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The Journal of Population and Sustainability

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Editorial introduction

David Samways – Editor

The previous issue of the JP&S (Vol.4 No.2) was published in the midst of the COVID-19 pandemic and as I write, although hope in the form of vaccines is on the horizon, the disruption and the costs to welfare (in the broadest sense) still appear to be far from drawing to an end. This issue of the JP&S could have been titled as a 'partial special issue' since of the six articles three are directly concerned with the pandemic, the lessons that can be drawn from it, and the opportunity for change that it may present. To some extent all the papers presented here touch upon issues concerning our relationship with the natural world which the COVID-19 pandemic has brought to the fore, such as the potential tension between liberal conceptions of individual freedom and collective welfare, the need for change in our socio-economic system and a need to reassess our vulnerability to natural forces that once were thought to be potentially within our control.

The idea of transcending nature and bringing it under human control is a theme familiar to scholars of the Enlightenment. The burgeoning science and technology of the modern era and the production of ever greater surpluses appeared to many thinkers to be removing humankind from the capricious forces of nature and offered the hope of a new kind of freedom. For many, this sentiment reached its apogee with this much quoted sentence from Marx's Capital Volume III.

> Freedom in this field [material existence] can only consist in socialised man, the associated producers, rationally regulating their interchange with Nature, bringing it under their common control, instead of being ruled by it as by the blind forces of Nature; (Marx, 1959 [1894] p.820)

This "Prometheanism" was considered a pernicious perspective by the founding figures of the contemporary environmental movement. Rachel Carson (1962) wrote:

> The ‘control of nature’ is a phrase conceived in arrogance, born of the Neanderthal age of biology and philosophy, when it was supposed that nature exists for the convenience of man (p.297).

The COVID-19 pandemic reminds us of the power of natural forces: while we can frequently find technical solutions – in this case a vaccine – our technical “mastery” of nature is far from complete. As William Rees’ article makes plain, population growth and density are critical vulnerabilities for any species. Rees, the co-developer of the ecological footprint concept, argues that the COVID-19 pandemic should be seen as one of the negative feedbacks consequent of our outsized footprint of which human population expansion is critical dimension. Rees takes us through a number of examples of how in nature the positive feedback of reproduction in favourable environmental conditions leads to population growth which is eventually checked by the negative feedback of the exhaustion of some fixed resource or environmental change due to population growth. Indeed, the SARS-CoV-2 virus itself demonstrates the biological principles behind any species’ population growth in conditions of resource abundance (non-resistant humans).

Rees also points out that growth in population densities beyond certain levels lead to conditions in which populations are more vulnerable to predators, which of course can include micro-organisms like the SARS-CoV-2 virus. All density-dependant species, that is those which are subject to negative feedback due to their own expanding numbers, are involved in these push-pull dynamics where numbers fluctuate up and down depending on environmental conditions around an unstable equilibrium. In nature, Rees argues, from the smallest to the largest, all organisms exhibit a “fractal geometry” in that the patterning of population dynamics differ only in temporal and spatial scale.

In the case of our own species, it is only recently (in species history terms) that our population has exponentially grown beyond the boundaries that in pre-industrial times would have corrected it to the environmental ‘carrying capacity’. Fossil fuels have been pivotal in this and allowed the ecological footprint of individuals as well as entire populations to grow. While only a fraction of the global population has until now been responsible for the vast majority of environmental degradation, the growth in consumption and populations of low and middle income countries is the present driver of humanity’s expanding footprint. As Rees observes, “the world community must confront egregious inequality and population growth as separate problems".

However, nothing can continue to grow for ever and we are now beginning to directly experience the boundaries of the ecosystem as negative feedbacks such as COVID-19 and climate change show their teeth. Rees points out that all species are ultimately subject to checks on population growth beyond carrying capacity. That human population will adjust back to a carrying capacity Rees is certain, the question is whether it is a consequence of highly unpleasant natural forces or our collective restraint on resource consumption and management toward a sustainable population.

