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Achieve Sustainability by Easing Population to 4 Billion by 2200

Mark Keegan[1] | Anastasia Pseiridis[2] | Philip Cafaro[3] | Jane O'Sullivan[4] | William Rees[5] | Estelle Monique Sidze[6] | Lawrence Whitmore[7] | Enrique J. Derlindati[8] | Mohammad Mainul Islam[9] | Khaoula Houssini[10] | S. Irudaya Rajan[11]

[1]Teachers College, Columbia University, New York, New York, USA | [2]Institute of Urban Environment and Human Resources, Department of Economics and Regional Development, Panteion University of Social and Political Sciences, Athens, Greece | [3]Department of Philosophy, Colorado State University, Fort Collins, Colorado, USA | [4]School of Agriculture and Food Sustainability, The University of Queensland, St. Lucia, Australia | [5]School of Community and Regional Planning, University of British Columbia, Vancouver, Canada | [6]African Population and Health Research Center, Nairobi, Kenya | [7]Department of Engineering and IT, Carinthia University of Applied Sciences, Villach, Austria | [8]Escuela de Biología, Universidad Nacional de Salta, Salta, Argentina | [9]Department of Population Sciences, University of Dhaka, Dhaka, Bangladesh | [10]Division of Solid Waste Management, Tsinghua University, Beijing, China | [11]International Institute of Migration and Development, Thiruvananthapuram, India

Correspondence: Anastasia Pseiridis (pseiridis@panteion.gr)

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ABSTRACT

The past century of massive increases in human population and resource use has seen many undesirable environmental effects, ranging from biodiversity loss to climate change. But a research gap exists, as the ultimate causes are often not described with precision or mentioned at all. In this study, metrics of biodiversity, consumption, and pollution show extremely strong correlations when charted against human population size and its per capita impacts. We describe causal mechanisms for these correlations. Then, using available data, we show that slowing and gradually reversing population growth to ~4 billion or less by 2200, while moderating per capita impacts, is the path toward sustainability. Among the benefits are habitat recovery and conservation of wild species, reduced greenhouse gas emissions and other pollutants, reduced conflict over resources, and the reduction of global poverty.

1 | Introduction

We may be living in the most critical century in human history. Unprecedented population size, resource consumption, and technological power have placed us in a most precarious position. While we have achieved significant progress in many areas—improving lifespan and quality of life, reducing child mortality, alleviating poverty, expanding access to education and upholding human rights—our collective impact upon the planet's ecosystems has become overwhelming and unsustainable. We would do well to more urgently address our individual and collective impacts, demanding no more than what they can sustain. The choices we make now, or neglect to make, will profoundly shape the world for future generations.

As occasional studies remark (e.g., Pimentel and Pimentel 2006), human population levels and per capita impacts multiply together to produce our total impact on the Earth's systems as well as society. The global picture for any particular resource depletion, pollution effect, or other impact can be conceived by a simple formula:

$$\text{Total Impact} = \text{Population} \times \text{Per Capita Impact}$$

This is the original form of the famous IPAT equation described over a half-century ago (Ehrlich and Holdren 1971) and the form Holdren (2018) later re-embraced. This often-cited equation will guide our analysis in this paper, though we acknowledge, as Ehrlich and Holdren did, many factors affect per capita impact. But the relationship among the three variables is so well-established, the model so validated, that per capita figures are calculated by dividing total impact by population. See for example the many global development indicators available from the World Bank Group (2025), such as per capita consumption of energy, or production of CO_2 emissions. The research gap we will help address in this: though total amounts of a metric may be mentioned (for example, total global CO_2 emissions), changes in per capita impact are not often remarked, nor the concept of global population growth. For example, although we see "Responsible Consumption and Production" as the 12th goal of the United Nations' 17 Sustainable Development Goals, none of the SDGs nor their 169 "targets" mention population size or growth (UNDESA 2025).

Over the past hundred years, the global population has grown from approximately 2 billion to 8.3 billion people (UNDESA 2024). Because of above-replacement fertility rates in previous and current generations, the global population continues to increase. The rate of increase is slowing, however, and the intricacies of this are described by others, as with the Demographic Transition Theory (e.g., Zhang and Brown 2026). More than half of all countries have fertility rates below the replacement level of ~2.1 children per woman. Population growth is currently about 0.85% per year, with the global total fertility rate at around 2.25 (UNDESA 2024).

Although technologies may increase or decrease per capita impacts to a degree, these impacts generally increase with affluence (York et al. 2003; Chancel 2022). The smaller part of this increase arises from people emerging from poverty (Kharas 2017), and the bulk of the impacts stem from countries at high and very high levels of consumption, over and above a moderate level. Energy use is a good overall indicator of resource consumption. High income nations (averaging roughly 60 times the income of low-income nations) consume about 13 times more energy per capita than low-income nations. To show this, one need only chart GDP per capita in constant 2015 US$ with Energy use in kg of oil equivalent per capita (World Bank Group 2025).

Sustainability outcomes can be conceived from many perspectives, for they have multiple drivers on many levels. Economics, technological impacts, policies, personal choices, abundance, scarcity, inequalities, natural phenomena, sociocultural factors, and more affect not only per capita impacts but even population growth. But after all of those inputs, we can conceive of Total Impact as the product of Population and Per Capita (average) Impact.

What might we define as a "moderate" or "acceptable" per person impact and "moderate" population size? Whatever it is, it ought to meet the definition of sustainability: "to meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). Samuel Johnson, the great lexicographer, defined the term "overshoot" as "to fly beyond the mark" (Johnson 1800), and the terms environmental and ecological overshoot appear more and more frequently in the scientific literature (Bajaj et al. 2024). In this context, "overshoot" means exceeding sustainable levels of resource use, damaging or degrading the biosphere, to the degree of decreasing its ability to sustain human and nonhuman life. The words overpopulation and overconsumption are once again appearing in print with increasing frequency (Google Books Ngram Viewer 2026), and rightly so.

