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# Planetary Overload, Limits to Growth and Health

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**Abstract** Since the use of atomic weapons in 1945 visionaries have warned that without major changes the survival of global civilization is in question. These concerns deepened in following decades, during the Cold War, with *The Limits to Growth*, the best-selling environmental book of the 1970s. Yet, since then, most concern has faded, fuelled by technological developments and a shift in dominant global ideology. Public health, with a few exceptions (one of which is the book *Planetary Overload*), has been slow to recognize this debate, even as evidence emerges that civilization may indeed be at risk, driven by an increasingly ominous complex of events. This article outlines the key relevant literature and concepts, attempting to bring emerging and future health consequences to the attention of health workers, including the idea of a "social vaccine," conveying sufficient anxiety to provoke action for environmental protection, but insufficient to induce paralysis.

**Keywords** Anthropocene · Civilization collapse · Climate change · Conflict · Environmental determinism · Human carrying capacity

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## Introduction

Since the use of atomic weapons in 1945, visionaries including leading scientists and philosophers have warned that without major changes in human behavior the survival of civilization is in doubt [1, 2]. These concerns increased in the 1960s and 1970s, when the best-selling environmental book of the time was called *The Limits to Growth* [3]. Yet, since about 1980, most anxiety about potential civilization collapse has dissipated, driven by a confluence of technological and social determinants. The most important of these reassuring factors include the slowing in the rate of population growth (in part due to the invention of oral contraceptives), the fall in the price of oil following the second oil shock in the 1970s [4] and the Green Revolution, which enabled more food to be grown in a given area and helped avert famines [5]. In recent decades these successes have been compounded by the astonishing increase in the power of computers and robotics, enabling remarkable, though uneven, levels of material affluence. Also important was the end of the Cold War in 1989.

However, many of the underlying problems that were apparent in the decades that followed World War II persist. The number of states armed with nuclear weapons has increased from one to at least nine, and global population still rises by over 80 million per annum [6]. In the last two decades, five major events should have made even optimists reconsider. These events can be conceptualized as an emerging "complex", the elements of which co-evolve and are not independent.

The first is the attack on two major US cities in 2001, showing the ruthlessness and ingenuity of fanatical terrorists. Although not the first assault on a high-income country linked to radical Islamism, its scale and audacity was unprecedented, and a major trigger for the ensuing "war on terror" which still continues. The second factor was the steep rise in the price of

oil from 2006, cresting at over US $140/barrel in 2008. This rise is consistent with long-expressed concerns over peak oil [7] and Limits to Growth [3]. The third element was the global financial crisis of 2008, puncturing the complacency, then dominant, that the errors of the Great Recession could never be repeated [8]. This was soon followed by the outbreak of civil war in Syria. There have been many other examples of state failure, such as in Somalia, but Syria is at Europe's door. Though not fully "developed", Syria is nowhere as poor as other failed states [9]. Syria is now a major source of refugees, in the worst refugee crisis since the Second World War, added to by people fleeing intractable poverty and environmental degradation in the Sahel and other parts of the Middle East [10]. The number of refugees in the world is identified here as the fourth major element for concern. Throughout this period, evidence of climate change, a fifth major factor has steadily accumulated [11].

Public health, with limited exceptions (one of which is the book *Planetary Overload* [12]), has been slow to recognize the integrated nature of these and similar elements and their relevance to population health this century, even though concern for the durability of planetary civilization is gradually reviving outside health. This article explores ways that these issues are connected and attempts to bring their emerging and future health consequences to the attention of health workers. It starts with an anecdote, illustrating some of these links, focusing on a wildfire in Canada.

## Linking Climate Change, Wildfires, and Peak Oil with Human Well-Being

In May 2016, a devastating wildfire overran Fort McMurray, a Canadian boom town enriched by the exploitation of "oil sands", once better known as tar or bituminous sands [13]. The fossil fuel embedded in these sands must be mined, heated, and then refined to form crude oil, before further processing to make useful products [14]. The steps in these processes are energy-intensive. The "energy return on energy investment" (EROEI) of oil sands is as low as three or four [14, 15]. In comparison, the first oil wells dug in the USA in the nineteenth century, which gushed skywards from their own pressure, had an EROEI exceeding 100 [15]. An EROEI for oil sands even of four is optimistic; for example it excludes the energy used to construct and supply remote cities like Fort McMurray. It also excludes negative externalities such as water pollution and the suffering and ill health experienced by indigenous people who are witnessing the desecration of their ancestral lands.