As argued in papers in this issue and in our special issue on economic growth (Vol. 3, No. 1), this management will need to be part of a larger transformation of our social and economic systems. Marxist thinkers have frequently been the most vociferous in their claims that capitalism is economically and socially unsustainable, yet a faith in human ingenuity and the technical transcendence of natural boundaries has led the majority to a dismiss population growth as a problem. As Julian Roche argues in his paper in this issue, "Marx, population and freedom", even when Marxists have embraced ecological concerns and drawn out 'ecological' themes in Marx's writing, few have critically engaged with Marx's antipathy to Malthus regarding population growth and natural limits. Indeed, Marxists have traditionally regarded those concerned about population growth with suspicion as it has been seen as an inevitable result of capital accumulation and the social problems associated with it, such as poverty, the result of capitalist relations of production and hence distributional in nature. Moreover, Marxists have tended to subscribe to a technological optimism whereby natural limits are continuously transcended.

However, Roche notes that even when Marxist ecologists have acknowledged natural limits, the issue of population growth has largely remained unaddressed with most focussing on overconsumption in the Global North. This has tended to go hand-in-hand with a liberal human rights-based stance rejecting state interference in individual fertility decisions coupled with a reliance on the observance of demographic transition and the argument that fairer resource distribution will lead to fertility reductions as incomes rise. However, Roche points out that notwithstanding the empirically problematic nature of Marxist arguments regarding population growth, there is a basic incompatibility between liberal individual freedom and Marx's own conception of individual freedom as social, collective and positive. Roche argues that the achievement of the this unalienated freedom requires not only the transcendence of capitalist social relations, but given the acceptance of natural limits, the active transition to a smaller global population.

The COVID-19 pandemic certainly demonstrates how liberal conceptions of individual freedom are unequal to dealing with such crises. In the same vein discretionary individual responses to the environmental crisis more generally will be inadequate and changes at the social systemic level will be needed. However, the COVID-19 pandemic may well increase public concern for the environment and increase receptiveness to social systemic change.

Although it is notoriously difficult to measure public attitudes to environmental issues, prior to the pandemic in the UK there was a noticeable shift in public environmental concern, especially regarding climate change. Indeed, environmental concern was at the highest level ever recorded (Smith, 2019). However, for the majority of people concerns about relatively remote existential threats such as climate change are not foremost in their everyday consciousness. The social and physical/technical structures of everyday life (the economic system, social institutions, transport systems, energy systems etc.) mean that not only is the ability to act externally constrained but also that the habitual aspects of life from food preferences to habits of personal hygiene and comfort make changes in behaviour hard to achieve. Frequently the conditions of action are such that we have no knowledge of the potential impact of a particular action. But even when levels of environmental consciousness and behaviour are high what have become the normal expectations of life can trump these concerns, meaning that we knowingly engage in environmentally damaging actions (Alcock et al., 2017). Such behaviour is partly attributable to the problem of collective action (the personal cost of cessation is high and the environmental benefits negligible if others continue), but it also stems from our ability to simultaneously hold multiple, often incompatible and contradictory, values and act on each depending on the situation. This is not some simplistic unthinking selfishness, but a hierarchical ordering and rationalising of purposes and concerns (see Giddens 1984) in a given social context.

It is also clear that where individuals perceive the threat to be more immediate, personal and immanent – or, more powerfully still, if they have direct experience of the consequences – then they are more likely to take action or change their behaviour. A number of studies show that local and short-term environmental issues such as water and air quality are ranked as of great concern (IPSOS, 2018; McCarthy, 2019). Moreover, personal experience of a phenomena connected to a global longer-term environmental issue can have a significant positive effect on the likelihood of engaging with the issue and changing personal behaviour (Spence et al., 2011; Broomell et al., 2015; Demski et al., 2017). Indeed, the more emotionally resonant the possible consequences of action are, the more likely we are to change our behaviour. A recent paper (Schneider-Mayerson and Leong, 2020) suggests that for those aware of the issues, the most intimate and personal decision of whether to have a child is more informed by concern about the wellbeing of the potential child than concerns about the environmental impact of their offspring.

Thus, the majority of our environmental impact emanates from the habitual everyday stuff in which we are engaged, which is inextricably embedded in the social systemic context. It follows that while individual environmental consciousness and choices are important, without system change those decisions will be largely impotent. As Graeme Maxton notes in his article published here, a transition to a sustainable society...