Some who have worked the numbers conclude we have already far surpassed sustainable levels of both population and per capita consumption. For example, Lianos and Pseiridis (2016) calculated the sustainable (overshoot-free) population at 3.1 billion living on the global 2011 average income. Dasgupta et al. (2023), using a different method, reached a roughly similar conclusion. Whitmore (2024) estimates the long-term carrying capacity of the planet as "2.5 billion with current resource usage, and 8 billion with one third of current resource usage." Willey (2000) presents an argument that a population around 1 billion would be sustainable for "a good quality of life available to everyone everywhere."

Some readers may balk at such low numbers, given a current population of over 8 billion. Yet accepting higher population numbers while still demanding sustainability means committing to even lower per capita environmental impacts—a fact that critics of population action rarely acknowledge. Some may construe these more as policy perspectives than as scientific conclusions, but a look at our still-expanding human footprint, including fuel and mineral consumption, suggests increasing resource use, waste creation, and environmental degradation cannot go on forever. The longer we avoid reining ourselves in, the worse the prospects for future generations (Cripps 2015). This paper explores the prospects for doing so by clarifying the role population growth and per capita impacts have played until now and may play in the future.

In the past 50 years, especially, many have pointed out the undesirable environmental effects stemming from increases in human population and resource use (May 2012; Bongaarts 2016; Cafaro et al. 2023). We are all familiar with the curve of human population growth in the past century, with years on the *x*-axis and population on the *y*-axis. This paper looks at eight of those effects in a novel way, by putting population on the *x*-axis. This appears at first to be a simple bivariate analysis, the approach others have taken when analyzing one variable against another (e.g., Crowther et al. 2015; Trimmer and Guest 2018; Rodríguez et al. 2022; Li et al. 2025). We later deduce the relative contributions population size and per capita impact have each made toward the global level of each metric; that is, the total impact.

We chart the global levels of each metric, because these are global effects produced by the global community, with long term global ramifications. This is our conceptual framework. In each case, the three necessary conditions are met for establishing causal inferences from the correlations (Zaniletti et al. 2023). First, the cause (population increase with its per capita impacts) precedes the effect (e.g., increased emissions of CO_2 from increased combustion of fossil fuels). Second, the empirical relationships are clear between cause and effect: our metrics reflect human use of energy, water, minerals, land, et cetera. Third, the effects cannot, in the main, be attributed to non-human causes. The correlations also meet Hill's nine criteria for causation (Hill 1965).

We investigate to what degree global human population levels (and their per capita impacts) correlate, since 1970, with 8 metrics for biodiversity, resource consumption, and pollution. Their trends did not begin in 1970, but they have greatly increased since then (McNeill and Engelke 2014).

We then look to the future, reviewing published population projections under high and low global fertility scenarios. Finally, we employ the trendline equations from the past half-century of data, that is, the equations describing the relationship between global population levels (with their per capita impacts) and the levels of each metric. These equations make cautious projections for each metric toward the year 2100 and then 2200, under various projections of population and its per capita impacts.

We hope our deliberately clear, global view can stimulate dialogue, focus research, nudge policy, and motivate optimism toward a better future.

2 | Materials and Methods

Our materials are publicly available data from well-regarded global institutions (e.g., United Nations, World Bank, FAO, OECD, The Energy Institute, Global Footprint Network, and the World Wildlife Fund), cited in the caption of each figure and table. Also, metrics are those for which a global dataset exists. For each metric, the best sources were sought which employed a single continuous methodology for 1970–2020. For population projections, we use the UN High and Low fertility scenarios (UNDESA 2024) and the "Fastest Progress" scenario from the Institute for Health Metrics and Evaluation (IHME 2020). The paper's size and purpose limit the exploration of regional variation and the effects of varied incomes, technologies, and policies on per capita impacts, but these are good topics for future research.

2.1 | Error Analysis and Uncertainty Measurement

Ours is a simple statistical analysis predicated on the well-accepted facts of rising global population, rising CO_2 emissions, rising consumption and disposal of plastics, and so on. Uncertainty assessment would have a role if we were questioning the precision of global census data or quantifying precise effects of energy conservation tactics, and so on. Instead, our study is about large changes over a half century, and we assume the data meets that purpose. We assume, for example, the UN has not erred by ± 0.5 billion in any global population estimate; we assume the Energy Institute did not err by ± 2 billion tonnes in global CO_2 emission data, and so on.

2.2 | Trendline Functions, *r*, *p*, and R^2 Values

In our charts, we show the type of trendline best fitting the data: linear functions for five of the eight metrics (CO_2 emissions, energy use, ecological footprint, freshwater use, and pesticides) and power functions for three metrics (Living Planet Index, mineral extraction, and plastics production). For all eight metrics we used the R statistical package (R Core Team 2026) to calculate r, R^2, and p values.

2.3 | Methods for Calculations Involved in Tables

To derive the figures of Table 1, the following formulas were used. For metrics changing upwards (as with increasing CO_2 emissions), the formula used is:

$$\text{Proportional change of Total Impact} = \frac{\text{metric's 2020 figure}}{\text{metric's 1970 figure}}$$

For metrics changing downwards (as with the decreasing Living Planet Index), the formula used is:

$$\text{Proportional change of Total Impact} = \frac{\text{metric's 1970 figure}}{\text{metric's 2020 figure}}$$

For example, for the Living Planet Index, the total impact (a decline from 1.00 to 0.27), equates to a proportional decline of $1.00/0.27 = 3.70$.

The following formulas were also used for Table 1.

$$\text{Proportional change due to Population, 1970 to 2020} = \frac{\text{global population in 2020}}{\text{global population in 1970}}$$

$$\text{Proportional change due to Per Capita Impact} = \frac{\text{proportional change of Total Impact, 1970 to 2020}}{\text{proportional change of Population, 1970 to 2020}}$$

The per capita impact for each of the eight metrics used in Table 2 were derived with the following formula:

$$\text{Per Capita Impact} = \frac{\text{Total Impact}}{\text{Population}}$$

Our dataset begins in 1970, so the amount of population growth dates from then. For each year since then, there have been varying (usually increasing) amounts of per capita impacts in addition to population growth. We calculated what the value of each metric would have been if population had remained at the 1970 level of 3.7 billion. The formula used is:

$$\text{value of metric if Population had not grown since 1970} = \frac{\text{Population at 1970}}{\text{Population at time } t} \times \text{value of metric at time } t$$

