National responsibility for ecological breakdown: a fair-shares assessment of resource use, 1970–2017

Jason Hickel, Daniel W O'Neill, Andrew L Fanning, Huzaifa Zoomkawala

Summary

Background Human impacts on earth-system processes are overshooting several planetary boundaries, driving a crisis of ecological breakdown. This crisis is being caused in large part by global resource extraction, which has increased dramatically over the past half century. We propose a novel method for quantifying national responsibility for ecological breakdown by assessing nations' cumulative material use in excess of equitable and sustainable boundaries.

Methods For this analysis, we derived national fair shares of a sustainable resource corridor. These fair shares were then subtracted from countries' actual resource use to determine the extent to which each country has overshot its fair share over the period 1970–2017. Through this approach, each country's share of responsibility for global excess resource use was calculated.

Findings High-income nations are responsible for 74% of global excess material use, driven primarily by the USA (27%) and the EU-28 high-income countries (25%). China is responsible for 15% of global excess material use, and the rest of the Global South (ie, the low-income and middle-income countries of Latin America and the Caribbean, Africa, the Middle East, and Asia) is responsible for only 8%. Overshoot in higher-income nations is driven disproportionately by the use of abiotic materials, whereas in lower-income nations it is driven disproportionately by the use of biomass.

Interpretation These results show that high-income nations are the primary drivers of global ecological breakdown and they need to urgently reduce their resource use to fair and sustainable levels. Achieving sufficient reductions will likely require high-income nations to adopt transformative post-growth and degrowth approaches.

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Institute for Environmental Science and Technology (Prof J Hickel PhD) **and Department of Anthropology** (Prof J Hickel)**, Autonomous University of Barcelona, Barcelona, Spain; International Inequalities Institute, London School of Economics and Political Science, London, UK** (Prof J Hickel)**; Sustainability Research Institute, School of Earth and Environment, University of Leeds, Leeds, UK** (D W O'Neill PhD, A L Fanning PhD)**; Doughnut Economics Action Lab, Oxford, UK** (A L Fanning)**; Independent Researcher, Karachi, Pakistan** (H Zoomkawala BS)

Correspondence to: Prof Jason Hickel, International Inequalities Institute, London School of Economics and Political Science, London WC2A 2AE, UK **j.e.hickel@lse.ac.uk**

Introduction

Human impacts on earth-system processes are overshooting several planetary boundaries, not only in terms of CO_2 emissions and climate change, but also land-use change, biodiversity loss, chemical pollution, and biogeochemical flows.[1–4] The current rate of biodiversity loss is particularly concerning; in a comprehensive review of extant evidence, the UN Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services found that, on our present trajectory, around one million species are now at risk of extinction, many within decades.[5] This trend is indicative of widespread habitat fragmentation, ecosystem disruption, and ecological breakdown.

These problems are being driven in large part by global resource use, through processes of material extraction, production, consumption, and waste. Resource use has a range of impacts on terrestrial and marine ecosystems, including on forests, soils, wetlands, lakes, rivers, and oceans, and resource use is understood to be a robust proxy for environmental pressure.[6–8] Steinmann and colleagues[9] showed that resource use accounts for more than 90% of the variation in environmental damage indicators. The UN International Resource Panel found that resource use is responsible for 90% of total global biodiversity loss and water stress.[10] Moreover, as van der Voet and colleagues showed,[11] although impacts vary by material and as technologies change, there is a link between aggregate mass flows and ecological impact, with a correlation coefficient of 0·73.[11] Although differences between individual materials are important, aggregate material use is a key indicator for environmental policy.[12]

Global material use has increased markedly over the past half century, to the point where, as of 2017, the world economy is consuming over 90 billion tonnes of materials per year—well in excess of what industrial ecologists consider to be the sustainable limit. This increasing trend holds across all categories of materials, including biomass, metals, non-metallic minerals, and fossil fuels.[13] However, not all nations are equally responsible for this trend; some nations use substantially more resources per capita than others.[14]

Although previous research has explored the question of national responsibility for CO_2 emissions and climate change,[15,16] such analysis has not been applied to other forms of environmental pressure. In this study, we quantify national responsibility for ecological damages related to excess material use, using a method rooted in

Research in context

Evidence before this study
Existing research has shown that global resource use markedly exceeds sustainable levels and is driving a crisis of ecological breakdown, endangering planetary health. Research has also found that higher-income nations have higher per capita resource use than lower-income nations, and these nations also exceed sustainability thresholds to a greater extent. However, to date there has been no attempt to quantify national responsibility for the cumulative excess of global resource use that is driving the ecological crisis.

