than one might expect by looking simply at current or cumulative national territorial emissions. The results provide guidance for conceptualising and quantifying liability for ecological, social, and economic damages, which is of particular importance for lower-income countries that suffer disproportionately from climate damages despite not having contributed to excess emissions at all.

	Country or region	Megatonnes of CO_2	Proportion of total (%)
1	China	10 300	29%
2	USA	5270	15%
3	EU-28	3473	10%
4	India	2340	7%
5	Russia	1740	5%
6	Japan	1220	3%

Table 1: **Annual territorial CO_2 emissions by rank, 2015**

	Country or region	Gigatonnes of CO_2	Proportion of total (%)
1	USA	410	26%
2	EU-28	358	23%
3	China	190	12%
4	Russia	116	8%
5	Japan	62	4%
6	India	46	3%

Table 2: **Cumulative territorial CO_2 emissions by rank, 1850–2015**

higher than suggested in table 2, whereas China's responsibility would be proportionally lower.

One way to approach this is to start from the principle that the atmosphere is a shared and finite resource, and that all people are entitled to an equal share of it.[5–11] Building on this principle, we can measure national responsibility for climate damages by looking at the extent to which nations have exceeded or overshot their fair share of a given safe global emissions budget. Such an approach would allow us to calculate national responsibility for emissions in excess of the global budget in a manner that takes account of both scale and population. Countries that have exceeded their fair share would then be said to owe a climate debt to countries that have remained within their fair share.

In the existing literature, Matthews[12] has come closest to this approach. Matthews uses the principle of atmospheric commons to quantify climate debts by looking at territorial emissions between 1960 (or 1990) and 2013. Countries whose per capita emissions exceed the global average per capita emissions (which Matthews defines as a fair share) are in debt, whereas countries whose per capita emissions are lower than the global average are in credit. Matthews finds that the USA is responsible for 32% of climate debt from 1990 to 2010. Other notable debtor countries include Russia (10·0%), Brazil (9·8%), Canada (3·9%), and Germany (3·4%). India has the largest climate credit (35% of the total credit), followed by China (26%), Bangladesh (4·9%), Pakistan (4·3%), and Nigeria (2·4%).

This approach marks a substantial contribution, but it yields results that understate the responsibility of high-income countries in a number of ways. First, Matthews' approach looks only at emissions since 1960 and 1990. The use of these late base years ignores the substantial contribution to emissions by industrialised countries during previous decades, at a time when low-income countries were emitting very little CO_2. Second, it relies on territorial emissions accounting, which ignores the

emissions that high-income countries have outsourced to lower-income countries since the rise of globalisation in the 1980s, thus shifting responsibility for emissions abroad. Consumption-based emissions better reflect the principle of equal access to atmospheric commons.

More importantly, for the purposes of this analysis, although Matthews' method is useful for quantifying national responsibility for total emissions in a manner that takes account of per capita fair shares, it does not allow quantification of responsibility for climate breakdown—in other words, for emissions in excess of a safe emissions budget. Nor does this approach allow an assessment of liability for damages caused by excess emissions. This analysis aims to address these limitations with a novel method for quantifying national responsibility for climate breakdown that accounts for long-term historical emissions, rendered as much as possible in consumption-based terms.

Methods

Study design and data analysis

The present analysis made three methodological choices. First, national fair shares were defined with reference to 350 ppm atmospheric CO_2, the safe planetary boundary as justified by Rockström and colleagues[13] and by Steffen and colleagues.[14] This boundary was used instead of some future emissions limit (1·5°C or 2°C) in order to assess damages that are already happening, and which will continue to worsen. Second, 1850 was used as the base year for calculating cumulative historical emissions. This year is commonly used in preference to earlier base years on the grounds that emissions before 1850 were minimal and it is more difficult to attribute them to any given country. Finally, this analysis drew on consumption-based emissions data as much as possible, as this better reflects the ethical principle of equal access to atmospheric commons. Consumption-based data, which are derived from Eora,[15] were only available for 1970 to 2015. For the previous period, 1850 to 1969, territorial emissions drawn from the PRIMAP-Hist dataset were used.[3] Only CO_2 was included in the present analysis, because the next most significant gas (methane) is so short lived that it cannot be meaningfully included in calculations of long-term stocks. For nations that do not have data for embodied emissions in any given year, territorial data were used instead. Figures exclude forestry and other land use.