For a metric in decline, the fraction is inverted:

$$\text{value of metric if Population had not grown since 1970} = \frac{\text{Population at time } t}{\text{Population at 1970}} \times \text{value of metric at time } t$$

For each of the three global population projections (UN High and Low fertility scenarios, and IHME low fertility scenario

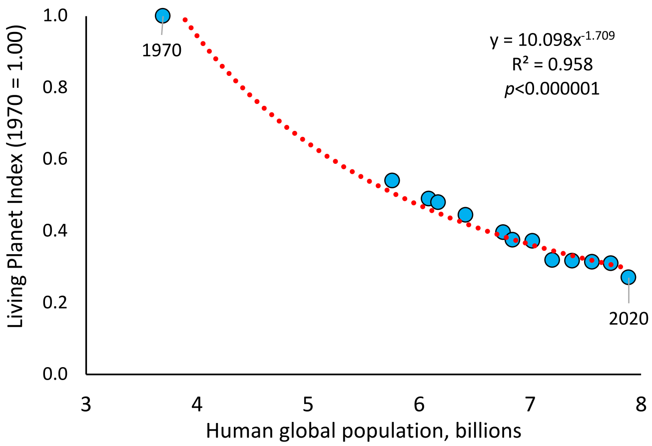

FIGURE 1 | Global human population and Living Planet Index 1970–2020; 1970 abundance is indexed as 1.0. Population data is from UNDESA (2024). Living Planet Index, from World Wildlife Fund (2024).

allowed to return to replacement level during the 22nd century), we extended the trendline functions shown by each metric's 1970–2020 data. For example, for a linear function such as $y = 89.796x - 126.34$, as for energy use (exajoules), the calculation for the UN High population projection for the year 2100 was calculated as follows:

$$\text{projected energy use by a population of 11.4 billion}$$
$$= (89.796 \times 11.4) - 126.34 = 886 \text{ exajoules}$$

As a validation test of the projected outcomes method we took the following approach. For the four metrics for which 2024 or 2025 data was available as of the time of writing, we tested the trendline functions arising from the 1970–2020 dataset, where the x-value (population with its per capita impacts) predicts the y-value (the level of the metric, for example, CO_2 emissions). For example, global population in 2025 was ~8.25 billion, while global CO_2 emissions were 38.1 billion tonnes, a record high (University of Exeter 2025). The trendline function for the 1970–2020 CO_2 emission data ($y = 4.7456x - 3.6404$) predicts a CO_2 emissions level of 35.5 billion tonnes. For energy use, the metric changed in 2025 to "energy supply"; the trendline function predicts energy use of 606 exajoules, and global energy supply in 2025 was 655 exajoules. The ecological footprint function predicts 21.5 billion global hectares for 2024 (no 2025 data yet); the reported figure was 21.4. For minerals extraction, 56.7 billion tonnes are predicted for 2024, while the reported figure is 63.6. In three of these four cases, the actual figures for consumption (energy, minerals) or pollution (CO_2 emissions) exceeded the 1970–2020 trendline function.

3 | Results

We present our results in 3 parts. First, we chart eight metrics against population growth (and its concomitant per capita impacts), 1970–2020. The second part quantifies population growth and per capita impacts on each metric. The third part makes projections toward the years 2100 and 2200.

3.1 | Population and Wildlife Abundance

There is an extremely strong correlation (Figure 1) between global human population increase and decline of wildlife populations as measured by the Living Planet Index, LPI (World Wildlife Fund 2024). The LPI is a metric of abundance of over 5000 species of mammals, birds, fish, amphibians, and reptiles. It has its detractors; for example, Toszogyova et al. (2024) contend the Index is overly sensitive to cases of extreme population declines. Still, the LPI has been deemed useful for estimating overall decline or recovery (McRae et al. 2025). As the human population doubled in the past half century, the Living Planet Index declined by more than half, population growth has been named as the main driver of the decline (Krishnadas et al. 2018; Cafaro et al. 2022). Declines vary by species and region, but the main causes are habitat loss (including habitat degradation and fragmentation), followed by overexploitation (IUCN 2023). There are cases where a decline in abundance is due partly or mostly to non-anthropogenic causes, but for the vast majority of the 35,000 datasets comprising the LPI, the declines are attributable to anthropogenic causes. More people need more housing, agriculture, infrastructure, and roads. Also, a larger human population is more likely to overexploit any resource, terrestrial or aquatic, to fulfill their needs or wants. Tal (2025) showed that countries with highest population growth rates also had the highest rates of biodiversity loss. Giraffe populations are down 40% in 30 years; 90% of blue whales have been lost in a century; all 3 species of orangutan are critically endangered—and the list goes on (IUCN 2023).

3.2 | Population and CO_2 Emissions

The population-and-CO_2-emissions trend is also extremely strong (Figure 2). As population doubled, CO_2 emissions slightly more than doubled (due to a slight increase in per capita emissions). Fossil fuel combustion produces most of this extra atmospheric CO_2, as most (81%) of our energy is still provided by oil, coal, and natural gas (International Energy Agency 2025a). With more people, there are more fossil-fuel-burning devices and thus more greenhouse gas (GHG) emissions. CO_2 constitutes about two-thirds of GHGs; total GHGs echo the CO_2 trend shown here. These GHGs, as we know, produce atmospheric warming, leading to melting of glaciers and ice shelves, sea level rise, more extreme weather, disturbance of wildlife habitat and phenology, ocean warming, and ocean acidification (see Steiner and Engdaw 2022 for a review). Deforestation also contributes to the increase of atmospheric CO_2 by the release of stored CO_2 and the removal of CO_2 sinks; it too is strongly linked to population growth (see, e.g., Sisay and Gitima 2002; Gorenflo et al. 2011; Krishnadas et al. 2018).

