

# Impacts of meeting minimum access on critical earth systems amidst the Great Inequality

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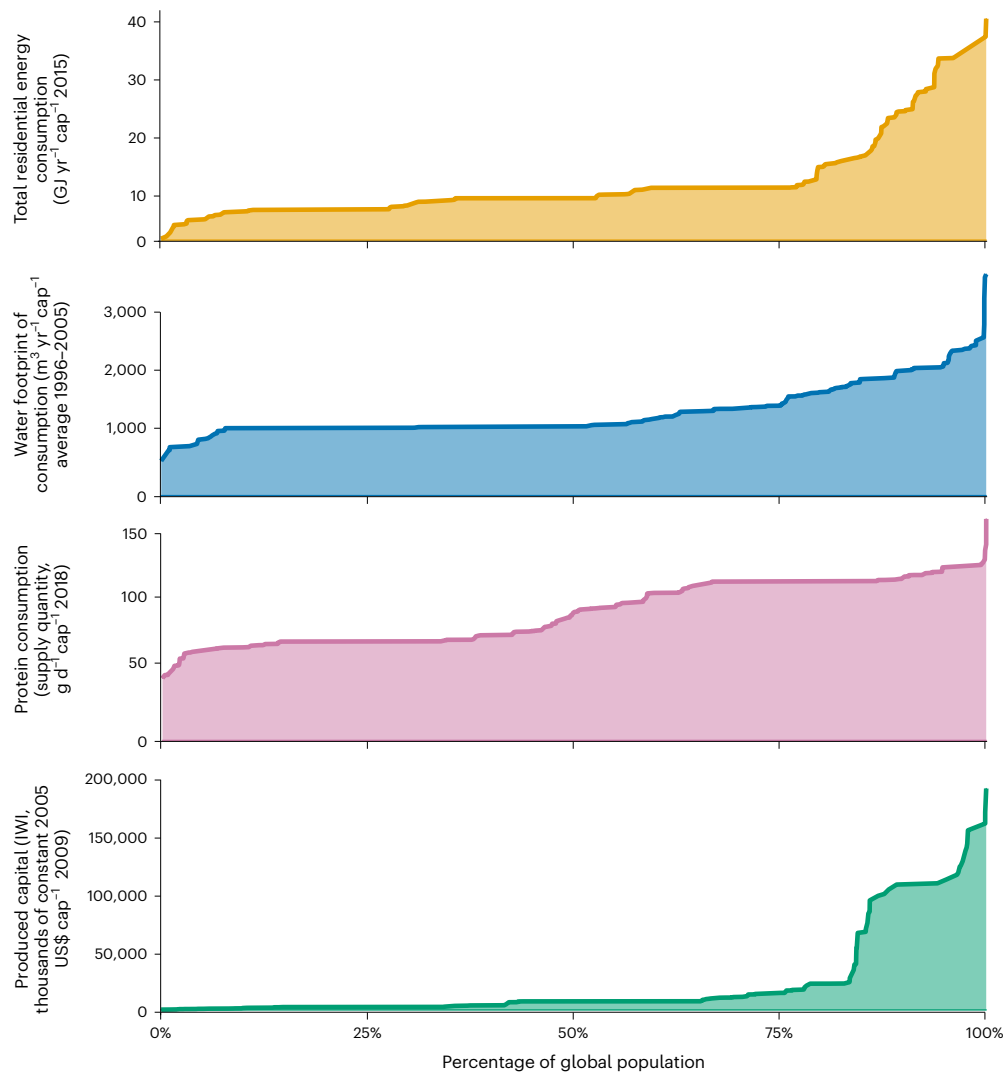
The Sustainable Development Goals aim to improve access to resources and services, reduce environmental degradation, eradicate poverty and reduce inequality. However, the magnitude of the environmental burden that would arise from meeting the needs of the poorest is under debate—especially when compared to much larger burdens from the rich. We show that the ‘Great Acceleration’ of human impacts was characterized by a ‘Great Inequality’ in using and damaging the environment. We then operationalize ‘just access’ to minimum energy, water, food and infrastructure. We show that achieving just access in 2018, with existing inequalities, technologies and behaviours, would have produced 2–26% additional impacts on the Earth’s natural systems of climate, water, land and nutrients—thus further crossing planetary boundaries. These hypothetical impacts, caused by about a third of humanity, equalled those caused by the wealthiest 1–4%. Technological and behavioural changes thus far, while important, did not deliver just access within a stable Earth system. Achieving these goals therefore calls for a radical redistribution of resources.

Humanity is destabilizing critical functions of the Earth system, which adversely affects human well-being<sup>1</sup>. However, there is growing evidence of inequalities in both responsibility for, and vulnerability to, environmental change. The people, countries and organizations making the largest contribution to the environmental impacts are not those (potentially) most affected by such impacts<sup>2</sup>. Meanwhile, billions struggle to survive whilst living below the minimum required access to resources for human well-being<sup>3</sup>. The UN 2030 Agenda calls for reducing inequality and recognizes that “eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest

global challenge and an indispensable requirement for sustainable development”<sup>4</sup>. It includes 17 Sustainable Development Goals (SDGs) to enhance human well-being and requires that these goals be met in an interrelated, integrated and indivisible manner<sup>4</sup>. This requires research into the potential interactions between social and environmental goals<sup>5</sup>.