> ...will not come about simply by encouraging people to treat the world around them with greater respect. The imperative to endlessly increase economic output makes that impossible, even before patterns of individual behaviour and the rising human population's need for more land are taken into account. To work, the change in human behaviour needs to be fundamental.

Personal experience of the COVID-19 crisis may come to represent just how disruptive to the taken-for-granted sense of ontological or psychological security anthropogenic environmental disruption can be and may represent a starting point for articulating the need for radical social and economic change.

Like Rees, Maxton sees the COVID-19 pandemic as one of a number of indicators of humanity's unsustainable encroachment on the natural world as a consequence of our economic and population growth. Maxton points to a whole range of impacts and their consequences for humanity including exposure to novel pathogens and ecosystem disruption leading to species extinctions but singles out climate change as the most pressing and immediate risk. While acknowledging the enormous social and personal cost of the pandemic, Maxton sees it as an opportunity to reset economic policy and for governments around the world to shift to a new economic system. The pandemic has forced governments to make drastic restrictions on normal social and economic behaviour, and this has had great short-term and potentially long-term environmental benefits. Importantly, this interruption and reversal of fossil-fuelled economic growth has shown that it is possible to cut carbon emissions. But perhaps most significantly, the pandemic has shown the level of investment required to tackle climate change. Maxton argues that the current economic crisis should not be seen as a problem but an opportunity. Governments should abandon the idea of returning economies to their previous size and permanently downsize them while building a system which can live within natural boundaries. To this end, governments should pay a basic income during the transition and support the new economic sectors required to address climate change. To pay for this governments should print money, and while this may lead to economic problems, Maxton is clear that such problems are easier and less costly to deal with than the run-away climate change which will indiscriminately force change upon us. COVID-19, Maxton argues, presents the opportunity to choose our fate.

Doug Booth also believes that the COVID-19 pandemic offers an opportunity to change economic direction. In "Achieving a Post-growth Green Economy" Booth blends what he calls the "post-materialist silent revolution" and the idea of a "post-growth green economy" and offers it as a framework to consider our economic and environmental future. The post-materialism thesis is based upon the research from the World Values Surveys which shows a significant increase in the number of middle-class youths who are significantly less interested in material wealth and possessions than previous generations and who also subscribe to values of freedom of expression and social tolerance and are more likely to live in high density urban environments. These factors, Booth argues, mean that, overall, the lifetime resource consumption of post-materialists is reduced.

Such changes in individual preferences and culture clearly represent a starting point for the establishment of a more sustainable society but need to be accompanied by overall change in social and economic structures. Importantly, Booth argues that post-materialists represent a political constituency to support a post-growth green economy founded on the principle that energy flows and wastes should be capped at levels which are ecologically sustainable. Booth points out that societies at the upper end of the development scale are already experiencing declining rates of growth. Importantly population growth in developed societies has slowed to very low levels and will soon be negative while economic growth has slowed to approaching 1% of GDP. Indeed, Japan has a population growth rate of zero and a GDP growth of 0.8%. A post-COVID-19 green new deal, although stimulating short-term economic growth, could decarbonise developed-world economies, while assistance to developing nations to grow and improve welfare while also simultaneously reducing their carbon footprint could be financed by the developed world at modest cost. Such development, Booth notes, would also have the added benefit of accelerating the decline of fertility rates.

All of the above papers acknowledge that a transition to a greatly reduced human population is necessary to achieve long-term environmental sustainability, but what is that level of population? Christopher Tucker argues in his book, *A Planet of 3 Billion* (2019), that a global population of 3 billion would be compatible with high welfare and environmental sustainability. In the commentary piece published here, he poses the question of how the already declining rate of population growth might be accelerated to achieve such a population well before the UN and other models predict. Tucker begins with the observation that all the data shows that we currently live well beyond the planet's sustainable capacity which has led to an ecological debt that will take generations to repay if we manage to avoid the collapse of our civilisation. In contrast to this, Tucker, like Rees, notes that for the majority of our species history humankind has had a population that has only seen very slow rates of increase as fertility barely exceeded replacement. However, the advent of what we now call modernity led to massive and relatively rapid improvements in infant and maternal mortality rates while decreases in fertility lagged behind. The resulting acceleration in population growth, stabilisation and now the beginnings of decline in the Global North is the core of the demographic transition theory that will be familiar to readers of this journal.