As concerns for peak oil rose early this century [7, 16], followed by the steep rise in the oil price in 2008, at least US $100 billion were invested in creating the oil sands industry in the sub-Arctic boreal forest [17, 18]. Such investment provides considerable employment, boosting human well-being. But such well-being is fragile. The petroleum used, refined, and produced in this region, though a tiny fraction of the global total, has exacerbated climate change, which in turn was, almost certainly, a factor in the May 2016 forest fire [19–21]. Maximum local temperatures on the day Fort McMurray was evacuated exceeded 32 °C (90 °F), as much as 20 °C (30–35 °F) above normal for that time of year. The number of evacuees approximated 80,000 people, at least ten times the number who fled the 2011 Slave Lake fire, also triggered by unseasonable warmth and dryness in the western boreal forests of Canada, and which may be regarded as a forerunner (a "canary event") [22].

Science does not rely principally on anecdotes. Although some scientists still argue that no specific extreme event (such as this fire) can be said to arise directly from climate change, an increasing number reverse the argument, proposing that climate change has "loaded the dice" so that no single extreme weather event can said to not have been influenced by climate change [23]. In this view, those who deny any attribution of climate change to such events may be making a type 1 error, i.e., they may be rejecting a genuine contribution of climate change to this, and many other extreme events [11, 23, 24•] when such a contribution truly exists.

Irrespective of whether climate change contributed to the Fort McMurray fire, the scientific evidence for climate change is now overwhelming; remaining legitimate debate concerns its severity and its consequences for the biosphere, including our own species [11, 25•]. However, whereas evidence that climate change has generally adverse effects on health is now well-established [26], there remains far less appreciation, including among health workers, that climate change constitutes only one of several elements of an even more complicated and systemic problem. This issue has many names, but here uses two longer-established terms: "planetary overload" and "limits to growth". Neither term has a precise meaning (see Table 1), but each has a respected history and the potential for wider application and revival. This article seeks both to outline the key relevant literature and concepts for these terms and to bring their emerging and future health consequences to the attention of health workers.

## Planetary Overload

More than 20 years ago, the late epidemiologist Tony McMichael [29] made the phrase "Planetary Overload" famous to a selected public health audience, publishing a book by that name in 1993 [12, 30]. Earlier in his career, McMichael had been influenced by René Dubos, the 1969 Pulitzer Prize winning microbiologist who is the father of planetary medicine and who may have coined the phrase "think global, act local" [31, 32]. Over four decades,

**Table 1** Some key terms, definitions, and references

| Term | Definition and key references |
|---|---|
| Limits to growth | The title of a popular book (published 1972), which summarized the findings of early computerized simulations of the Earth eco-social system (i.e., the interaction between the global environment and global civilization). It concluded that major policy changes are needed if civilization is to endure for many centuries, and that without such changes collapse of civilization could occur in the twenty-first century [3]. |
| Planetary overload | The title of a popular book (published 1993), written by a public health worker, which in part also warned that global civilization faces collapse from exceeding human carrying capacity [27], due to policies that fail to understand the dynamic eco-social properties of humans on a finite planet [12]. |
| Cornucopian enchantment | A term (coined in the late 1990s) that attempts to gently mock the idea that ingenuity is not only necessary but *sufficient* to overcome limits to growth [28]. It recognizes that ingenuity cannot *fully* compensate for a lack of physical resources, such as copper, oil, or biodiversity. Nor can ingenuity fully overcome selfishness and distrust. |
| Human carrying capacity | The limit to the "person years of affluence" which can exist on Earth at any one time. It can be increased by ingenuity and cooperation, but not infinitely. It can be reduced by conflict and adverse environmental change [27]. Technically, it can be considered as the interaction between five forms of wealth, sometimes called human, natural, social, built, and financial capital. Moral capital could be proposed as a sixth dimension; however, it can also be considered a category of social capital as it is so important for cooperation. |
| Ingenuity | The human capacity of invention and adaptation. |

McMichael strived to make these issues comprehensible, accessible, and compelling to a wider audience, particularly of health professionals [33]. His book is wide-reaching, but its title summarizes its central message. McMichael warned, that "business as usual" could destroy human civilization, by eroding what he called (and possibly coined) "life-support systems". By this, McMichael referred to the ecological and environmental determinants of civilization—living and non-living—rather than of life itself.