Hence, we ask three questions. (1) How are access to resources and impacts on the environment distributed? (2) How can we quantify a minimum access to resources for the poor? (3) What would have been the hypothetical environmental consequences of achieving such minimum access in 2018 in the context of current inequalities,

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**Fig. 1 | The Great Inequality.** The graph shows inequalities for selected material needs with cumulative population on the x axis (by country and as percentage of global population) and consumption or spending levels on the y axes, for energy (total residential electricity consumption in gigajoules per year per capita<sup>59</sup>),

water (average water footprint of consumption for 1996–2005 in cubic metres per year per capita<sup>60</sup>), food (protein consumption in grams per day per capita<sup>61</sup>) and infrastructure (produced capital from the Inclusive Wealth Index (IWI) in US\$ per capita<sup>62</sup>).

technologies and behaviours? In answering these questions, we contribute to a broader operationalization of ‘Earth system justice’<sup>6,7</sup>. Earth system justice includes both procedural justice (access to information, decision-making, courts and civic space) and substantive justice across communities, nations, generations and species<sup>8</sup>. Substantive justice addresses the driving forces of both environmental degradation and vulnerability. It ensures (1) minimum access to essential resources (just minimum access, hereafter ‘just access’) and (2) equitable allocation of the remaining resources, risks and responsibilities<sup>9</sup>. This justice perspective is part of a broader project of the Earth Commission (<https://earthcommission.org>) to define safe and just ‘Earth system boundaries’ and to identify transformations towards living within these boundaries<sup>6</sup>.

This paper focuses only on one aspect of Earth system justice: just access for the most disadvantaged to resources and services for either a dignified life beyond mere survival or an escape from poverty. Just access requires just allocation<sup>9</sup>, but allocation issues and transformations will be taken up in future publications. Just access supports human rights<sup>10</sup>, reduces vulnerabilities to enable everyone to live healthy and productive lives<sup>11</sup> and aligns with discussions on SDG targets<sup>12</sup>. We develop indicators and quantifications of just access and embed these

in an analysis of the overall unequal distribution of claims and their impacts on the Earth’s natural systems (for example, climate and biodiversity). To do so, we provide evidence of a ‘Great Inequality’, which we define as a period of increasing social and material divergence. This complements, be it at different time-scales, the so-called Great Acceleration<sup>13</sup>—the post-1950s period of dramatic growth rates across many measures of humanity’s impact on Earth’s geology and its ecosystems.

Existing literature explores the relationships between just access and planetary boundaries. Notably, Kate Raworth’s doughnut concept places a social foundation for well-being (for example, food and health) within planetary boundaries (for example, climate and biodiversity), suggesting that meeting access can improve well-being for all<sup>14</sup>. Others suggest ‘decent living standards’ to assess the environmental impacts of eradicating poverty<sup>15</sup> or ‘consumption corridors’ with floors that ensure a good life and ceilings to consumption that would guarantee sufficient access for all, including future generations<sup>16</sup>. Yet others focus on specific access domains or Earth system impacts, such as energy consumption<sup>17</sup> or carbon emissions<sup>18,19</sup>. Some studies take a more top-down approach and correlate bundles of social floors with potential impacts on environmental indicators (material footprint and so on)<sup>20,21</sup>.

Our approach differs as we: (1) bring together four key access domains (water, food, energy and infrastructure) and four Earth systems (climate, water, land and nutrients); (2) focus on minimum material needs as a first step; (3) take a consistent bottom-up approach based on existing literature; and (4) translate these requirements into Earth system impacts. More specifically, we first identify minimum recommended levels of access to a resource (for example, an amount of water in litres per capita (cap) per day). We also quantify the impacts of consuming or using those resources on the Earth systems (for example, average amount of CO<sub>2</sub> emissions per litre of water from typical blue water supply systems). We then use these two magnitudes to calculate hypothetical per capita Earth system impacts if we had achieved minimum access to each resource in the year 2018 (for example, the per capita amount of CO<sub>2</sub> emissions from minimum water access). Finally, we multiply this per capita impact by the number of people who lacked access in 2018. This gives us the hypothetical total additional impacts of achieving just access under current technologies and behaviours (for example, total CO<sub>2</sub> emissions from achieving minimum water access for all). We repeat this for all access and impact domains, for example, from energy to carbon emissions, from food to biogeochemical flows and so on (Methods and Supplementary Information giving detailed methods).

In what follows, we first present the inequalities in the distribution of income, wealth and material needs. We then define minimum just access levels. Third, we show the impacts of achieving such just access levels on critical Earth systems. Finally, we discuss these impacts in the context of the Great Inequality and the implications for redistribution.

## Results

### The Great Inequality

Estimations of the Earth system impacts of achieving minimum access for those below a minimum must be part of a broader assessment of the distribution of material consumption and associated environmental impacts<sup>22</sup>. Otherwise, we lose sight of who is responsible for the current environmental crises and how inequitably the benefits of the world economy have been shared<sup>23,24</sup>. Globally, relative income inequality (Gini index), strongly associated with gender inequality<sup>25</sup>, increased and stabilized at a very high level between 1910 and 2020<sup>26</sup>. However, absolute income inequality (referring to monetary differences rather than proportion differences between income groups) is still rising<sup>27,28</sup>. Wealth inequality is even greater than income inequality. The world's 2,153 billionaires own more wealth than the bottom 60% of the world population<sup>29</sup>. Wealth inequality affects both the Global North (for example, the richest 10% in the OECD countries own as much wealth as the poorest 52% (ref. <sup>30</sup>)) and South (for example, the top 10% in India owns 60% of all the wealth, while the bottom 40% owns less than 4% (ref. <sup>31</sup>)). Wealth gaps are also widening<sup>29</sup>, for example, with the share of global wealth going to the top 1.1% rising from 35% in 2000 to 46% in 2020<sup>32</sup>. The COVID-19 pandemic has exacerbated both income and wealth inequalities<sup>33</sup>.