Tucker sets out his argument elsewhere for why a sustainable global population is around 3 billion; here he asks what is required to bend the population curve from the UN's median projection of nearly 11 billion by 2100 toward this sustainable number. Tucker notes that Vollset et al (2020) question the UN modelling and project that average global fertility will fall to replacement levels by 2064 and global population will grow to no larger than 9.7 billion. Vollset et al. base their lower projection on the anticipation that factors such as increased access to contraception, female education and participation in the workforce are likely to bring fertility rates down much faster than had been previously assumed. Tucker argues that this demonstrates that population growth is not some autonomous force beyond human agency and given this it must be possible to actively manage it by investing in the very same ethical, humane and empowering strategies which are already reducing fertility. Tucker asks what level of investment in such strategies would be required to accelerate the reduction in global fertility from the present level of just over 2.4 to the European average of around 1.5 by 2030.

In many respects, energy consumption is central to the question of population and sustainability. Rees points to fossil fuels as a critical determinant in the massive acceleration of human population growth from the 18th century onwards. Indeed, population growth in all eras can be closely correlated with the availability of energy in the widest sense: the Neolithic agricultural revolution spurred considerable population growth as did earlier changes in hunter-gatherer lifeways (see Feeney, 2019). Yet while increased availability of energy can be seen as inextricably linked with changes in the rate of population growth, population growth itself increases the demand for energy and when that energy is mostly derived from fossil fuels it makes the transition to sustainable energy that much harder to achieve.

Aalok Ranjan Chaurasia's paper looks at the effects of population change on world energy consumption growth and carbon emissions between 1990 and 2019. As emphasised by other papers published in this journal, energy consumption, and in particular its carbon intensity and the changing energy intensity of GDP, is seen by many as one of the key issues in tackling climate change and environmental sustainability more generally. Chaurasia employs a development of the IPAT equation which separates energy use per capita from income per capita to analyse the contribution of population change to energy use and carbon emissions, but also more importantly to separate the direct effect of population growth from the effects of energy efficiency gains.

Chaurasia's research shows that while two thirds of the growth in energy consumption was confined to China, India, the USA, South Korea and Iran, that over 80% of carbon emission growth was accounted for by China, India, Iran and Indonesia. The contrast between the world's most populous countries, China and India, is illuminating with the former accounting for around four times the growth in both energy consumption and carbon emissions. Chaurasia's analysis clearly shows that growth in GDP is the primary driver of energy consumption and carbon emissions, but critically that population is also a key determinant – accounting for up to 20% of the differences between countries in the study. Of particular significance is the observation that (globally) increases in population are shown to offset the impact of energy intensity and carbon reduction measures by over three quarters. However, these offsets vary enormously from country to county and are related to the level of development and the rate of population growth. Chaurasia concludes that population factors are significant in driving increases in energy use and carbon emissions, but that they are not properly integrated into environmental policy. Moreover, population is neglected and in conflict with the objectives of the UN's Sustainable Development Goals since, for example, population growth can be shown to be a significant contributor to economic growth in developing countries such as India.

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COMMENT

The fractal biology of plague and the future of civilization

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Abstract

At the time of writing, the CoViD-19 pandemic was in its second wave with infections doubling every several days to two weeks in many parts of the world. Such geometric (or exponential) expansion is the hallmark of unconstrained population growth in all species ranging from sub-microscopic viral particles through bacteria to whales and humans; this suggests a kind of 'fractal geometry' in bio-reproductive patterns. In nature, population outbreaks are invariably reversed by the onset of both endogenous and exogenous negative feedback – reduced fecundity, resource shortages, spatial competition, disease, etc., serve to restore the reference population to below carrying capacity, sometimes by dramatic collapse. H. sapiens is no exception – our species is nearing the peak of a fossil-fueled ~200 year plague-like population outbreak that is beginning to trigger serious manifestations of negative feedback, including climate change and CoViD-19 itself. The human population will decline dramatically; theoretically, we can choose between a chaotic collapse imposed by nature or international cooperation to plan a managed, equitable contraction of the human enterprise.