CO_2 concentrations crossed 350 ppm in 1990, at which point climate change can be said to have begun to be a problem, causing what is referred to in the present analysis as climate breakdown. By calculating the total CO_2 emitted from 1850 to 1990, the budget for cumulative historical emissions within the planetary boundary was derived (830 gigatonnes). Building on the method developed by Fanning and O'Neill[16] and by O'Neill and colleagues,[17] this budget was distributed among countries according to each country's population as a share of the global population, with populations averaged from 1850 until today (or 2015 in this analysis, which is the final year of consumption-based data). This approach allowed determination of each country's fair share of the planetary boundary. The equation is as follows:

$$\textit{National fair share} = 830 \times \frac{\textit{National average population}}{\textit{Global average population}}$$

Notably, these fair shares are not static; they change over time as populations change. This analysis is not, in other words, a metric for individual fair shares at any given time in history (ie, how much a person can emit in any year), but rather for national fair shares over a historical period. The unit of responsibility here is the nation-state across time.

These fair shares were then subtracted from countries' cumulative emissions since 1850, to determine the extent to which these countries have overshot their fair shares. This approach allowed quantification of responsibility for climate breakdown, which in turn provided a guide for attributing liability for associated damages. Responsibility here was measured in terms of each country's overshoot as a proportion of total national overshoots. Notably, some countries have cumulative emissions that fall entirely within their boundary fair share. Such countries would be said to be in a state of undershoot, and bear no responsibility for climate breakdown; instead, they hold a climate credit with

	Country or region	Gigatonnes of CO_2	Proportion of total (%)
1	USA	420	28%
2	EU-28	377	25%
3	China	160	11%
4	Russia	105	7%
5	Japan	70	5%
6	India	43	3%

Table 3: **Cumulative territorial (1850–1969) and consumption-based (1970–2015) CO_2 emissions by rank**

	Gigatonnes of CO_2	Proportion of total (%)
Global North *vs* Global South		
Global North	1032	68%
Global South	484	32%
Total	1516	100%
Annex I *vs* non-Annex I nations		
Annex I	1073	71%
Non-Annex I	443	29%
Total	1516	100%

For the purposes of this analysis, the term Global North refers to the USA, Canada, Europe, Israel, Australia, New Zealand, and Japan, whereas the term Global South refers to the rest of the world: Latin America, Africa, the Middle East, and Asia.

Table 4: **Cumulative territorial (1850–1969) and consumption-based (1970–2015) CO_2 emissions by region**

respect to overshooting countries, and overshooting countries in turn owe them a climate debt. The equation is as follows:

$$\textit{National responsibility} = \frac{\textit{Cumulative emissions} - \textit{fair share}}{\textit{Total national overshoots}}$$

Role of the funding source

There was no funding source for this study. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Tables 3 and 4 show total historical emissions based on the dual-database approach described above. Inclusion of consumption-based emissions data since 1970 yields somewhat different conclusions to when only territorial data are used (table 2). Based on this approach, high-income countries have generated a greater share of historical emissions than territorial data would make it seem (the USA has gone up from 26% to 28% and the EU-28 has gone up from 23% to 25%), whereas China's share is smaller (down from 12% to 11%). Table 5 shows the extent to which these emissions exceed national fair shares.