These economic inequalities translate into unequal impacts and claims on the environment. For example, the carbon emissions share of the top 10% of income earners is estimated at 34% of the global total in 2015, whereas the bottom 50% accounted for only 15% of all emissions<sup>34</sup>. The super-rich (net assets above US\$1 million and less than 0.5% of the world population) emit 13.6% of global lifestyle-related emissions<sup>35</sup>. Cumulative assessments show higher carbon inequality<sup>36</sup>. Furthermore, the disproportional climate impacts of a minority should not be attributed to consumption alone but also to investment and production patterns with 100 corporations emitting 71% of global CO<sub>2</sub> emissions<sup>37</sup>.

A material footprint analysis<sup>38,39</sup> that accounts for upstream appropriation of resources required for the production of traded goods and services shows that the material footprint per capita of high-income countries was -13 times larger than that of low-income countries in 1993. The difference rose to -18.7 times in 2000 and fell back to -14.6 times in 2010—not because low-income countries were catching up

**Table 1 | Minimum access requirements for energy, water, food and infrastructure and for both access levels**

Access domain	Access level	Value	Unit
Energy	1	74.5	Kilowatt-hours per capita per year (kWh cap <sup>-1</sup> yr <sup>-1</sup> )
	2	255	
Water	1	50	Litres per capita per day (l cap <sup>-1</sup> d <sup>-1</sup> )
	2	100	
Food	1	2,100	Kilocalories per capita per day (kcal cap <sup>-1</sup> d <sup>-1</sup> )
	2	2,500	
Infrastructure—housing	1	7	Square metres per capita (m <sup>2</sup> cap <sup>-1</sup> )
	2	15	
Infrastructure—transport	1	3,500	Passenger kilometres per capita per year (pkm cap <sup>-1</sup> yr <sup>-1</sup> )
	2	4,500	

but because those flows declined in high-income countries following the 2007/08 financial crisis<sup>39</sup>. High-income countries are also the only net importers of global flows of materials embodied in traded goods (in raw material equivalents), which grew from -4 billion tons (1990) to 10 billion tons annually (2015)<sup>40</sup>. All other income groups are net exporters of raw materials. Nations tend to become net importers of raw material equivalents with growing income. Turning to energy and accounting for within-country differences, the top 10% consume about as much as the bottom 80% (-39% of total final energy), while the lowest 10% consume -2% (ref. <sup>41</sup>). Again, high-income countries are the only net appropriators of rising global flows of energy embodied in traded goods<sup>40</sup>. The appropriation of (embodied) materials, energy, land and labour from the Global South to the North is worth over US\$10 trillion per year, which outstrips their aid receipts by a factor of 30 (ref. <sup>42</sup>). These inequalities reveal that it is neither humanity as a whole, nor on average, nor those escaping from extreme poverty but a relatively small and wealthy group that is responsible for most resource claims and ecological damage—and hence for the existential threats faced most severely by impoverished populations<sup>2</sup>.

We term these growing disparities the Great Inequality, inspired by and characterizing the Great Acceleration<sup>13</sup>. To reflect the just access dimensions discussed in this paper, Fig. 1 shows the recent state of the Great Inequality for selected material needs for energy, food, water and infrastructure. A smaller share of the world population places disproportionately larger material claims on the ecospace. In the Great Inequality, it is the wealthy who appropriate the bulk of the Earth's resources and drive the Great Acceleration—not the poor.

Figure 1 reveals distribution patterns using parade curves showing a succession of countries with their height proportional to their average access to the titled resource, starting with the lowest on the left of the *x* axis. We use average per capita levels since individual-level data is not available for the chosen indicators. Since the inequality within countries is generally higher than between countries<sup>43</sup>, the graphs make the distribution look more equal than it actually is. We also rescale the *x* axis by the population per country (as percentage of global population) so that countries with a larger population get a larger bin-size compared to smaller countries (Methods). On the *y* axis, we show the total consumption (water and energy) or spending levels (food and infrastructure). A horizontal line would depict full equality between countries.

### Just access levels

Against this background of unequal material claims on the ecospace (Fig. 1), we operationalize just access levels for the poorest and most marginalized. But what is lack of access? Income contributes to 'just access' as it enables people to pay for basic market goods and services

**Table 2 | Conversions from minimum per capita access requirements to per capita pressures on critical Earth systems for 2018**