Keywords: pandemics; CoViD-19; SARS-CoV-2; fractal geometric growth; overshoot; plague; human population collapse.

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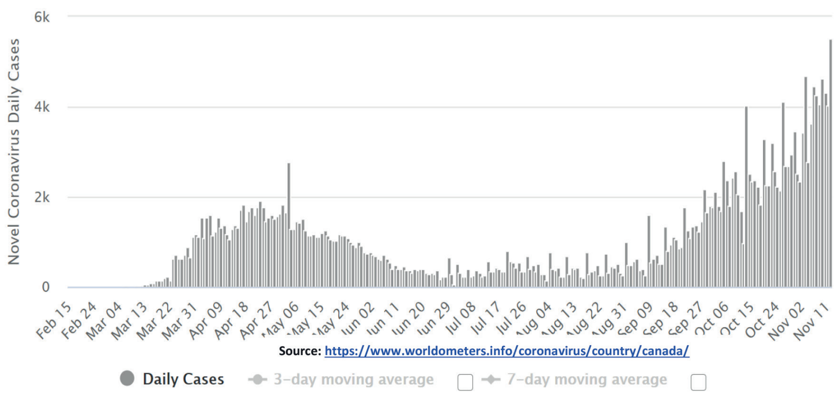
Universal fundamentals of population growth

Early in the SARS-2-CoV pandemic (Feb to Mar 2020), CoVid-19 infection rates in various European and Asian countries were doubling every two to ten days (see Nunes-Vaz, 2020). The wide spread in doubling times reflected the relative effectiveness of differing national control policies and population behaviours. Many of these nations managed to reverse the trend and 'flatten the curve', from several thousand to only a few hundred cases daily, by late May or June, a situation that obtained through the summer months. However, by early September 2020, the number of new daily CoVid-19 cases was again on the uptick. People were spending more time indoors at work, at play, at school, crowding together and more effectively transmitting the virus. Infection rates were doubling every two weeks in my home country, Canada, and doublings at an equivalent or even greater pace were again the norm in countries that had previously had things under control. The 'second wave' of the pandemic was taking serious hold and threatening to become far more serious than the first (Figure 1).

Figure 1: Daily new cases of CoViD-19 in Canada



Source: https://www.worldometers.info/coronavirus/country/canada/

Whenever you hear reports of some entity doubling at a constant rate, think 'exponential growth' – or perhaps more accurately, *geometric* growth.[2] Exponential/ geometric growth is the expression of natural reproductive exuberance. Virtually every living species is capable of expanding geometrically in a favourable, previously unexploited environment as SARS-2-CoV demonstrates convincingly.

Reproductive potential is perhaps the major form of *positive feedback* in every living system.[3] Inoculate a Petri dish of nutrient-rich agar with bacteria at ideal temperature and the starter population may double in as little as 12 minutes (although some species may take a few hours). Twelve minutes later, the bacterial population will have doubled again and, after just an hour, our little colony will have expanded by a factor of 32. So it is with all living organisms – introduced to an ideal resource-rich environment, the initial population will begin to grow geometrically. From the perspective of SARS-2-CoV, today's globally dense population of non-resistant humans is a fertile Petri dish.

What does differ among species is the generation time and hence the doubling rate. As noted, it can be just a few minutes with bacteria (or viruses); house-mice have a generation time of less than ten weeks and a pair may become 40 individuals in just five months; at 7-8%/year an unmolested population of mature blue whales or elephants can double in less than ten years; the human doubling time reached a minimum of about 33 years in the late 1960s when our growth rate maxed out at 2.1%/year.

Today's 1.05%/year growth rate would double the current human population in 67 years (by 2087) to 15.6 billion. Fortunately, this will not happen. The rate continues its long decline; current estimates suggest that, *conditions permitting*, we might make 10.9 billion by the end of the century and top out shortly thereafter (Roser, 2019).