McMichael wrote "the idea that the survival of *Homo sapiens* depends upon the sustaining of ecosystems still seems a bit far-fetched" [12]. Puzzlement was indeed shared by some within epidemiology and public health, though his work had immediate impact with many, including via keynote addresses by McMichael and John Last at the 1993 International Epidemiological Association Congress [30]. Soon after, last published the groundbreaking book *Public Health and Human Ecology* [34].

This article next reflects on some of the key issues relevant to *Planetary Overload*, before discussing the relevance of *Limits to Growth* to health. It concludes with a brief discussion of the contemporary relevance of these topics to public health.

## Population, Affluence, and Consumption

LMcMichael's book (and the earlier *The Limits to Growth*, to be discussed in a following section) is relevant to the balance between population and environment, as is the work of Thomas Robert Malthus (1766–1834) [35] and many scholars before and since [36, 37, 38••]. Malthus is mainly remembered for his prediction that human population growth (if left unchecked) would outstrip increase in the food supply, leading to a reduction in human population size. Within two decades of Malthus's death, the devastating Irish famine appeared to confirm his main hypothesis, though critics pointed instead to social, political, and economic factors, particularly the inadequate scale of relief from England, then not only politically tied to Ireland, as a colonial power, but also the richest country on Earth.

However, although it is true that most famines involve a combination of social and political, together with agricultural and climatic factors, Malthus' key insight can be distilled as the fact that species compete for scarce resources. This principle is central to theory of evolution by natural selection, and a debt to Malthus was freely acknowledged by both Darwin and Wallace [39].

Critics concerned with issues of global sustainability have often been characterized as simplistically focusing on human population size or even "environmental determinism" [40], but such accusations are very rarely justified when the published evidence is fairly considered, at least in peer reviewed papers. For example, Paul Ehrlich, author of The Population Bomb [41] and probably the most vilified such critic [38••], more than 40 years ago co-created the formula I = PAT, which acknowledges affluence (A) and technology (T) as influencing total environmental impact (I), along with population (P) [42]. In turn, affluence is a proxy of consumption, as has long been recognized by some within population health [43]. McMichael's book *Planetary Overload*, along with virtually all other leading literature relevant to sustainability science, accepts that population is of central importance, but that sustainability has many other determinants.

Technology can, in theory, offset the impact of population, by generating affluence with lower environmental harm. For example, many modern appliances (e.g., lights, cars, refrigerators) are less energy intensive than in the past. But some technologies (e.g., chain saws, bulldozers, and factory-fishing fleets, air travel) amplify environmental impact. In recent decades, environmental impact has grown enormously, driven by increased population, increased affluence, and more powerful technology. Furthermore, not only has population increased approximately 40-fold in the last two millennia to almost 7.5 billion today, but average global life expectancy has also risen [6], meaning that person-years of life have expanded, and hence person-years of consumption.

To fuel affluence, population and technology have increased the human impact on the environment, via energy, and other resources enabling the transformation of the biosphere [44]. Humans now drain not only rivers, but whole aquifers, by, for instance, using electricity to extract water from deep underground in the north west of India [45]—a resource that is not replenished on the time-scale in which it can be exploited. The misuse of technology has polluted much of the biosphere and the marine food web with plastic [46]. Some of this transformation has also been inadvertent, such as from cascades of ecosystem change following the introduction, both deliberate and inadvertent, of foreign species such as rabbits and foxes and pathogens such as smallpox [47].

There are repeated claims of the "decoupling" of economic "growth" (i.e., as measured non-ecologically) [48] from environmental harm, by developing technologies that use renewable energy, and thus preserve or enhance affluence with less environmental damage, and a lower carbon footprint. However, although some decoupling has occurred, including such as from increased energy efficiency and the development of the Internet (reducing communication cost), environmental impact continues to rise, though at a declining rate per person in many technically advanced nations [49]. However, some technologies such as electric cars may make a substantial contribution to decoupling, even using life-cycle analysis, provided their batteries are recharged using renewable sources of power [50].