Access domain	Access level	Value	Per capita pressure on Earth system domains				
			Climate (tCO <sub>2</sub> e cap <sup>-1</sup> yr <sup>-1</sup> )	Water—blue (m <sup>3</sup> cap <sup>-1</sup> yr <sup>-1</sup> )	Land (ha cap <sup>-1</sup> )	Nutrients—P (kg P <sub>2</sub> O <sub>5</sub> cap <sup>-1</sup> yr <sup>-1</sup> )	Nutrients—N (kg N cap <sup>-1</sup> yr <sup>-1</sup> )
Energy (kWh cap <sup>-1</sup> yr <sup>-1</sup> )	1	74.5	0.04	0.16	4.57×10 <sup>-8</sup>		
	2	255	0.13	0.54	1.57×10 <sup>-7</sup>		
Water (l cap <sup>-1</sup> d <sup>-1</sup> )	1	50	0.15	18.25	1.82×10 <sup>-6</sup>		
	2	100	0.31	36.50	3.96×10 <sup>-6</sup>		
Food (kcal cap <sup>-1</sup> d <sup>-1</sup> )	1	2,100	1.60	82.51	1.42×10 <sup>-1</sup>	1.1	3.1
	2	2,500	1.91	98.23	1.69×10 <sup>-1</sup>	1.4	3.7
Infrastructure—housing (m <sup>2</sup> cap <sup>-1</sup> )	1	7	0.30	5.97	2.69×10 <sup>-4</sup>		
	2	15	0.65	12.80	5.77×10 <sup>-4</sup>		
Infrastructure—transport (pkm cap <sup>-1</sup> yr <sup>-1</sup> )	1	3,500	0.36				
	2	4,500	0.46				
Total pressure	1		2.45	106.89	1.42×10 <sup>-1</sup>	1.1	3.1
	2		3.45	148.07	1.70×10 <sup>-1</sup>	1.4	3.7
Average current pressure			4.87	550.80	7.50×10 <sup>-1</sup>	6.4	15

and it correlates (up to a point) with other aspects of well-being<sup>44</sup>. Global poverty—based on the current international poverty line target of \$1.90 (2011 purchasing power parity)—fell from over -42% of the world population to -9% in the 1981–2017 period<sup>45</sup>. It rose again due to COVID-19 (ref. <sup>46</sup>). However, there is ongoing debate about the level of the international poverty line as a ‘social floor’<sup>47</sup>. For example, 3 billion people (~40% of the world population) cannot afford a healthy diet—even if they spend most of their income on food<sup>48</sup>, let alone sanitation services. Several higher poverty lines that coincide with notable improvements in health and resilience have therefore been proposed<sup>49,50</sup>. On the basis of those thresholds, global poverty is up, not down<sup>45</sup>.

Other factors besides private income also bear on access, such as the provision of public and merit goods and the ‘free’ services from nature (nature’s contributions to people), such as clean air, potable water, building materials, healthy soils, vital pollinators and a stable climate. These non-market goods and services are critical to the lives of the poorest<sup>51</sup>. However, environmental degradation and extreme climatic events from local to global levels affect the ability of people to access and use these basic resources necessary for a healthy and dignified life<sup>52</sup>. For example, 2.2 billion people lack access to safely managed drinking water, and half of the world population is predicted to be living in water-stressed areas by 2025 (<https://www.who.int/news-room/fact-sheets/detail/drinking-water>).

While the SDGs call for achieving access, they have inadequately operationalized this in quantitative terms. Hence, we define threshold levels for just access and present these in the context of the Great Inequality. We have operationalized just access levels as minimum per capita access requirements for energy (with a focus on electricity), water (with a focus on household consumption), food (with a focus on caloric intake but accounting for a healthy diet composition) and infrastructure (with a focus on housing and transport). Just access levels range from those that enable a dignified life beyond survival (level 1—dignity) to those that enable escape from poverty and vulnerability (level 2—capability) (Methods). Table 1 summarizes our assumptions about access needs for energy, water, food and infrastructure for these two levels on the basis of scientific and grey literature and expert judgement within the Earth Commission (Methods and Supplementary Information). As explained, our aim is to estimate the environmental

impacts if just access had been achieved in 2018, with prevailing levels of technology and patterns of inequality. We therefore make no assumption about technological and behavioural change. Future transformations could, of course, alter the access levels in Table 1, for example, walkable cities could reduce transport requirements. Other transformations, for example, towards more efficient energy and water systems, will surely influence the Earth system impacts (in Table 2). However, these transformations are not feasible in the very short term and not within the scope of this paper.

Clearly, energy includes more than electricity and infrastructure includes more than housing and transport. It is important to note that the labels and values in Table 1 do not reveal the entire spectrum of needs that we have accounted for. For example, climate impacts from minimum thermal heating are not included under ‘energy’ but under ‘infrastructure/housing’ as it depends on the minimum required square metre space. Similarly, impacts from minimum irrigation needs are incorporated under ‘food’ not ‘water’. Our goal is to cluster the biophysical impacts, and the causes are therefore distributed across different access domains where they best serve that goal. This also minimizes double counting (Supplementary Information).

### Earth system impacts of just access

We now examine the hypothetical additional impacts of achieving just access (at both levels) on critical Earth systems (climate, water, land and nutrients), that is, on top of existing total impacts (except for land, where the impact is a deduction from remaining intact land). We focus on the pre-COVID year 2018 to avoid the effects of the pandemic. To calculate these further impacts, Table 2 converts per capita just access levels into per capita pressures on the Earth systems, on the basis of current technology and global averages (Methods). For example, yearly per capita electricity consumption is converted into yearly per capita greenhouse gas emissions or yearly per capita food consumption into yearly per capita phosphate use. The conversion factors are based on multiple sources (Supplementary Information; Table 1). Table 2 presents the per capita impacts arising from per capita access. As noted earlier, some minimum energy requirements fall under access to water, food and infrastructure. This explains why the climate impact of ‘energy’ (which contains only electricity) may appear low.