3.3 | Population and Energy Consumption

All forms of resource consumption involve energy. And so, we see a near-perfect correlation between population growth and increased energy consumption (Figure 3). As population doubled, energy use almost tripled. Population growth is the main driver, with increased per capita consumption a strong second. Industry and Transport demand the most total

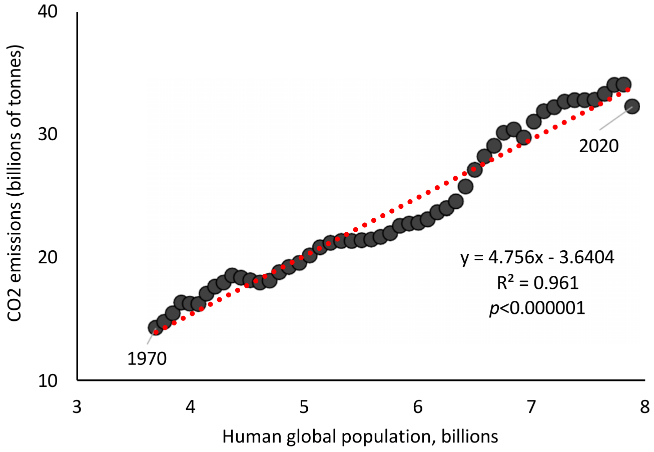

FIGURE 2 | Global human population and CO_2 emissions 1970–2020. For CO_2 emissions, billions of tonnes are equivalent to gigatons. Population data is from UNDESA (2024), CO_2 data from The Energy Institute (2025).

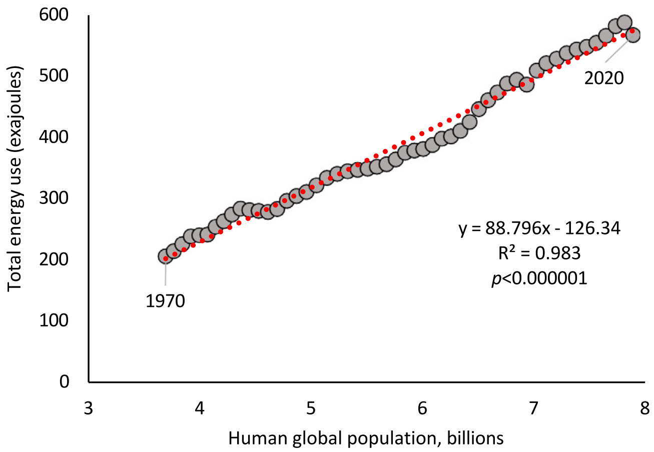

FIGURE 3 | Global human population and total energy consumption 1970–2020. Population data is from UNDESA (2024), energy data from The Energy Institute (2025).

energy consumption (each ~30%) with Residential demand third (~20%). Commercial and Public Services follow, then Agriculture, Forestry, Fisheries, and "Other non-specified" (International Energy Agency 2025a). There is an immense range of per capita energy consumption levels around the world, even among industrialized nations. The world average is 1,851 kg oil equivalent per capita, and Portugal and the United Kingdom are at 1948 and 2264. Meanwhile, the United States and Canada are at 6506 and 7632, respectively (World Bank Group (2025) showing 2022 figures, the latest complete World Bank dataset).

3.4 | Population and Ecological Footprint

As the global population doubled, our ecological footprint doubled (Figure 4). Ecological footprint (EF) analysis estimates the productive land and water areas required to supply the bio-resource demands of a specified human population (Rees and Wackernagel 2023). The EF metric includes cropland, forests, area for absorbing anthropogenic CO_2 emissions, grazing land,

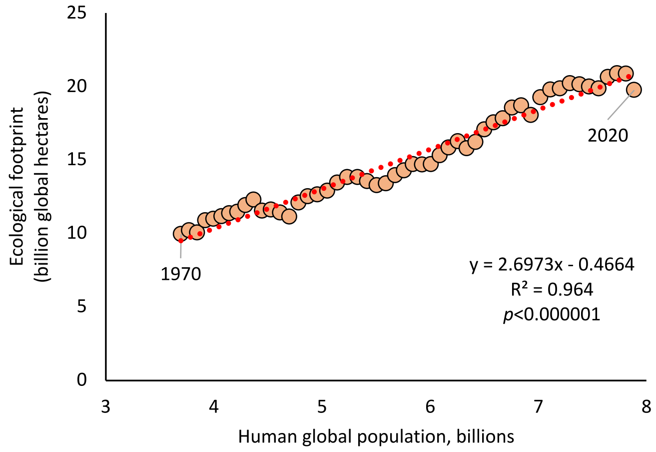

FIGURE 4 | Global human population and ecological footprint 1970–2020. Population data is from UNDESA (2024), ecological footprint data from Global Footprint Network (2024). A global hectare is "a biologically productive hectare with world average biological productivity for a given year."

marine and inland waters providing human food, and built-up land for human infrastructure. EFs enable comparison of available biocapacity with demand. Not all countries use more than 100% of their biocapacity, but most do (Global Footprint Network 2025). So, the world community as a whole is running an eco-deficit since 1971, growing and maintaining ourselves, in part, by liquidating stocks of essential natural capital (e.g., biodiversity, wild habitat, fossil fuels, wood fiber, soils, and groundwater) that have accumulated for thousands or even millions of years in nature. Uncorrected, this eco-overshoot could be a terminal condition (Rees 2023a).

3.5 | Population and Freshwater Use

As population doubled in the past half-century, freshwater use rose about 64% (Figure 5). Groundwater is about 25% of the use, and it has risen more steeply than surface extractions, almost exactly in proportion to population growth (Loaiciga and Doh 2024). Though agriculture and industry use the most, domestic use has increased ~600% since the 1960s (World Resources Institute 2020). In precipitation-rich areas, increased water withdrawals may not be a concern. But freshwater use is a serious matter in water-scarce areas, where shortages exacerbate adverse effects on ecosystems and crops. Groundwater is dropping in 71% of the world's aquifers, a clear indicator of unsustainable use, and the declines are accelerating (Jasechko et al. 2024). For surface water, Prigent et al. (2012) found a decline in global average maximum inundated area of about 0.5% per year. Extreme water scarcities can generate political conflict, to the degree that it has earned a name: "hydropolitical conflict" (Wilner 2005).