## The Limits to Growth

Many of the core concepts of *Planetary Overload* [12] were once much better known outside public health, particularly its best known antecedent "Limits to Growth". This phrase was popularized as the title of the best-selling book of that name, commissioned by the Club of Rome and published several years later in 1972 [3]. Led by the charismatic Donella Meadows [51], the book used a systems approach and a computerized simulation of the interactions between the planet and the human system we call civilization. This was groundbreaking at the time. The book warned that, without radical reform, civilization faced collapse, perhaps by about 2050. These central conclusions have been repeatedly endorsed [37, 38••, 52–54], though by relatively few public health workers [55–57].

The concerns raised in *The Limits to Growth* were once endorsed at the highest political levels, including by UN Secretary General U Thant [3] and Pope Paul VI [58•]. *The Global 2000 Study*, initiated by US President Jimmy Carter in 1977 [59] is another example. The purpose of this study was to report on "probable changes in the world's population, natural resources, and environment through the end of the [20th] century" [59] It became one of the most popular reports ever produced by the US government, selling 1.5 million copies, before losing its influence during the presidency of Ronald Reagan [28], whose election coincided approximately with the "cornucopian enchantment", (see Table 1) a view that human ingenuity is not only necessary but sufficient to overcome scarcity [60].

The late twentieth century strengthened the belief that environmental limits could be indefinitely overcome strengthened, fuelled by cheap oil, the Green revolution, and wider use of family planning. By the 1990s, the central message of *Limits to Growth* was ridiculed by some influential people and magazines, including The Economist [53, 61–63].

*The Limits to Growth* had little discussion of climate change but recognized that population growth, combined with industrialization, resource scarcity, and environmental decline had the capacity to lead to "overshoot" followed by collapse [63, 64]. Climate change is rarely considered a form of pollution, presumably because most of the gases that drive it (carbon dioxide, methane, and nitrous oxide) are invisible and odorless. Nonetheless, these gases accumulate as a consequence of the burning of fossil fuels such as coal and oil (for power, transport, and industry), aggravated by forest clearance expansion of agriculture and industrialization [11].

## Limits to Growth and Ecosystem Services

The *Limits to Growth* referred to many other forms of pollution, local and regional, including "novel entities" [65] ranging from endocrine disruptors to radiation. Pesticides, most recently neonicotinoids, have contributed to colony collapse disorder, and thus constitute a severe threat to bees and their ecosystem services to humanity, especially pollination [66•]. This has been exacerbated by "bee overload", including the pitiless and relentless of trucking of hives, already exhausted, across vast distances. Bees, too, have limits [66•], as do many other ecosystem services [67].

There are many functions and resources that are limited (Table 2). Some of these are physical, both renewable (such as biodiversity) and non-renewable, such as affordable energy

**Table 2** Key resources that are limited, their health benefits, and their risks from growing scarcity

| Resource/entity (key references) | Health and other benefits | Main identified health risk of growing scarcity |
|---|---|---|
| Fossil fuels and other mined sources of energy [68] | Much of civilization: cooking, industry, trade, and travel, regulation of interior temperature | Energy wars, energy scarcity, and poverty for vulnerable populations, use of energy-intensive sources (e.g., oil sands), financial instability, diversion of food crops to fuel |
| Greenhouse gas absorptive capacity of the biosphere [69] | Helps to limit runaway climate change [69] | Marked sea level rise, extreme weather events such as heatwaves, droughts, floods, fires and storms, conflict, heat stress, rising food prices |
| Absorptive capacity of the biosphere for other wastes [69] | Reduces pollution | Contamination of species, including of humans, with harmful substances, including electronic waste |
| Phosphorus [70] | Food security: an essential element | Rising prices leading to reduced crop yields, more undernourishment of the poor and will help limit Green Revolution in Africa |
| Other metals and raw materials, including rare earths [71, 72] | Much of civilization: cities, modern communications including mobile phones and computers | Rising prices leading to inferior products; trade wars and possible conflict concerning rare earths |
| Biological diversity [67, 73] | Many ecosystem services, including potential novel pharmaceuticals and human colonization of new territory | Lost ecosystem services, potentially catastrophic in some ecosystems, emergence of some diseases [73], solastalgia, and other forms of mourning for lost nature |
| Crop yield growth [74] | Food security, protection of forests, and wilderness | Rising food prices, more undernourishment of the poor, use of agriculturally marginal land |
| Freshwater including in aquifers [75] | Much of civilization: food security, industrial production, hydro-electricity | Food insecurity, increased water washed diseases, economic collapse [75], water wars [76] |
| Cooperation [77] | Much of civilization: societies, productive Lprocesses, defense forces, and alliances | Tension, hostility, conflict, in some cases genocide, and in the worst case global war; with numerous adverse health effects [78] including adverse mental health |
| Complexity of human systems [79] | Much of civilization | Reduced efficiencies, stress on vulnerable and poor minorities |
| Ingenuity | Much of civilization | Civilization's collapse |