**Table 3 | Further pressures on the Earth systems of meeting water, food, energy and infrastructure access levels 1 and 2 and shares of population below the access levels, for 2018**

		Climate change (GtCO <sub>2</sub> e yr <sup>-1</sup> )	Water—blue (m <sup>3</sup> yr <sup>-1</sup> )	Land (Mha)	Nutrients—P (TgP <sub>2</sub> O <sub>5</sub> yr <sup>-1</sup> )	Nutrients—N (TgN yr <sup>-1</sup> )
	Current levels	38.00	4.30×10 <sup>12</sup>	5,847.72	50.22	117.14
<b>Access level 1</b>	Absolute further pressure	5.62	1.02×10 <sup>11</sup>	132.86	1.00	3.14
	Relative further pressure	15%	2%	2%	2%	3%
	Number of people below access	4.1billion	2billion	2billion	1.8billion	2billion
	Share of population below access	52%	25%	25%	23%	26%
<b>Access level 2</b>	Absolute further pressure	10.06	1.96×10 <sup>11</sup>	189.83	1.43	4.46
	Relative further pressure	26%	5%	3%	3%	4%
	Number of people below access	4.8billion	2.7billion	2.3billion	2.1billion	2.4billion
	Share of population below access	62%	34%	29%	27%	31%

Note: Relative further pressure is the absolute further pressure divided by current level plus further pressure, except for land where further pressure is divided by current level (as pressure is a deduction from intact land).

Table 3 and Fig. 2 present the current total pressure on each Earth system and the further pressures resulting from achieving minimum access levels, other things equal. We first estimate how far different percentile groups are from achieving minimum access (insufficient access does not mean zero access) and then calculate the associated pressure using the per capita conversions in Table 2. Due to lack of data availability, however, we use global individual-based income distribution as a proxy for the distribution of access and associated pressures (Methods). Finally, we add up the shortfalls of each percentile below the minimum, which gives us the aggregate pressure of achieving universal minimum access (Methods). Table 3 provides our estimates of the further pressures that would have occurred if the access gaps (level 1 and level 2) had been closed in 2018. It also indicates the number and share of people below the access levels.

Table 3 and Fig. 2 reveal that achieving access is likely to have the highest impacts for climate change (15% and 26% additional impacts from access levels 1 and 2, respectively). The added impacts for all other Earth systems stay between 2% and 5%. These impacts would be added on top of existing pressures and transgressions of planetary and Earth system boundaries. From Table 2, we see that from all the access variables, food accounts for the strongest effect by far. On average, 30% (23–52) of the world population lacks access at level 1 and 37% (27–62) at level 2. Hypothetically achieving access level 1 in 2018 would have added climate impacts from about 52% of the world population at the bottom of the distribution (or 62% for level 2), but these additional impacts amount to less than the current impacts of the top 1% (or top 4% for level 2). For all other Earth systems, achieving access level 1 or level 2 would have added impacts from 23% to 34% of the world population at the bottom of the distribution. However, these impacts all remain well below the current impacts of the top 1%. Thus, living within planetary boundaries while meeting access needs will require redistribution.

## Discussion

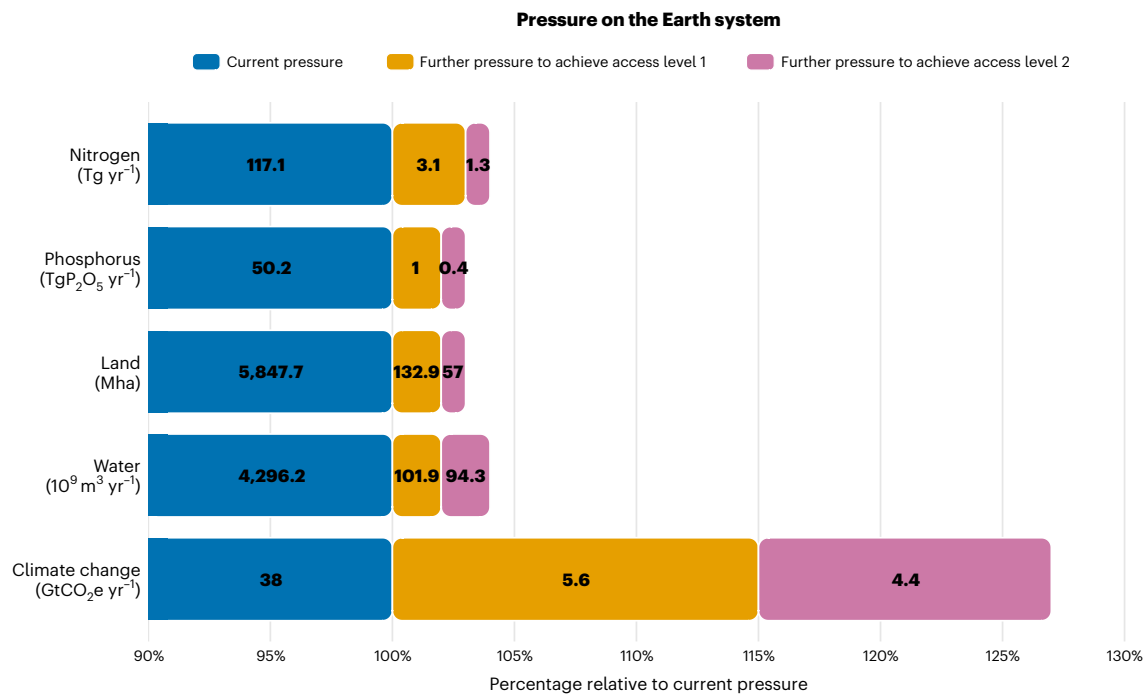
Achieving just access is not only important ethically (for distributive justice) but also legally (for human rights), economically (for minimum purchasing power), socially (for democratic decision-making) and ecologically (for environmental integrity and reducing resource conflicts). Just access must be understood in the context of the Great Inequality, which demonstrates that a relatively smaller part of the world population claims too much of the Earth's resources at the expense of others who cannot claim enough to satisfy basic needs. Insufficient access is not innate but created by our economic, political and institutional

structures, such as globalized markets that integrate unequal spending power and therefore result in net flows of embodied resources from the Global South to the Global North<sup>40,42,53</sup> or through deregulated financial systems that weaken the capacity of states in the Global South to provide public and merit goods<sup>54</sup>. To a large extent, having 'too little' therefore results from others having 'too much'.