Added value of this study
This study advances existing research by assessing the extent to which nations exceed equitable and sustainable resource use corridors, in terms of cumulative material consumption. The study uses these data to quantify national responsibility for excess global resource use over the period 1970–2017. The study proceeds on the principle that all people have the right to an equitable fair share of global resource use at a sustainable level, drawing on the logic of the commons as developed in the climate literature.

Implications of all the available evidence
The results of this analysis indicate that high-income nations are the primary drivers of global ecological breakdown and must urgently reduce their resource use to fair and sustainable levels. Given existing evidence on the strong coupling between economic growth and resource use, this will likely require high-income nations to adopt transformative post-growth and degrowth approaches.

the principle that the planet's resources and ecosystems are a commons, and that all people are entitled to an equal, sustainable share. This principle has been articulated in the climate literature,[17,18] and the approach used here builds on a method that was developed for CO_2 emissions.[15]

Methods

Quantifying material use

Two primary methodological issues require attention. The first is the extent to which a nation's resource use can reasonably be considered to contribute to ecological breakdown on a global level. With CO_2 emissions, national emissions have global effects. Something similar is true of resource use, given the reality of international trade—particularly in an era of globalisation and complex commodity supply chains. Material flows data reveal that the products consumed in any given country rely on resources extracted from many countries around the world.[19] An iPad, for instance, involves materials from 748 international suppliers.[20] Consumption of iPads and similar items in the USA or Sweden has impacts in countries ranging from China to Bolivia to DR Congo. Global economic integration, and the globalised nature of resource supply chains, makes it necessary to think about national resource use in terms of aggregate global ecological pressure.[21]

For quantifying national use of material resources, two indicators are available. One is domestic material consumption (DMC), which represents the total mass of material extraction within a nation's borders, plus the mass of imports, minus the mass of exports. Although this metric accounts for trade to some degree, it does not include the upstream material extraction required to produce traded goods. The second metric is material footprint (MF), also known as raw material consumption. MF accounts not only for domestic extraction and the mass of traded goods, but also for the upstream material extraction required to produce these goods.[21–23] For example, although DMC includes the mass of an imported smartphone, MF includes the smartphone plus the materials involved in the supply chains that produce it. By accounting for these dynamics, MF represents the total materials embodied in national final demand. Given the dynamics of offshore production and global supply chains, MF data are preferable to DMC data when it comes to assessing the contributions of national consumption to ecological breakdown.

Recognising the international nature of material flows allows us to resolve questions that might arise from a more methodologically territorial perspective. For instance, one might argue that countries such as Finland and Costa Rica should not be penalised for resource use in the same way as countries such as Brazil and the USA, on the grounds that resource extraction in the former countries is more heavily regulated, and uses more sustainable technologies than in the latter countries (ie, represents less ecological impact per tonne of material extracted). But although Finland might apply stronger regulatory standards to its own domestic extraction, it does not apply those same standards to extraction embodied in products and intermediate parts imported from abroad. When accounting for the complexity of global commodity chains, differences in national regulatory frameworks and technological endowments become less important. Consumption in Finland involves resources extracted in Brazil, while consumption in Brazil involves resources extracted in Finland.

Having established that MF allows meaningful assessment of national contributions to extraction-related ecological breakdown, there is a second methodological issue to address. Although all resource use entails ecological pressure, some level of resource use is of course necessary for sustaining human society, and countries with larger populations will therefore require more baseline resource use than countries with smaller populations. Considering this, our focus should not be on national resource use as such—ie, in absolute terms—but rather on some metric of excess resource use, measured with respect to a conception of fair shares that is grounded in principles of equity and sustainability.