3.6 | Population and Mineral Extraction

Although its products are vital to modern life, each ton of minerals and metals we extract leaves less for future generations. As population doubled in the past half-century,

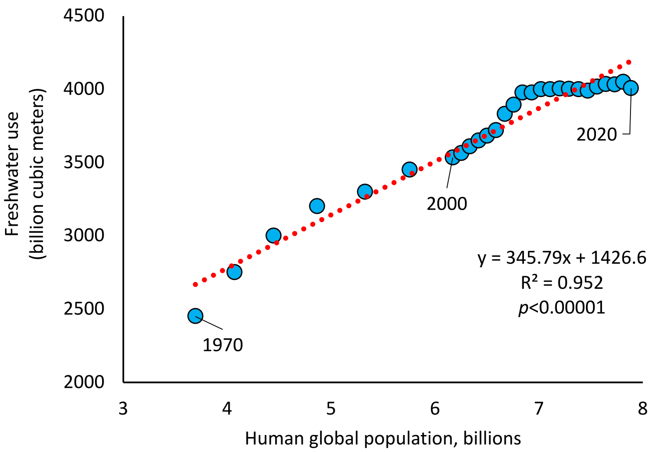

FIGURE 5 | Global human population and freshwater use. FAO's (2025) dataset begins at 2000. For 1970–1995 we relied on Loaiciga and Doh (2024). Population data is from UNDESA (2024).

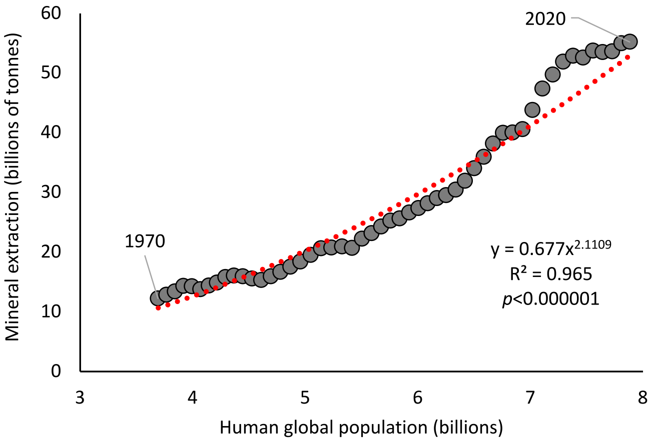

FIGURE 6 | Global human population and mineral extraction 1970–2020. Mineral extraction data combines tonnage of metal ores and non-metallic minerals. Population data is from UNDESA (2024), mineral data from Schandl et al. (2024).

per capita mineral extraction also doubled, and so mineral extraction has more than quadrupled. The correlation between population growth and mineral extraction is strong despite fluctuations of mineral prices and production incentives (Figure 6; note the "boom" of the 1980 data point, and the "slump" of 2000). As population increases, demand for minerals increases for construction of material infrastructure and durable goods. For example, there has been a recent huge increase in lithium extraction to supply the non-fossil fuel energy industry (The Energy Institute 2025). There are many more examples of environmental consequences of mining (Giljum et al. 2025, provide a review of 47 metal ores), from the disruption of flamingo habitats by lithium mining (Vera et al. 2023) to immense plumes of pollution by deep-sea mining (Sumaila et al. 2023).

3.7 | Population and Plastics Production

Large-scale production and use of plastics began around 1950, and they have brought obvious benefits. As population doubled

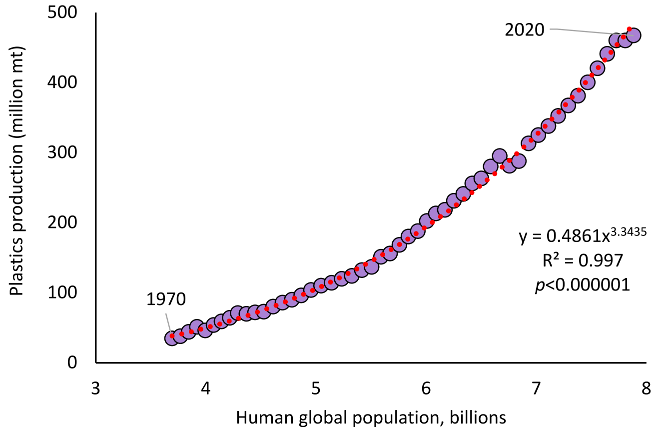

FIGURE 7 | Global human population and plastics production 1970–2020. Population data is from UNDESA (2024), plastics data from Geyer et al. (2017) and OECD (2022).

in the past half-century, plastics production increased 25-fold (Figure 7). Clearly, increased per capita consumption has been more important than population growth as a driver of plastic production. There exists no global metric for plastic pollution, but since a proportion of plastics become waste in the environment, plastics production is a rough proxy for plastics pollution. Houssini et al. (2025) found plastic packaging to be the main component of the estimated 30 million tonnes per year of plastic escaping into the environment. Some of those million tonnes (along with the chemical substances contained in them) might be prevented by bans on single-use plastic. Bangladesh in 2002 was the first nation to ban single-use plastic bags (UNEP 2021), and Rwanda soon followed (UNDP 2023). Still, per capita consumption is increasing rapidly, and population growth worsens the growing problem of plastic pollution.

3.8 | Population and Pesticide Use

As global population doubled from 1970 to 2020, agricultural pesticide use quadrupled (Figure 8). Pesticides have increased crop yields, and their efficiencies have been improved; but they have numerous adverse effects in the environment (Phillips McDougall 2019). Dangers to human health remain especially serious to agricultural workers and their offspring (Pinto et al. 2020). For consumers with high intake of certain non-organic foods in France, "acceptable daily intake" was exceeded by about two dozen pesticides (Nougadère et al. 2012). Pesticide use varies widely by nation, and this, too, suggests the importance of human choices. In 16 nations, annual use exceeds 2 kg per person; in Thailand, it is only 0.05 kg (World Population Review 2025).