The matter of defining 'too little' justifies our focus on just access, in part also because the SDGs inadequately operationalize minimum access levels in quantitative terms. We show that the estimated additional claims and impacts on the Earth systems that arise from achieving minimum access are, relatively speaking, not major environmental concerns—with the exception of climate. There is clearly a need to compare the impacts of achieving just access to disproportionately larger impacts caused by the rest of humanity. Our estimates show that the hypothetical impacts from eradicating severe deprivations for about a third of the world population in 2018 amounted to the same impact currently caused by the wealthiest 1%. Our estimates of minimum needs and impacts align with other findings in the literature, for example, for energy<sup>55</sup> and climate<sup>21,34</sup>. Our estimates also differ from those reported elsewhere. This may be due to the use of different methodologies, for example, for nutrients<sup>20,21</sup> or to the setting of higher targets for minimum access, for example, for climate<sup>19</sup>.

While it is beyond the scope of this paper, it is worth reflecting briefly on future implications. We must first reiterate that our calculations do not rely on assumptions regarding future changes in patterns of inequality, levels of technology and so on. We merely show that just access—had it been achieved in 2018 on the basis of existing technologies and in the context of prevailing inequalities—would have produced additional environmental impacts. Thus far, technological and behavioural advances, while important, have not succeeded in realizing the needs of the poorest while respecting safe planetary and Earth system boundaries. Hence our call for resource redistribution in the short term.

Looking ahead, many have also argued that improvements in technology and behaviour will not eliminate the need for redistribution<sup>17,21,55</sup>. At the same time, redistribution will not eliminate the need for those other improvements. For example, our most severe impact is the emission of 3.45 tCO<sub>2</sub>e cap<sup>-1</sup> yr<sup>-1</sup> from achieving access level 2 (Table 2). If everyone's emissions were equalized at that level (a highly exaggerated scenario), it would amount to 26.9 GtCO<sub>2</sub>e yr<sup>-1</sup> (based on 2018 population). These annual emissions far exceed the limit of 12.3 GtCO<sub>2</sub>e yr<sup>-1</sup> assigned to a 2015 population for a 50% chance of less



**Fig. 2 | Earth system impacts of just access for 2018.** The x axis is truncated at 90%. Total current pressure amounts to 100%. We include percentages to show the additional pressures in relative terms. The purple area ‘Further pressure to achieve access level 2’ is equal to the impact of achieving level 2 minus the impact of achieving level 1.

than 2 °C warming by 2100<sup>56</sup>. Redistribution is essential, but it must go hand in hand with changes in technology and behaviour, particularly towards climate goals<sup>57</sup>.

Planetary and Earth system boundaries imply a limited environmental utilization space. Being limited, this space needs to be shared more equitably. This implies the need for a just transformation<sup>7</sup> to reorganize economies and institutions, to change consumption patterns and value systems, to go beyond technology development and to support a fair redistribution of resources that ensures both just access and just allocation<sup>9</sup>. The Great Inequality also confronts us with the need to place limits on ‘too much’ access, that is, overuse and overconsumption<sup>7,21,24</sup>. Thus, meeting social needs without addressing inequality leads to an impossibly large burden on Earth systems.

### Limitations and recommendations

There are several conceptual and methodological limitations: (1) we only focus on the access element of substantive justice; (2) we translate justice into a biophysical parameter which justice scholars may object to (if these findings are taken in isolation from the wider justice approach presented in the introduction); (3) we identify a universal access level which does not do justice to geographical, demographic, cultural and other contextual differences; (4) we include only a few of the access indicators—implying an oversimplification and underestimation (which we believe is still useful); (5) we use income distribution as a proxy indicator for impact distribution; (6) we do not account for differences in gender and/or age in our per capita numbers; (7) we focus on 2018 only, with existing technology (and related impacts and needs) and inequality; and (8) the Great Inequality does not account for within-country distribution. Despite these limitations, we argue that justice scholars must engage with quantifications that can make explicit existing injustices. Future work should ideally include sensitivity analyses to ensure robust outcomes, cover more social and biophysical domains<sup>58</sup>, incorporate other material and non-material needs for which data are currently not available and consider future impacts. Moreover, from a justice

perspective, it is also critical that such numbers are debated publicly to refine them and ensure their legitimacy.

## Methods

### The Great Inequality

We connected datasets for the four indicators<sup>59–62</sup> to the population dataset from the World Bank<sup>63</sup>. We rescaled the x axis by the population per country. The script matched country names to connect population data with the other four datasets. Some countries were excluded where there was no match at all (for example, Viet Nam, Côte d’Ivoire and others for energy), and others were replaced (for example, Republic of the Congo with Congo or Democratic People’s Republic of Korea with Korea). We then used population size to scale the bin-size. We ordered countries from low to high consumption/spending levels. As we draw from different datasets and different years, the global population was not consistent across the four graphs. We therefore expressed the x axis as a percentage of global population. Our use of mean per capita levels instead of individual-level data underestimates actual inequalities.