One straightforward method to account for equity is to assess the extent to which nations' per capita resource use exceeds the global mean per capita level. This approach has been used to quantify nations' contributions to excess global CO_2 emissions.[16] The limitation of this approach is that although it works for modest levels of global resource use, it makes little sense to assume that aggregate resource use can increase indefinitely. From an ecological perspective, some kind of upper limit or boundary, similar to those that are used in climate policy (such as the 350 ppm planetary boundary, or the 1·5°C and 2°C limits) could be posited, beyond which any additional aggregate resource use would be considered excessive, regardless of how it is distributed.

Quantifying national responsibility

It is impossible to pinpoint precise boundaries for any complex geophysical process; such an exercise will always involve uncertainty and have a normative element. This is true for resource use just as it is for atmospheric CO_2 concentrations, ocean pH, land-use change, and other processes represented in the planetary boundaries framework. However, the boundary is somewhere, and it is clear that it has already been exceeded. Industrial ecologists have proposed that a sustainable boundary for global resource use might be around 50 billion tonnes per year.[24–28] Global resource use exceeded this level in 1997. This level is generally considered to be an upper-limit boundary; Bringezu proposes a target sustainability corridor of about 25–50 billion tonnes per year (Gt/a).[27] Global resource use exceeded 25 Gt/a in 1970.

We operationalised this sustainability corridor as follows. When aggregate global resource use was between 25 Gt/a and 50 Gt/a (ie, for the years 1970–96) we set the boundary at the level of global resource use in each year. Thereafter, we used the 50 Gt/a upper limit (ie, for the years 1997 and thereafter). Building on methods developed by Fanning and O'Neill,[28] O'Neill and colleagues,[29] and Hickel,[15] we distributed the boundary according to each country's population as a share of the global population, in other words, on an equal fair-share basis, in keeping with the principle of ecological commons. Population data were obtained from the World Bank.[30] This approach allows us to determine each country's fair share of the boundary in each year. Note that these fair shares are not static; they change over time *t* as populations change, as follows:

$$\text{national fair share}_t = \text{boundary}_t \times \frac{\text{national population}_t}{\text{global population}_t}$$

In years when national resource use was larger than the national fair share, the difference between these quantities was used to calculate overshoot, as follows:

$$\text{national overshoot}_t = \text{national resource use}_t - \text{national fair share}_t$$

In all other years, overshoot was defined as zero, so that undershoot in one year does not compensate for overshoot in other years. Summing national overshoots over the period from 1970–2017 yielded each nation's cumulative overshoot. Finally, dividing each nation's cumulative overshoot by the sum of all nations' cumulative overshoots (ie, cumulative global overshoot) allowed us to quantify national responsibility for total excess resource use:

$$\text{national responsibility} = \frac{\sum_{t=1970}^{2017} \text{national overshoot}_t}{\sum_{t=1970}^{2017} \text{global overshoot}_t}$$

Ideally, we would have used MF data for the full analysis period. However, the best MF data available, published by the UN Environment Programme-International Resource Panel (UNEP-IRP), only cover the period from 1991–2017. Moreover, the first year of these data contains some anomalies, due to the dissolution of the former Soviet Union. Therefore, we constructed an approximation of the material footprint for the years 1970–91 using DMC data, which are available from UNEP-IRP for most countries back to 1970.[13] Because the DMC data for former Eastern Bloc countries only begin in the early 1990s, we disaggregated data for the Soviet Union, Yugoslavia, and Czechoslovakia to estimate values for modern-day countries back to 1970, based on the relative DMC of the countries in the first year for which reliable individual country data were available (generally 1992).