3.9 | Population Growth and Per Capita Impacts

This part of our results discerns the relative degree population growth and growth in per capita impacts contribute to the total impacts graphed in the figures shown above. Table 1 shows

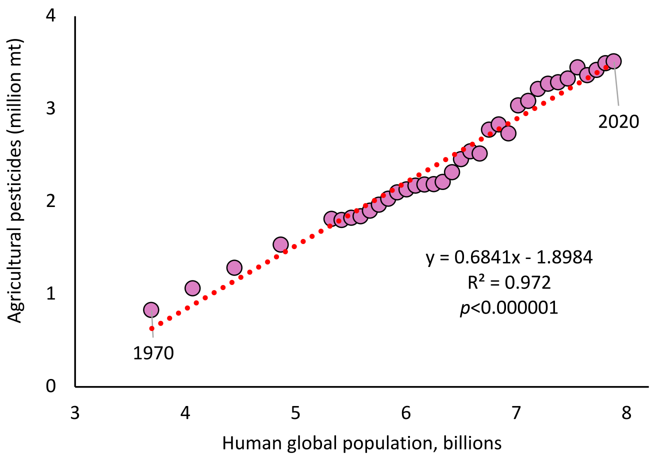

FIGURE 8 | Global human population and pesticide use 1970–2020. Population data is from UNDESA (2024), pesticide data from FAO (2026). FAO lacks pre-1990 pesticide data, so our 1970–1985 points are extrapolations backwards towards the origin of synthetic pesticides (EPA 2025).

TABLE 1 | Proportional changes in each metric between 1970 and 2020 attributable to population growth and per capita impact.

Metric, 1970–2020	Proportional change due to population	Proportional change due to per capita impact	Proportional change of total impact
Living Planet Index	**2.13**	1.74	3.70
CO_2 emissions	**2.13**	1.06	2.26
Energy use	**2.13**	1.30	2.76
Ecological footprint	**2.13**	0.93	1.99
Freshwater use	**2.13**	0.77	1.64
Mineral extraction	**2.13**	**2.12**	4.51
Plastics production	2.13	**6.26**	13.3
Pesticides	**2.13**	1.94	4.13

Note: Bold text indicates the factor responsible for the larger share of change. In the case of Mineral extraction, figures are considered roughly equal. Those two quantities multiply together to produce the proportional change of total impact (±0.01 differences may occur due to rounding).

proportions of change attributable to population growth and changes in per capita impacts. For six of the eight metrics described here, per capita impact has increased since 1970; for two metrics, per capita impact has decreased slightly.

With the absolute total impacts known, we can also calculate the actual values for per capita impact (Table 2). These are simply the total impact (e.g., total global energy use) at a point in time, divided by the population. For six of our eight metrics, the per capita impact increased from 1970 to 2020 (Living Planet Index, CO_2 emissions, energy use, and especially mineral extraction, and production of plastics and pesticides). Slight decreases were seen for per capita impact for ecological footprint and for freshwater use. It should be noted that these are global per capita impacts. The highest impacts among individuals might be many times the global average. Consider energy use per capita (World Bank Group 2025). The world average energy consumption is 1851 kg oil equivalent per capita, for example, while the per person consumption in the United States is 6505 and Canada's figure is even higher. European Union nations average 2918; sub-Saharan Africa averages 482.

TABLE 2 | Global per capita impact for seven metrics in 1970 and 2020.

Metric	1970	2020
CO_2 emissions per capita (tonnes/year)	3.87	**4.09**
Energy use per capita (gigajoules/year)	55.5	**71.8**
Ecological footprint per capita (global hectares/year)	2.69	2.50
Freshwater use per capita (cubic meters/year)	663	508
Mineral extraction per capita (tonnes/year)	3.3	**7.0**
Plastics production per capita (kilograms/year)	9.5	**59.2**
Agricultural pesticides per capita (kilograms/year)	0.22	**0.43**

Note: Figures are total impact divided by population at that date. Bold = increase relative to 1970.

3.10 | What Amounts Are Sustainable?

We know that, in the long run, population growth itself is unsustainable. Specifying truly sustainable per capita impacts is more complicated, as they would depend on:

- the metric, the region, and its population density (e.g., extremely little freshwater use is unsustainable in an arid region, even for a small population);
- biophysical reality (e.g., what is the CO_2 absorptive capacity of the biosphere?);
- time frame for the sustainability period, since it cannot be infinite (e.g., how far into the future are we planning to extract from the earth's mineral deposits, and by how much per year?);
- amount of adverse effect deemed "tolerable," and to whom (e.g., what degree of plastic pollution produces neither physical harm to humans and other species, nor aesthetic displeasure?).

For all eight metrics, there have been periods where their adverse trends would have reversed had there been no population growth (Table 3). Note that three goals policymakers have perhaps given the most attention to (CO_2 emissions and conservation of water and minerals) would have shown the highest improvements, had there been no population growth.

3.11 | Future Projections

We present three scenarios of future global fertility rates and associated population trajectories. The "UN High" and "UN Low" projections are the upper 95% and lower 95% prediction intervals from the most recent projections from the UN's Population Division (UNDESA 2024). The "IHME fastest progress" trajectory projects a more successful global scenario of increased contraceptive availability and use, suggested by the Institute for Health Metrics and Evaluation (2020).

In Table 4, we show how the different future population levels might influence our metrics by using their trendline functions to predict total impact. We do not know precisely to what degree each trend will change as population changes or as global per capita impacts rise or fall. Per capita impacts may generally rise with increasing affluence, but as shown in Table 3, there have been periods for each metric in which global per capita impacts declined.

The value of the figures is less in their precision than in their direction, improving or worsening compared to the present day. The changes may be slower or quicker than projected and would vary from region to region. Wild habitat can recover, either passively or by habitat restoration efforts (e.g., Trujillo-Miranda et al. 2018), but not as fast as humans destroyed or degraded it. For more technologically-dependent metrics (e.g., CO_2 emissions, plastics, pesticides, consumption and use of minerals and metals), better efficiencies might reverse their adverse trends faster than we expect.

TABLE 3 | Periods where improvement might have occurred had there been no population growth.

Metric, 1970–2020	Period with decreasing per capita impact	Amount metric might have improved if there was no population growth
Living Planet Index	2012–2018	3% recovery of the Index
CO_2 emissions	2011–2020	9% decrease in emissions
Energy use	1979–1983	7% decrease in energy use
Ecological footprint	1989–1993	8% contraction of footprint
Freshwater use	1975–2005	16% decrease in water use
Mineral extraction	1978–1982	10% less extraction
Plastics production	2006–2007	6% less production (and waste)
Agricultural pesticides	2008–2009	5% reduction

Note: The causes of these hypothetical improvements are decreases in per capita impact. See methods section for formulas involved.