from fossil fuels, for use by industry, individuals and households. Energy scarcity has received more attention in public-health circles than the other aspects of the limits to growth, including a special issue on peak oil in the American Journal of Public Health [18].

## Ingenuity, Peak Oil, and Climate Change

The reality of "peak oil" has been challenged as the price has fallen in recent years. But this fall will not be perpetual. The huge Gharwar oilfield, located in the Eastern Province of Saudi Arabia, was reported, in a 2014 paper, as being injected with seven million barrels of sea water per day, in order to maintain oil extraction by increasing the pressure in the reservoir, forcing oil to the surface. This energy-intensive technique reduces the EROEI, increases the extraction rate, and will only accelerate its depletion [80]. This is an illustration of human ingenuity [61] but only overcomes scarcity temporarily.

Further, if additional oil reserves can be found, their exploitation will be greatly limited by the imperative to slow the rate of $CO_2$ accumulation [81] and the limited capacity of the biosphere to absorb greenhouse gases, whether in the ocean or on land. This non-finite "sink capacity" is another limit to growth; put differently, Earth does not have an infinite waste bin.

As climate change accelerates, so does sea-level rise [25•]. The rate of $CO_2$ accumulation is now at a record high [82] and there are increasing fears that some of this increase is from positive (reinforcing) feedbacks, releasing stored carbon, such as from the tundra, marine hydrates, forest, and peat [83, 84].

## Limits to Cooperation; Conflict and Complexity

There are also limits to human's collective capacity to deal with multiple crises. Terrorism and the global financial crisis are two cases in which deep problems in human society have undermined attempts to solve other problems in the human system, such as poverty and inequality. The current refugee crisis in Europe (and elsewhere) and rising xenophobia in much of the world are arguably themselves influenced by climate change and other aspects of limits to growth, including

aquifer exhaustion in Syria [85•] and insufficient social tolerance. They are also products of poor leadership, one aspect of which has been high-level denial of *Limits to Growth* in recent decades. Many leaders have also been inappropriately pronatalist, including in many sub-Saharan nations. Others have been quick to turn to violence, or to favor minorities who inflame tensions. Terrorism has also been argued as linked to inequality in the global eco-social system [86, 87].

Environmental degradation is well documented as contributing to the collapse of many past civilizations. Examples include from soil salinity [88], drought, and volcanic eruptions [89, 90]. However, social factors that interact with environmental changes are also important [91]. The anthropologist and historian, Joseph Tainter has suggested that a unifying theory to explain the collapse of many past civilizations is a reduction in the marginal return to societies from a marginal increase in complexity. Note that returns to investment may fail because of pollution, climate change, or another environmental factor. In the early stages of a civilization's growth, complexity increases, but the marginal return on additional effort is still positive, so that society prospers. However, beyond a threshold, Tainter argues, the benefits of additional complexity fade, allowing the emergence of dynamic processes that, if not altered, harm civilization. This can lead, in some cases, to vulnerability, conflict, and invasion [79].

Two decades ago, the trajectory of modern civilization appeared to some to be inexorably global and upward. Today, more regions are succumbing to lawlessness, conflict, no-fly zones, authoritarianism, and states of emergency, a global milieu not forecast by optimists but long predicted by a minority such as Meadows and McMichael. As the global population and its impact increases, more and more authorities are sounding the alarm [92].