We then indexed the DMC data for all countries to the year 1992 and multiplied this index series by the MF data for 1992, yielding an approximation of the material footprint over the 1970–91 period. We joined these data with the real MF data from 1992 onwards. As our data series is not a true material footprint for the full time period, we refer to it as material use or resource use throughout this Article. Although these data capture the year-on-year changes in both domestic extraction and traded goods, they do not capture any changes in the upstream material extraction required to produce traded goods before 1992. However, from 1992–2017, the data do fully capture these changes. The dataset covers 163 countries, and accounts for 99% of cumulative global material extraction over the whole period of analysis.

Role of the funding source

There was no funding source for this study.

Results

Nearly 2·5 trillion tonnes of materials were extracted and used globally from 1970–2017, with high-income and

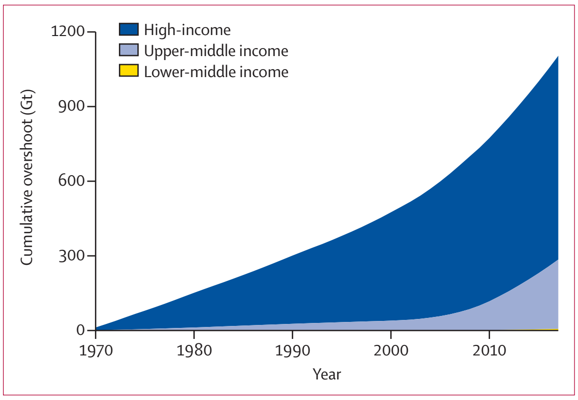

Figure 1: **Cumulative excess resource use of countries by income group, 1970–2017**
Excess resource use for low-income countries is close to zero (see table 1), and thus not visible in this figure.

	Cumulative overshoot (Gt)	Share of global overshoot
Income group		
High-income countries	813·4	74%
Upper–middle-income countries	273·7	25%
Lower–middle-income countries	6·3	1%
Low-income countries	2·7	<1%
Countries		
USA	296·6	27%
China	167·2	15%
Japan	96·0	9%
Germany	54·9	5%
France	38·1	3%
UK	37·4	3%
Canada	35·7	3%
Italy	31·5	3%
Brazil	26·4	2%
Australia	25·2	2%
Spain	22·8	2%
Korea	20·7	2%
Poland	14·0	1%
Saudi Arabia	13·2	1%
Netherlands	11·0	1%
Other overshooters	205·6	19%
World total	1096·1	100%

Income groups are based on the World Bank income classification as of fiscal year 2019 (for calendar year 2017). The classification is static across the whole period (ie, the analysis does not account for movement of countries between income groups). Results for all countries are available in appendix 1.

Table 1: **Cumulative excess resource use by country and income group, 1970–2017**

upper–middle-income countries using the vast majority of the resources. Of this, 1·1 trillion tonnes were in excess of the sustainable corridor. High-income countries (according to the World Bank classification) were collectively responsible for 74% of cumulative excess material use, and upper–middle-income countries were responsible for 25% of cumulative excess material use. Lower-middle-income countries and low-income countries were collectively responsible for less than 1% (figure 1).

Table 1 shows the share of responsibility for cumulative excess resource use, both for individual countries and income groups. Full country results are available in appendix 1 and regional aggregates are shown in appendix 2. The results indicate that the USA is the single largest contributor to excess resource use and is responsible for 27% of the world total. EU countries and the UK are together responsible for 25% of the world total of excess resource use. China, an upper–middle-income country, is responsible for 15%, and the rest of the Global South (ie, the low-income and middle-income countries of Latin America and the Caribbean, Africa, the Middle East, and Asia) is responsible for 8%. There are 58 countries, representing 3·6 billion people, that have remained within their fair shares of the boundary over the whole period from 1970–2017 (including India, Indonesia, Pakistan, Nigeria, Bangladesh, and other large populous countries), and therefore bear no responsibility for excess resource use, according to our analysis.

See Online for appendix 1
See Online for appendix 2

National responsibility for excess resource use has changed over the period analysed. Although the USA's overshoot has grown consistently in absolute terms, its share of global overshoot has gradually diminished over the past two decades. A similar trend is visible for Europe and other high-income nations. This change is due primarily to increasing resource use in China, which is mostly comprised of construction materials. China's overshoot began only in 2001, but has grown rapidly in the years since (figure 2).