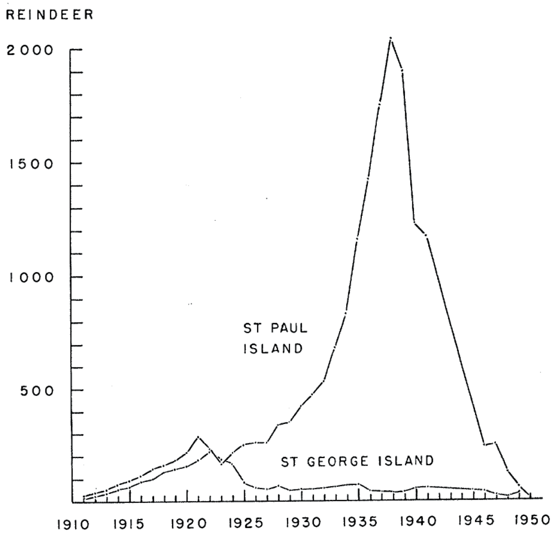
2 Some mathematicians make no distinction between 'exponential' and 'geometric' growth. Others argue that an exponential distribution involves raising each number in a series by the same power to get the next number (e.g. 2, 4, 16, 256...), while geometric growth is defined more generally as involving performing a constant operation on a sequence of numbers (e.g., 2, 4, 8, 16...).

3 'Positive feedback' implies a process that is deviation-accelerating; 'negative feedback' is deviation-correcting.

Overshoot – triggering a feedback

In fact, conditions may not be 'permitting'. Population estimates are usually based on demographic data alone with no consideration of exogenous factors. This is unrealistic. *For living organisms, the fact of their own existence ensures that no environment or habitat remains ideal for long.* As the subject population expands, it will invariably use up any crucial resource in fixed supply. Even renewable resources can be depleted once the population goes into 'overshoot', a situation in which aggregate consumption exceeds food species' recovery rates or waste accumulation exceeds natural assimilative capacity. The rise and fall of reindeer populations introduced to two previously unoccupied (by reindeer) Pribilof Islands in the early 20th Century is a classic example (Figure 2). Collapse was attributed to overgrazed food sources (primarily lichen) abetted by the stress of exceptionally cold winters (Scheffer, 1951).

Figure 2: Reindeer population outbreaks and collapse on the Pribilof Islands (Scheffer, 1951)



With food shortages and pollution, survival and reproductive rates *necessarily* decline. Meanwhile, other forms of 'negative feedback' may also set in – dense populations make our subject species more attractive to predators; crowding and malnutrition facilitate the spread of disease and parasites; there may be intra-specific conflict over habitat in short supply. Invariably, growth ceases and may be reversed, sometimes precipitously.

In nature, the populations of density-dependent species are determined by push and pull, the interplay of positive and negative feedback.[4] *Macroscopic* organisms such as whales, elephants and (pre-industrial) humans typically maintain a fluctuating unstable equilibrium near their habitat's average 'carrying capacity' (though perhaps not until after a dramatic crash in the case of severe overshoot – see reindeer on St George Island, Fig 2,). Microscopic organisms have evolved quite different approaches to stress. Many species of bacteria (*Bacillus, Clostridium, Desulfotomaculum, Sporosarcina, Sporolactobacillus,* and *Oscillospira*, spp., for example) adapt to declining nutrient supply or other hostile conditions by transforming into endospores, smaller, hardy, tough-walled dormant cells that can survive conditions that would kill the active bacterium. 'Sporulation' thus protects the organism's genetic material from extreme environmental stress until the return of better times. Endospores may also be readily transported by wind or water and will reactivate within minutes or hours after being deposited in a new environment of favourable conditions.

Like the CoViD-19 virus, various small mammal and insect populations exhibit large-scale population outbreaks on an irregular basis enabled by temporarily abundant food supplies, periods of favourable weather, increased survival (e.g., from reduced predation) or some combination; other species have regular repeating high-amplitude population cycles perhaps synchronized by the seasons or, in the case of predators, by other natural cycles in prey species.