### Just access levels

The first step in the access calculations is to translate just access into two quantitative minimum access levels per capita. Just access aims for minimally sufficient living conditions and prioritizes those who are worst off (see Introduction). The 2030 Agenda offers a set of SDGs that can be categorized as access to: basic services (for example, water, food, health care and financial services); natural resources (for example, clean water, land and green spaces); and equal rights (for example, gender equality, labour rights, information and decision-making)<sup>9</sup>. The 2030 Agenda also elaborates on international access, for example, to trade and markets, science and technology, access and benefit sharing and participation in international decision-making<sup>9</sup>. In this paper, we examine four key elements of access and sustainable development: access to food, energy, water and infrastructure (in terms of access to shelter and transportation). This is a practical shortlisting based on the availability of existing data and direct connection to Earth system change.

What levels of access to food, energy, water and infrastructure are needed for people to live with dignity and escape from poverty? While Agenda 2030 proposes, for example, a minimum income threshold of \$1.90 (2011 purchasing power parity) per day, we consider this to be insufficient to purchase minimally required consumption bundles of water, food, energy, shelter and transportation<sup>64</sup>. Accessing these goods and services outside the market is also problematic in a world where the capacity and willingness of states to provide public/merit goods (such as free water or food subsidies) and the ability of ecosystems to provide free services are shrinking<sup>24</sup>. We propose two categories of minimum access: level 1—dignity, represents a level of access which enables a dignified life beyond mere survival<sup>65</sup>, and level 2—capability, represents a relatively higher level of access that may be sufficient to escape from poverty and vulnerability<sup>66,67</sup>. At each level, quantitative estimates of per capita requirements for water<sup>68</sup>, food, energy and infrastructure were based on a review of the literature (see ‘Access levels’ for each Earth system in the Supplementary Information).

In the case of food access, we define level 2 using the EAT-Lancet diet<sup>69</sup>. Level 1 is based on the daily 2,100 kcal intake suggested by WHO<sup>70</sup> while keeping the EAT-Lancet diet composition, that is, share of each food group to support a healthy diet (Supplementary Data—Food). In the case of energy access, both level 1 (365 kWh yr<sup>-1</sup> household<sup>-1</sup>) and level 2 (1,250 kWh yr<sup>-1</sup> household<sup>-1</sup>) are defined using the World Bank report on energy access<sup>71</sup>. The water access levels (50 l d<sup>-1</sup> cap<sup>-1</sup> and 100 l d<sup>-1</sup> cap<sup>-1</sup>) are defined using the WHO report on domestic water quantity, service level and health<sup>72</sup>. The infrastructure access levels are defined for housing and transportation. Housing minima are defined using requirements of housing area per capita, level 1 = 7 m<sup>2</sup> cap<sup>-1</sup> (ref. <sup>73</sup>) and level 2 = 15 m<sup>2</sup> cap<sup>-1</sup> (ref. <sup>74</sup>). The transport minima are difficult to define due to a lack of policy regulations on this subject, but we used level 1 = 3,500 pkm yr<sup>-1</sup> and level 2 = 4,500 pkm yr<sup>-1</sup> (ref. <sup>74</sup>).

### Earth system impacts of just access

The next step is to connect the above per capita access requirements for food, energy, water and infrastructure to Earth system pressures on climate, land (measured as land intactness), nutrient cycles (for phosphorus and nitrogen) and blue water use. Each Earth system will be affected by multiple access domains (Supplementary Information—‘From access to pressure’). For example, climate is impacted by access to energy (emissions from household electricity use) and food (emissions from production). Each access domain will affect multiple Earth systems. For example, access to food has an impact on climate change, land use, water use and fertilizer use. Subsequently, we use the literature to identify case-specific estimation associated with these causal links, for example, CO<sub>2</sub> emissions per kcal, water use per kcal or land use per kcal. For further rationales, limitations and assumptions, please see ‘From *x* to *y* pressure’ for each Earth system in the Supplementary Information.

We use 2018 because of the urgency of meeting minimum needs, the availability of data and to set aside the influence of COVID-19. We assume 2018 patterns of resource use and technology, which include substantial dependence on fossil fuels, industrial agriculture, land conversion and so on. The paper’s estimates focus only on these relationships, although we recognize that there are many other interconnections between the Earth system pressures. Further ‘downstream’ impacts in the Earth system are therefore beyond the scope of this paper. For example, achieving access in 2018 would have increased phosphorus and nitrogen use (assuming 2018 technologies and patterns of resource use), which would have heightened the risks of eutrophication and anoxia. Achieving access also increases demand for land which will add to current losses of biodiversity and regulating capacities.

Finally, using the information from the previous steps, we estimate the impact of the access levels on the biophysical domains (Supplementary Information—‘Additional Earth system pressures’). For this, we

estimate the gap between existing and intended levels (because those who are currently below minimum access levels still have some level of access and therefore impact). For this, we need to know the current distribution for all four categories of water, food, energy and infrastructure. However, we are unable to use the Great Inequality graphs of Fig. 1 because (1) our own access level indicators differ from those in Fig. 1, and (2) we need global individual rather than country-based distribution data. We therefore rely on individual-based income distribution as a proxy for the impact on the Earth system domains (Supplementary Data—‘Access gap’).