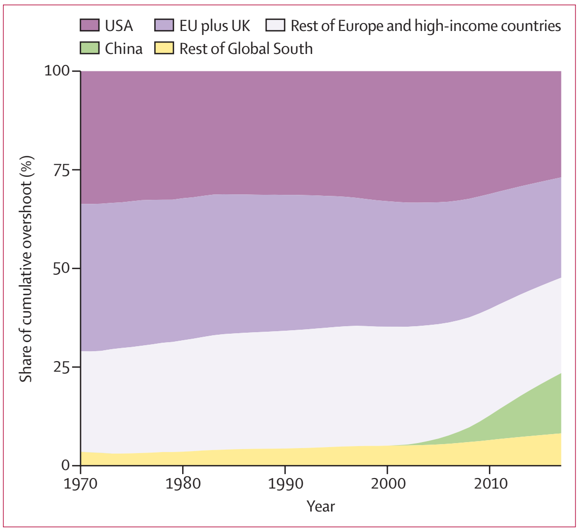

Figure 2: **Share of responsibility for excess resource use by region, 1970–2017**

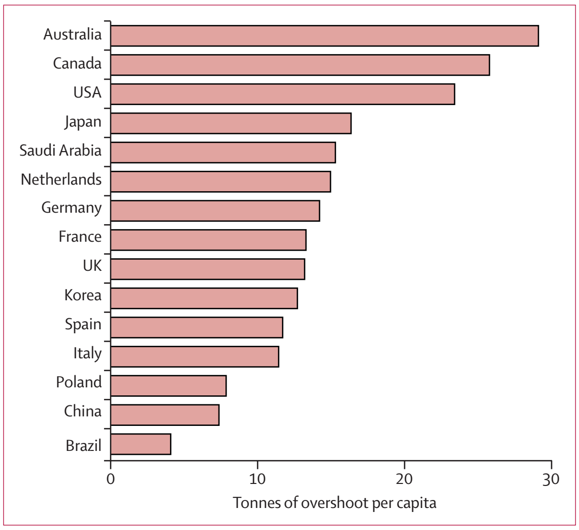

Figure 3: **Mean annual overshoot per capita of the 15 largest absolute overshooters, 1970–2017**

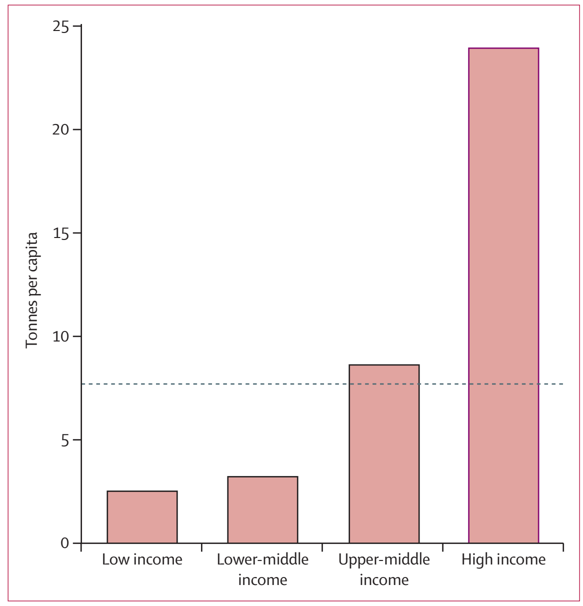

Figure 4: **Mean annual material use by country income group, 1970–2017, relative to the mean annual per capita boundary (7·7 tonnes per capita)**
The dotted horizontal line indicates the mean annual per capita boundary (7·7 tonnes per capita).