## The Impact of *Planetary Overload*

Outside public health, *Planetary Overload*, published at the height of the "cornucopian enchantment", had little impact. Yet, the war in Syria, the increased fortification of national boundaries, even in Europe, the continual press of new refugees, including from the Sahel [36, 93], and the steadily accumulating months of record temperatures and extreme weather events are of concern. Despite the hope of the 2015 Paris agreement concerning climate change, critically dangerous climate change now appears almost inevitable [11], not least as the Paris agreement relies on an unproven, ambitious technology to extract carbon pollution from the atmosphere, called BECCS (biomass energy carbon capture and storage). According to leading climate scientist and BECCS critic Kevin Anderson, this technology will apportion:

> "huge swathes of the planet's landmass to the growing of bioenergy crops (from big trees to tall grasses) — which absorb carbon dioxide through photosynthesis as they grow. Periodically, these crops will be harvested, processed for worldwide travel before finally being combusted in thermal power stations. The $CO_2$ will then be stripped from the waste gases, compressed (almost to a liquid), pumped through large pipes over potentially very long distances and finally stored deep underground in various geological formations (from exhausted oil and gas reservoirs through to saline aquifers) for a millennium or so" [94].

Civilization, now in the Anthropocene [92], is in danger of missing the crucial opportunity once given to it by the authors of the Limits to Growth (a book widely known at the time) and by McMichael, whose book was less widely known. Continuing expansion of the human population and its impact cannot be taken for granted—as these two seminal works made clear. Sufficiently severe declines in the ecological determinants of civilization could not only reduce population size but cause catastrophic harm to most indicators of human health. We could be approaching a massive loss of human numbers in a proportion that matches that which occurred during the Black Death [95].

While this could happen through a series of epidemics or mass starvation, slowly unfolding against a background of spreading failed states [95], a less drawn-out route would be through conflict, including via displacement and increased competition for resources. Although Pinker has argued that violence has recently declined [77], the twentieth century experienced two catastrophic wars. The chance of a limited nuclear war cannot be dismissed [96], nor can the use of "dirty bombs" or other nuclear weapons by terrorists [97].

However, despite the possibility that this century could see a massive reduction in the number of our species, we cannot sink into despair. Could civilization yet be saved?

## Solutions

In coming decades, Fort McMurray, the Canadian city whose size depended on the mining and refining of oil sands, may have shrunk to close to its former size, as the falling price of renewable energy continues to out-compete that from fossil fuel. Many who have lost fossil-fuel related livelihoods could be engaged in the renewable energy revolution that is now emerging. For those still living in the boreal forest, partial solutions to fires, driven by ingenuity, can still be imagined. Fires fuelled by drought and higher temperatures, themselves underpinned by climate change, may be partly offset by the planting of less fire-prone deciduous species, especially around towns [19]. Small numbers of people may live

underground, as already occurs in some desert locations in Australia, such as the mining town of Coober Pedy. In this way, even tornados and lightning sparked by future fires [98–100] could be survivable. However, such adaptations seem scarcely feasible at the scale civilization will need.

Humanity will need to do much more than cope with more mega-fires. It will need to humanely resettle millions of people displaced by coastal and island retreat, sea-level rise, and conflict spurred by climate change and drought [76, 78, 85•]. We will have to promote family planning and other determinants to make the demographic transition possible in terrains that are not only physically harsh but hostile to the rights of women, such as the Sahel [36]. We will have to distribute food on a global scale especially during times of widely dispersed El Niño-driven drought and food scarcity, such as in 2016, when the regions affected included Ethiopia, Malawi, New Guinea, and Vietnam. We will also, very probably, have to find substitutes for former bread baskets and food bowls, such as the Mekong delta, which is already becoming contaminated by salinity [101].