For the **list of Annex I and non-Annex I countries** see https://unfccc.int/process/parties-non-party-stakeholders/parties-convention-and-observer-states

The results in table 5 show that the USA has contributed 40% of total national overshoot emissions. This same ratio can be used to determine the extent of national responsibility for emissions in excess of the global planetary boundary, and therefore for climate breakdown. The USA is therefore responsible for 40% of climate breakdown. The USA and the EU-28 together are responsible for 69% (figure). The G8 countries (the USA, EU-28, Russia, Japan, and Canada) are together responsible for 85%.

The majority of the world's countries (108 of the 202 in this dataset) are in climate credit. India is in credit of 90 billion tonnes of CO_2, or 34% of the total credit. China is in credit of 29 billion tonnes of CO_2. According to this method, therefore, China bears no responsibility for climate breakdown, at least through 2015. However, given that China's annual emissions are roughly 9 billion tonnes per year, it will soon overshoot its fair share and will thereafter be a contributor to climate breakdown.

Table 6 shows results for countries classified by the UNFCCC as Annex I and non-Annex I, and countries defined as being in the Global North and Global South. For the purposes of this analysis, the term Global North refers to the USA, Canada, Europe, Israel, Australia, New Zealand, and Japan, whereas the term Global South refers to the rest of the world: Latin America, Africa,

	Country	Allocated budget (gigatonnes of CO_2)	Cumulative emissions (gigatonnes of CO_2)	Overshoot or undershoot emissions (gigatonnes of CO_2)	Proportion of total national overshoots or undershoots (%)
World total	..	830·1	1516·2	686·1	..
Overshooters (climate debtors)					
1	USA	41·5	420·4	378·9	40%
2	Russia	27·2	105·1	78·0	8%
3	Germany	18·4	91·3	72·9	8%
4	UK	13·0	79·3	66·4	7%
5	Japan	21·5	70·0	48·6	5%
6	France	13·3	42·6	29·4	3%
7	Canada	4·1	30·2	26·2	3%
8	Ukraine	9·6	30·2	20·6	2%
Other overshooters	..	..	..	228·7	24%
Total national overshoots	..	..	..	949·6	100%
Undershooters (climate creditors)					
1	India	133·4	43·2	–90·2	34%
2	China	189·0	159·6	–29·4	11%
3	Bangladesh	15·9	1·3	–14·5	5%
4	Indonesia	25·1	10·7	–14·4	5%
5	Nigeria	13·4	2·1	–11·2	4%
6	Pakistan	14·5	3·8	–10·7	4%
7	Ethiopia	7·0	0·1	–6·9	3%
8	Vietnam	9·4	2·9	–6·4	2%
Other undershooters	..	..	..	–81·3	31%
Total national undershoots	..	..	..	–265·0	100%

Table 5: **Overshooting or undershooting of boundary fair shares**

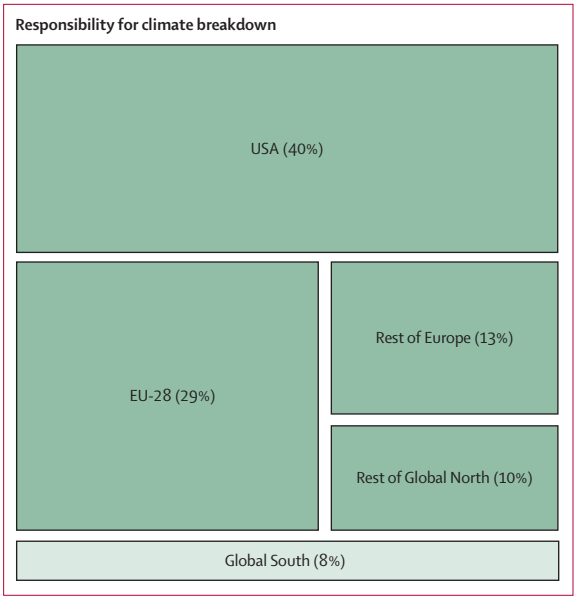

Figure: **Responsibility for excess emissions**
For the purposes of this analysis, the term Global North refers to the USA, Canada, Europe, Israel, Australia, New Zealand, and Japan, whereas the term Global South refers to the rest of the world: Latin America, Africa, the Middle East, and Asia.