Using the conversions from the previous step, we calculate the total per capita Earth system pressures that would arise from achieving access in all four domains (as shown in Table 2). For example, the emissions from having achieved access to energy, food, water and infrastructure add up to a total per capita impact on climate (if access is achieved). We multiply these per capita impacts by the 2018 world population to get to the aggregate impacts per Earth system. We then distribute the aggregate pressure between population percentiles using income distribution as a proxy. With this, we can estimate the additional impact of hypothetically closing the access gap (as shown in Table 3).

In other words, we calculate the added Earth system pressures if everyone below access levels 1 and 2 reached those levels—again, on the basis of technologies and patterns of resource use in 2018. These pressures are added on top of current levels, except for land where the pressure is deducted from remaining intact land. For land impacts, we look at how much intact land is currently still available per capita. The potential impact from access then leads to a deduction of intact land—as opposed to, say, an addition of emissions or water use.

Finally, we count the percentiles for which the current pressure is below the potential pressure that would come from achieving access. This gives us the percentage of the world population that exerts pressure below what would arise from achieving access (on the basis of current technology).

### Methodological limitations and assumptions

We have not sought to achieve a complete enumeration of the impact of minimum access levels but rather sought to quantify the broad implications of bringing those currently without access to resources, up to some minimum level, and compare that with the relative impact of all other existing users of the Earth’s resources. Our approach clearly does not capture all components of consumption by humans, including infrastructure needs for services such as education, health care, garbage disposal and telecommunications. Additionally, travel distance does not automatically imply access to work, health care, markets and so on. As such, our estimates may underestimate current impacts on the Earth system. Further work would also need to be done to include the biodiversity impacts on marine environments.

Our approach relies on a series of assumptions that come with their own limitations. For example, our number for minimum energy access is based on household consumption of electricity only. However, we do account for many more energy needs. The impacts of those needs are spread across other domains, such as energy expenditures from water supply to wastewater treatment, which are accounted for in access to water. Decisions around where and how different components of the production cycle were allocated were made on the basis of pragmatism and data availability but with the overarching goal of avoiding the double counting of resource use. We have listed all our assumptions and limitations in the Supplementary Information. Future research can help to integrate more explicit data to either support or refine the assumptions, which will help further clarify the extent of the impacts.

### Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

## Data availability

The data used and calculations performed in this study are published in the Supplementary Data.

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## Author contributions

All authors contributed to the work presented in this paper. C.F.R. and J.G. jointly wrote the main paper, and C.F.R. and D.C. wrote the Supplementary Information. All other authors gave conceptual advice and commented extensively on the manuscript at all stages. C.F.R., J.G., D.L., J.S., D.C. and K.P. jointly designed and implemented the methods. J.F.A. produced the figures. All authors discussed these methods, as well as the results and implications.

## Competing interests

The authors declare no competing interests.

## Additional information

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Research sample	Our research sample is the world population, which we analyze either on a country-level average per capita basis or on a global-level percentile basis. Figure 1 represents the distribution of material needs for total world population. It relies on the following publicly available datasets: 1. World Energy Statistics and Balances (International Energy Agency, 2015), <a href="https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en#archive">https://www.oecd-ilibrary.org/energy/data/iea-world-energy-statistics-and-balances_enestats-data-en#archive</a> 2. Hoekstra, A. Y. & Mekonnen, M. M. The water footprint of humanity. Proceedings of the national academy of sciences 109, 3232-3237 (2012). 3. FAOSTAT - Supply Utilization Accounts (Food and Agriculture Organization, 2022), <a href="https://www.fao.org/faostat/en/#data/SCL">https://www.fao.org/faostat/en/#data/SCL</a> 4. Popular indicator downloads (non-spatial data) / All / National Institutions / Inclusive Wealth Index - Produced Capital (Thousand of constant 2005 US dollars per capita) (UN Environment, 2022), <a href="https://wesr.unep.org/downloader">https://wesr.unep.org/downloader</a> 5. Population, total (World Bank, 2022). <a href="https://data.worldbank.org/indicator/SP.POP.TOTL">https://data.worldbank.org/indicator/SP.POP.TOTL</a> For Figure 2, we combine parameters from a range of sources to estimate minimum access levels and their environmental pressures. We then distribute current total environmental pressure using global income distribution as a proxy. For that we use the following publicly available dataset: UNU-WIDER, 2021. World Income Inequality Database (WIID). <a href="https://doi.org/10.35188/UNU-WIDER/WIID-310521">https://doi.org/10.35188/UNU-WIDER/WIID-310521</a>
Sampling strategy	No sample size calculations were performed. We use global datasets.
Data collection	We relied entirely on datasets available online from international organisations (IEA, EFN, FAO, UN Environment, UNU-WIDER and World Bank).
Timing	Data was collected between mid December 2021 and April 2022.
Data exclusions	No data was excluded, but we focused on the four material needs dimensions (water, energy, food and infrastructure).
Non-participation	Not applicable
Randomization	Not applicable

## Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

### Materials & experimental systems

- |                                     |  |
|-------------------------------------|--|
| n/a                                 | Included in the study                                  |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Antibodies                    |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Eukaryotic cell lines         |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Palaeontology and archaeology |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Animals and other organisms   |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Human research participants   |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Clinical data                 |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Dual use research of concern  |

### Methods

- |                                     |   |
|-------------------------------------|---|
| n/a                                 | Included in the study                           |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> ChIP-seq               |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> Flow cytometry         |
| <input checked="" type="checkbox"/> | <input type="checkbox"/> MRI-based neuroimaging |