4 | Discussion

Our results suggest that ever-increasing levels of population and resource consumption are not in the interests of future generations, and not the way to sustainability. Helping population growth end and gently and justly reverse, while also moderating per capita impacts, is our best hope to secure a sustainable, desirable future worldwide. Problems and their solutions will vary among regions, nations, and communities. At all these scales, research is needed to characterize and address adverse trends. But our global view suggests the general, long-term picture for the metrics we have presented.

As Table 1 shows, population growth has been the main driver by far for five of eight important environmental impacts (Living Planet Index decline and increases in CO_2 emissions, total energy use, ecological footprint, and freshwater use). For two other metrics (mineral extraction and pesticide use), population growth and per capita consumption increases have been the twin drivers. Population growth also contributed to the doubling of plastics production and pollution, but greatly increased per capita consumption appears as the main driver of plastics.

In the data shown in Figures 1–8, the near-perfect correlations arise from fairly direct causation; all have p values below 0.000001, with R reporting many as below its display floor of 2.2e−16. These close correlations are a function of clear causality. Global environmental problems are caused by people, nothing else. The more of us there are, the greater our overall economic demands and the greater the associated environmental problems. The larger the population, the more total energy consumption by people, CO_2 emissions from our fossil fuel engines, loss of natural habitat and biodiversity as we appropriate land for agriculture, buildings, roads, and so on. The more people, the more fresh water is used, the more minerals are extracted, and the more pesticide and plastics pollution.

TABLE 4 | Projected outcomes for 2100 and 2200 under three global Total Fertility Rates scenarios.

		2100			2200		
Metric	**2020**	**UN High**	**UN Low**	**IHME Fastest**	**UN High**	**UN Low**	**IHME Fastest**
Global total fertility rate	2.32	2.25	1.63	1.60	2.35	1.85	2.10
Global population (billions)	7.9	11.4	9.0	6.9	21.2	3.2	4.1
Living Planet Index (1970 = 1)	0.27	0.13	0.21	0.35	0.04	1.48	0.92
CO_2 emissions (billion mt)	32	51	39	29	97	12	16
Energy use total (exajoules)	566	886	673	486	1,756	158	238
Ecological footprint (billion gha)	20	30	24	18	57	8	11
Freshwater use (billion m^3)	4,007	5,369	4,539	3,813	8,757	2,533	2,884
Mineral extraction (billion mt)	55	115	70	40	427	8	13
Plastics production (million mt)	460	1,661	754	310	13,223	24	54
Agricultural pesticide (million mt)	3.4	5.9	4.3	2.8	12.6	0.3	0.9

Note: "UN High" and "UN Low" projections for 2100 from UNDESA (2024). The 2200 fertility and population projections are also from UNDESA (2004). The "IHME Fastest" is the fastest progress scenario from IHME (2020).

Technological, social, and economic factors have deflected each of these trends upwards or downwards, year by year, region by region. Still, the power of population growth, along with any increases in per capita impacts, shapes the trends shown here. Population density obviously increases with population growth. Water pollution has been curtailed in many areas but is on the rise globally (UNESCO 2023). Numbers of armed conflicts (UCDP 2023), nearly half of which are linked to resource scarcities (UN 2021), also correlate somewhat strongly with population growth. More studies are likely to find more metrics strongly linked to changes in population size and per capita impacts.

The per capita impacts (Table 2) also bear reflection. Average CO_2 emissions are 4 t annually per person; 14 t for the average person in the USA (International Energy Agency 2025b). Imagine 7 t of minerals mined: an amount of ore with the weight of several automobiles. Sixty kg of plastics are produced for the average person each year, and much more than 60 kg for the affluent, with too much of it escaping as waste into the environment. We need more progress toward "Responsible Consumption and Production," the 12th goal of the United Nations' 17 Sustainable Development Goals.

Still, there are encouraging signs. Table 3 names periods for each metric when improvement would have occurred had there been no population growth. Global fertility rates continue to decline toward replacement level, and this has contributed to declines in both child mortality rates and poverty (see for example Wietzke 2020). Literacy rates continue to improve (World Bank Group 2025). Ozone layer recovery is said to be "on track" (UNEP 2023). Per capita freshwater use is declining due to increased efficiencies. Fine particulate matter air pollution (PM 2.5) shows a slight decrease even with population growth (World Bank Group 2025).

Efforts to use resources more conservatively have been ongoing for decades, and those efforts must certainly have served to keep per capita impacts from being even higher than they are. Better technology can play a role, whether for non-fossil fuel energy sources (decarbonization), greater fuel efficiency, more efficient irrigation systems, recycling of metals and plastics, and so on. A circular economy approach could help, keeping materials in use, trimming waste, and reducing adverse impacts on the environment. Still, we ought not to expect technological innovation on its own to solve the problems produced by large populations and their per capita impacts. Carbon capture technology is advancing, for example, but it removes only a miniscule fraction, on the order of millions of tonnes, of the billions of tons of global CO_2 emissions (The Energy Institute 2025). As we have seen, even significant reductions in per capita impacts can be overwhelmed by population growth.

What kind of world do we want for the children of the future? Most people would opt for a world free of resource conflicts and poverty, a world of thriving nature and a stable climate. But as seen by the trends graphed here, our efforts are not urgent enough.

Consider where the arcs of these metrics will go if we accept global population settling at over 10 billion by 2100 or continuing to rise beyond that. Table 4 shows a projected 21 billion people by 2200 under the UN High fertility scenario, reducing the Living Planet Index to just 0.05 (compared to 1.00 in 1970). Even the 11.4 billion projection for 2100 might deplete that Index to half its current value and produce a world with nearly double the current CO_2 emissions, energy and pesticide use, and quadrupled plastics waste. For projections to the year 2100, only 1 of the 3 scenarios in Table 4 forecast recovery from the adverse trends we have described in our Results. That scenario is the "IHME Fastest," with a global population of 6.9 billion at 2100.