	Total national overshoot (gigatonnes of CO_2)	Proportion of total national overshoots (%)
Annex I *vs* non-Annex I nations		
Annex I	851	90%
Non-Annex I	99	10%
World total	950	100%
Global North *vs* Global South		
Global North	875	92%
Global South	75	8%
World total	950	100%

For the purposes of this analysis, the term Global North refers to the USA, Canada, Europe, Israel, Australia, New Zealand, and Japan, whereas the term Global South refers to the rest of the world: Latin America, Africa, the Middle East, and Asia.

Table 6: **Regional groupings**

the Middle East, and Asia. The results show that Annex I countries are responsible for 90% of climate breakdown, and countries in the Global North are responsible for 92% (substantially higher than suggested by the more traditional approach to cumulative emissions represented in tables 3 and 4).

Discussion

The fair-shares approach articulated above offers a robust method for quantifying national responsibility for climate breakdown that is consistent with the principles of planetary boundaries and equal access to atmospheric commons. The results provide guidance for determining just approaches to liability for damages related to climate change. High-income countries must not only reduce emissions to zero more quickly than other countries,[18] but they must also pay down their climate debts, which are here conceptualised with respect to the planetary boundary. It can be argued that damages sustained by undershooting countries as a result of global warming should be paid by overshooting countries in proportion to their responsibility.

These results illustrate what could be referred to as a process of atmospheric colonisation. A small number of high-income countries have appropriated substantially more than their fair share of the atmospheric commons. Just as many of these countries have relied on the appropriation of labour and resources from the Global South for their own economic growth, they have also relied on the appropriation of global atmospheric commons, with consequences that harm the Global South disproportionately.[19]

There are some limitations to this analysis that are worth mentioning. One has to do with the debate over appropriate base years. Some might cite excusable ignorance as justifying a more restricted historical accounting, to distinguish between knowing contributions to harm versus accidental ones. This does not pertain to the question of responsibility for climate breakdown in the causal sense (ie, certain countries caused excess emissions regardless of whether they knew it), but it does raise questions about the extent of liability. That said, it has long been understood that the processes by which high-income countries industrialised were socially and ecologically harmful in other ways (eg, colonialism, land enclosures, the slave trade, extractivism, deforestation, pollution, and so on), which, like emissions, have been generally in proportion to the scale and intensity of industrial activity. Excusable ignorance is limited to the extent that CO_2 emissions are but one manifestation of a process that has had a wide range of long-known harms.

A second limitation, also related to the choice of distant historical base years, relates to the question of liability in cases where there has been a substantial change of government, such as a revolution or secession. This is particularly salient when it comes to the question of allocating responsibility for emissions generated by low-income and middle-income countries before their decolonisation (ie, during the 1850–1950 period). Should post-colonial states be held responsible for territorial emissions generated by colonial governments? Or should responsibility for those emissions be allocated at least in part to the relevant colonial power, on the grounds that they were the primary beneficiaries of the underlying industrial processes? The method presented above could be adjusted accordingly in future research.

A final limitation relates to the debate over whether gross emissions data should be used rather than net emissions data for calculating national responsibility. A net emissions approach would take account of sequestration capacity from either deforestation or

reforestation, showing countries such as Brazil to have greater responsibility whereas others have less responsibility, or, more controversially, crediting forested countries such as Russia and Canada for their sequestration capacities. Although this debate has its merits, in the present analysis a gross emissions approach was used for the sake of simplicity, and because it aligns more elegantly with the ethical principle of equal access to atmospheric commons.

Contributors

I was responsible for all aspects of the study.

Declaration of interests

I declare no competing interests.

Data sharing

The data that support the findings of this study, and the complete results, are available from the corresponding author upon request.

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