Figure 3 shows the mean annual overshoot per capita of the 15 countries with the largest total overshoot (those listed in table 1). Overshoot in high-income nations is substantially more intensive than among their lower-income counterparts. Australia's per capita overshoot is four times higher than China's, and seven times higher than Brazil's. Figure 4 shows the mean annual per capita resource use by countries according to income group, compared with the mean per capita boundary over the period.

It is also possible to consider differences between renewable and non-renewable resource use.[12,31] Bringezu proposes global boundaries for biotic and abiotic resources, at roughly one-third and two-thirds of the aggregate boundary, respectively.[27] Biotic resource use comprises biomass, and abiotic resource use comprises metals, non-metallic minerals, and fossil fuels. We applied Bringezu's proportions to the 50 Gt/a boundary. Table 2 shows regional responsibility for excess biotic and abiotic resource use, with a 16·8 Gt/a boundary for the former and a 33·2 Gt/a boundary for the latter, alongside aggregate figures for comparison. As lower-income nations rely more on biomass, their share of responsibility for biotic resource use overshoot is generally higher than it is for aggregate resource use overshoot, whereas for abiotic resource use the opposite is true.

For comparison, we also tested higher and lower upper-limit boundaries for annual resource use, with a 20% shift in either direction, to assess the extent to which outcomes are sensitive to this parameter. Our results show that the share of responsibility does change slightly, although it does not alter the overall pattern of our findings (appendix 2). With the lower boundary, the responsibility of lower-income nations generally increases (because more of them have resource use that exceeds the boundary), while the responsibility of higher-income nations declines accordingly. With the higher boundary, the opposite occurs: higher-income nations have a greater share of responsibility.

	Aggregate (50 Gt/a)		Biotic (16·8 Gt/a)		Abiotic (33·2 Gt/a)	
	Cumulative overshoot (Gt)	Share of global overshoot	Cumulative overshoot (Gt)	Share of global overshoot	Cumulative overshoot (Gt)	Share of global overshoot
USA	296·6	27%	42·6	20%	253·7	28%
EU + UK	278·7	25%	44·7	22%	234·7	25%
Rest of Europe and high-income countries	265·1	24%	56·5	27%	218·9	24%
China	167·2	15%	6·8	3%	165·1	18%
Rest of Global South	88·6	8%	57·2	28%	49·5	5%

Biotic resource use comprises biomass, and abiotic resource use comprises metals, non-metallic minerals, and fossil fuels.

Table 2: **Regional responsibility for cumulative excess resource use, 1970–2017**

Discussion

The fair-shares approach articulated here offers a novel method for quantifying national responsibility for ecological breakdown. High-income countries, which represent only 16% of the world population, are responsible for 74% of resource use in excess of fair shares and are therefore the primary drivers of global environmental degradation, representing a process of ecological colonisation.[18] Furthermore, the majority of the ecological pressure from excess consumption in rich nations is outsourced to poorer nations. According to a recent analysis, more than 50% of excess consumption in rich nations is net appropriated from poorer nations in the Global South.[32] This appropriation not only causes ecological damage in poorer nations, but depletes them of the material resources that they could otherwise use to provide for human needs and expand their sovereign industrial capacity.[19]

Our results show that high-income nations need to urgently scale down aggregate resource use to sustainable levels. On average, resource use needs to decline by at least 70% to reach the sustainable range. Such reductions will require strong legislation on both domestic extraction and material footprints. The European Parliament recently took steps in this direction by calling on the European Commission to adopt binding targets to reduce resource footprints by 2030 and bring them within planetary boundaries by 2050.[33]

It is unlikely that such reductions can be achieved while pursuing economic growth. There is no evidence of long-term absolute decoupling of economic growth from resource use occurring either in historical data or in modelled projections, even under high-efficiency scenarios.[8,34–36] Indeed, global gross domestic product (GDP) and global resource use are tightly coupled, and have increased in parallel for 50 years, despite substantial technological innovation and an increase in the contribution of services to GDP.[37] Therefore, the transition to sustainable levels of resource use will probably require adopting transformative post-growth and degrowth approaches, including abandoning GDP growth as a goal, reducing inequality, and organising the economy around human needs, while scaling down unnecessary commodity production.[38,39] Empirical evidence shows that degrowth strategies can be deployed to achieve substantial reductions in resource use while providing good lives for all people.[40–42] However, such a shift will require confronting the powerful network of think tanks, trade associations, lobby groups, philanthropic foundations, and other actors that develop and spread misinformation (such as so-called green growth narratives) in an attempt to legitimise an unsustainable status quo.[43–45]