The years 2100 and especially 2200 may seem far in the future. But navigating in fog is preferable to abandoning the wheelhouse and sailing randomly, then suffering the consequences imposed by biophysical realities on a finite planet (Rees 2023b). The numbers in Table 4 warn of degradation or even catastrophe on many fronts if population continues to grow. Gently reversing population growth is the better course. Embracing a smaller population may seem discouraging or strange, as we have lived in an era of rapid global population increase. But the global population quadrupled over the past century, and that is a much more disruptive change than if population were to shrink by half over the next 170 years. Easing to a smaller and sustainable population would not deprive additional billions of life but instead ensure that when they do arrive conditions will be good.

The fear of aging populations leading to economic decline is not well-supported. From 1970 to 2020, the percentage of the working age population declined, globally, from ~77% to ~55%. During the same period, the global GDP per capita (in constant 2015 US$) increased from $4,960 to $10,569 (World Bank Group 2025). In other words, even though the global population is in an aging phase, the numerically average person has become twice as prosperous see the World Bank Group (2025) indicators "Age dependency ratio" and "GDP per capita". In fact, contrary to popular belief, the progression to lower populations can improve economic well-being. Many countries with declining populations have seen increases in per capita GDP, work participation, and real wages (Lianos et al. 2023).

Achieving the UN low fertility scenario would be preferable to settling for its median or high fertility scenarios. Even better would be significant global sub-replacement fertility sooner, as in the IHME Fastest scenario discussed above. There is considerable evidence this could be achieved quickly and non-coercively, by fulfilling women's and couples' unmet needs for reproductive health services and by improving girls' educational opportunities, especially in poorer countries (Hardee et al. 2014). Over the past 25 years, global total fertility dropped from 2.75 to 2.25 (UNDESA 2025). Continuing that drop for another 25 years brings us to a global average of 1.75 children per woman. We are already slowly progressing toward such a rate by the sum of billions of individuals' choices; this could be accelerated with the right non-coercive policies and support. Most world regions have already achieved it and continue to prosper. The list includes China (TFR 0.999 as of 2023), Japan (1.21), Europe, Northern America (a UN designation, does not include Central America), Australia and New Zealand (1.48), and South America (1.71; all data from UNDESA 2024).

When women are free to decide how many children to have, fertility rates tend to fall toward replacement level or below, often rapidly (see a meta-analysis of 508 studies worldwide by D'Souza et al. 2022). Iran needed only 9 years to accomplish this, once the nation made a concerted effort to promote family planning (4.08 in 1992 to 1.94 in 2001); South Korea took 12 years (4.07 in 1972, 1.93 in 1984); and Tunisia 15 years (4.10 in 1987, 1.97 in 2002). Other countries took longer: Costa Rica, for example, took 37 years of family planning promotion to achieve sub-replacement fertility (4.16 in 1972, 1.98 in 2009). But the trends are clear. Europe achieved a TFR below 1.75 in 1990 and has settled to below 1.50 since then. By 2020, North America had reduced its TFR to 1.63, while Latin America and the Caribbean was at 1.89 and on track for a TFR of 1.75 by 2030 or soon after. We see also that once fertility declines to sub-replacement levels, it tends to stay there, with only minor oscillations.

Still, globally, over 200 million women do not have access to the family planning services they need (Anderson and Johnston 2023). Africa averaged 4.2 children per woman as of 2022, and its population growth of 2.37% per year forecasts a doubling in 30 years. Though progress has been made (TFR was 5.2 in 2000), more and quicker progress could be achieved with increased family planning availability, improved educational opportunities, and more awareness of the benefits of small families (Götmark and Andersson 2022), including poverty reduction (Eastwood and Lipton 1999; Speidel and O'Sullivan 2023). Kerala state in India, for example, achieved sub-replacement fertility three decades ago (Nair 2010), driven by higher education, female empowerment, delayed marriage, smaller family norms, and extensive access to voluntary family planning (UNFPA 2025; Rajan 2025), and has risen from one of the poorest to one of the most prosperous Indian states (Thomas 2021). Worldwide, smaller families have more income per child, infrastructure can catch up to demand, and child survival increases (UNDESA 2024). A study of 172 countries (Ahmed et al. 2012) estimated that meeting unmet contraceptive needs could prevent almost 2 million neonatal and infant deaths per year.

As for excessive per capita impacts, ever-growing wealth and consumption are not ecologically sustainable, and the sooner our societies grapple with this inconvenient truth, the better (Hickel 2020; Rees 2023c). Fortunately, there are signs that excessive per capita impacts can be reined in, either by individuals' choices (Daly and Farley 2010) or by goals and policies. Think of the benefits accruing from long-accepted standards on land use, curbs on pollution, energy efficiency targets, and quotas limiting amounts and means of extraction of resources ranging from fish to forest. In view of the adverse trends we have presented, we need more of these measures, and sometimes stronger ones, whether at the local, national, or international levels.

5 | Conclusion

Gently ending and reversing population growth and moderating per capita impacts is a pro-nature and pro-human strategy. It will ease pressure on natural resources, lessen poverty in high fertility regions by way of smaller family sizes, reduce pollution, reduce resource and immigration conflicts, and improve quality of life in densely populated areas. A more modest population (e.g., gently easing population to 4 billion by 2200) would protect Earth's natural heritage, including its wild habitats, wild species, and its climate. Such a world is within our grasp.

Author Contributions

Philip Cafaro: validation, methodology, writing – original draft, writing – review and editing. **Jane O'Sullivan:** validation, methodology, writing – original draft, writing – review and editing, investigation. **William Rees:** writing – original draft, writing – review and editing, validation. **Mark Keegan:** writing – original draft, writing – review and editing, conceptualization, methodology, formal analysis, data curation, validation, investigation, project administration, supervision, software, resources, visualization. **Anastasia Pseiridis:** funding acquisition, writing – original draft, writing – review and editing. **Estelle Monique Sidze:** writing – original draft. **Lawrence Whitmore:** writing – original draft. **Enrique J. Derlindati:** writing – original draft. **Mohammad Mainul Islam:** writing – original draft. **Khaoula Houssini:** writing – original draft. **S. Irudaya Rajan:** writing – original draft.

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Conflicts of Interest

The authors declare no conflicts of interest.

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