Other promising adaptations exist for the human diet. A large fraction of the global population ingests more animal products than are necessary. Meat production is at a level now that causes substantial harm to the ecology, the climate, and to human population health [102]. Beneficial health consequences of meat consumption are doubtful, as demonstrated by the many studies that show greater life expectancy among vegetarians and vegans [103, 104]. As a result, some have argued for a "contract and convergence" policy, by which populations with a high rate of meat ingestion improve their health and the environment by lowering their intake, especially of beef and sheep meat [102]. At the same time, many populations ingest a level of animal products which is probably inadequate for health. Increasing their intake of meat and dairy from almost zero may benefit health, especially if combined with the reduction and treatment of chronic parasitic infections such as hookworm which deplete iron stores. Combined, this contract and converge policy would improve global health and simultaneously help preserve existing ecological integrity. Encouragingly, revised dietary guidelines released in 2016 by the Chinese health ministry will, if followed, reduce meat consumption in China by 50 %, to between 40 and 75 g per day [105]. The large size of China's population makes this decision of global importance.

Widespread corruption limits the paying of taxes and this, in turn, erodes public goods, and thus contributes to public-health catastrophes from the Ebola outbreak in West Africa [106] to extremely drug-resistant tuberculosis in Papua New Guinea [107]. Corruption may yet be reduced by more determined global governance when citizens, empowered by the internet and education, and also benefiting from the demographic dividend [108], effectively demand greater equality and transparency.

A rapid energy transition (especially solar and wind) might allow us to keep within our carbon budget [108]. Geo-engineering solutions have been proposed such as attempts to cool Earth by injecting aerosols into the stratosphere, thus reducing the penetration of solar radiation [109]. Another form of geo-engineering that has been proposed is to fertilize the oceans with iron, in an attempt to increase photosynthesis, so that the additional algae that is grown falls to the ocean floor sequestering large amounts of carbon [110]. Geo-engineering is certainly another form of ingenuity, and may alleviate some of the effects of greenhouse gas accumulation and climate change, even if the carbon budget is exceeded [109]. However, it remains to be seen if this can rescue us; all of its current forms have serious drawbacks [27], including no known proposal to reduce ocean acidification.

Research funding agencies, such as the Wellcome Trust can help to identify predictors and find solutions. Although the problems of planetary overload and limits to growth are not identical to infectious diseases there are some similarities, as there are to the epidemic of chronic diseases. Education of public health professionals is an important contribution [93], as will be interdisciplinary, truly integrative reviewers, and journals.

## Conclusion

McMichael made the phrase "planetary overload" famous to some more than 20 years ago. Though enlightening and innovative for its mainly public health audiences, its core concepts were once more widely known, including at the highest political levels, by the term "Limits to Growth". His book was published at a time when contemplation of collapse seemed almost fantastic—and certainly not favored [111]—especially collapse that results from climate change and its downstream catastrophes. Outside public health, *Planetary Overload* had little impact, an opportunity whose loss is increasingly obvious; however, while we cannot avoid critically dangerous climate change, we might still create opportunities to save civilization, and to also avoid the worst harm to nature.

Understanding these linked issues is vital if global population health is to endure. The topic is unsettling. It is important that health workers who grapple with the implications of these topics do not transmit pessimism. Equally, however, they should not project complacency. A "social vaccine" could help, conveying sufficient concern (a social antigen) to motivate action, but not so much to cause despair [112]. Encouragingly, many other sectors and powerful individuals are starting to realize the risk we face, at least from climate change; including Mark Carney, governor of the Bank of England, and Pope Francis [58•, 113••]. Such leaders have genuine influence.

Yet, despite so much evidence, the issues of planetary overload and limits to growth remain peripheral to most health workers, including to the framers of most public health conferences, who appear to still regard these issues as boutique. A heartening exception is a recent report by the Canadian Public Health Association [114]. Funding for these multidisciplinary issues has also been scarce, though the Wellcome Trust's recent round called "Our Planet Our Health" is welcome, as is support from the Rockefeller Foundation and The Lancet for the Planetary Health Commission [115]. Future Earth Health may consider these issues, complementing those of Health-Earth, which is a unique network of workers in public health, environmental science, and epidemiology founded in 2014 [93]. Time is short; there is much to be done. Enormous opportunities lie ahead, if they can be grasped. These issues must be central to twenty-first century public health; if not, we may not have public health worthy of that name in the twenty-second century.

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**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

## References

Papers of Particular Interest, Published recently, Have Been Highlighted as:
- • Of importance
- •• Of major importance


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