There are three key limitations to the present study that are worth discussing. One is that cumulative overshoot accounting is highly sensitive to the start date of the analysis. Starting in 1970 effectively erases excess resource use that might have happened before this date, which has substantial distributional implications. For instance, the USA has consumed resources in excess of 8 tonnes per capita per year since at least 1870 (when national records began). Resource use in the USA increased particularly rapidly in the middle of the 20th century, more than doubling from 13 tonnes per capita in 1932, to 29 tonnes per capita by 1970, due in large part to infrastructure buildout.[46] We can assume that the UK, the EU, and most other high-income nations followed a similar trajectory during the same period, yet excess resource use during this period is absent—effectively forgiven—in the cumulative accounts presented here.

By contrast, nations in the Global South that have industrialised more recently are penalised for the same activity because it happened within the analysis period, and during a period of aggregate resource overuse. This issue is particularly evident in the case of China, where infrastructure buildout has occurred primarily since 2000. If responsibility for excess resource use were to be calculated in a manner that accounted for asynchronous patterns of industrial development, the responsibility of the USA and EU would likely be substantially higher than our results suggest, and the responsibility of countries in the Global South would probably be lower.

This dynamic explains much of the difference between the results of this study and those of a previous study on responsibility for excess CO_2 emissions.[15] Because the CO_2 analysis covered a longer time period (1850–2015), the USA was found to have a higher share of responsibility (40%), whereas China was found to be still within its fair share of the planetary boundary. However, the two studies are not directly comparable because the CO_2 emissions overshoot was quantified according to a longitudinal budget, whereas material use overshoot is quantified in this study according to an annualised boundary.

A second limitation has to do with the aggregated nature of the boundaries, particularly for abiotic resource use. The analysis could potentially be deepened by disaggregating abiotic materials (ie, into the constitutive categories of metals, non-metallic minerals, and fossil fuels), so as to determine responsibility for more specific environmental pressures. However, further research is needed to quantify material-specific boundaries that disaggregated values could be compared with.

A third limitation has to do with the annualised nature of the material use boundary. The boundary does not diminish no matter how much—or for how long—it is transgressed. In reality, if we have used too much in the past, less will be available in the future. Ultimately, what matters is how much we are using versus the capacity of ecosystems, a message that indicators such as the ecological footprint continue to convey.[47]

Other approaches for assigning national fair shares could also be explored to account for differences between countries (eg, colder regions might require more buildings and infrastructure), or to share responsibility for excess resource use between consumers and producers.[48,49] It is also important to note that there is substantial variation of responsibility within countries, given that rich individuals consume more than poor individuals. However, ultimately, a country's aggregate resource use is an effect of its economic model and provisioning systems, so the concept of responsibility is best understood as pertaining to the national level, where policy decisions and regulatory frameworks are determined.

In conclusion, a fair-shares assessment of resource use shows that high-income nations bear the overwhelming responsibility for global ecological breakdown, and therefore owe an ecological debt to the rest of the world. These nations need to take the lead in making radical reductions in their resource use to avoid further degradation, which will likely require transformative post-growth and degrowth approaches.

Contributors

JH conceived the study. JH, DWO, and ALF designed the study methodology. DWO, ALF, and HZ collected the data. All authors contributed to the data analysis. JH wrote the original draft of the manuscript. ALF and HZ produced the original study figures. JH, DWO, and ALF reviewed and edited the manuscript. DWO and ALF accessed and verified the data. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The national-level data collected for this study are publicly available from the UN Environment Programme's International Resource Panel and the World Bank, as described in the Methods section. The results for all countries are available in appendix 1.

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