Again, like the corona virus, outbreaks of non-human animal populations can seriously harm people. The desert locust (*Schistocerca gregaria*), for example, may qualify as the world's most devastating agricultural pest. During the swarm phase of a locust outbreak, the insects may multiply exponentially by 20-fold in just three months to attain densities of 80 million per square kilometre. A swarm of 80 million can consume food equivalent to the needs of 35,000 people. In 2020, favourable conditions spawned locust outbreaks – the worst in decades – in

4 Density dependent species are those subject to negative feedback triggered by their own growing populations. Negative feedback can be endogenous (e.g., reduced fecundity, infanticide) or exogenous (resource shortages, increased predation).

several African and Asian countries including Kenya, Ethiopia, Uganda, Somalia, Eritrea, India, Pakistan, Iran, Yemen, Oman and Saudi Arabia (Njagi, 2020). Many of the affected regions are already food-stressed.

The term 'plague' is usually reserved for the horrendous zoonotic infection caused by *Yersinia pestis*, a bacterium usually carried and transmitted to humans by small mammals and their fleas. (The resultant 'Black Death' or bubonic plague killed 75 -200 million people in Africa and Eurasia during the 14th Century.) However, when swarms of locusts infect large geographic areas or several countries, the outbreak is also known as a plague. Even small mammal outbreaks can reach plague proportions. Australia's worst ever mouse plague caused $A96 million of damage in 1993 ($A184 million in 2020 dollars). The nearly equivalent 2010/11 mouse plague affected three million hectares of crops in New South Wales, as well as parts of Victoria and South Australia (CSIRO, 2020).

What all the above data illustrate is that *the population dynamics of living species, from sub-macroscopic viruses to gargantuan whales, reflect a universal fractal geometry:* the same basic patterns are repeated in all species, differing only in terms of vastly differing temporal and spatial scales.[5]

Implications for humans

How might this reality enlighten *H. sapiens* beyond helping to understand the waves of our current pandemic? To begin, humans are certainly not exempt from the fundamentals of population dynamics. For at least 99.9% of anatomically modern *H.sapiens'* evolutionary history (200,000 – 350,000 years) human populations, like those of other large mammals, fluctuated in the vicinity of local carrying capacities.[6] Local constraints might have been relieved at times by trade

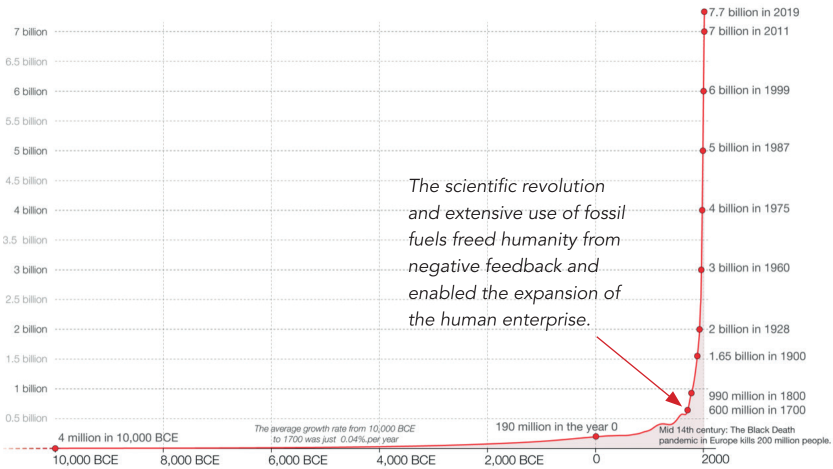
5 In theoretical mathematics, fractals are infinitely iterating, similar, detailed mathematical constructs having fractal dimensions at all scales. A fractal dimension is a ratio giving a statistical index of complexity comparing how detail in a particular fractal pattern changes with the scale of measurement. By analogy, the population dynamics of species from viruses to whales display self-similar, iterative, detailed properties (fecundity, growth rates, geometric potential, etc.) that vary among species only in terms of temporal and spatial scale.

6 Carrying capacity (CC) refers to the average maximum population of a species – the maximum fluctuates with exogenous conditions – that can be supported by a given habitat more or less indefinitely without permanent damage to that habitat. With humans, CC varies inversely with average material standard of living (consumption).

and certainly the (possibly reluctant) adoption of agriculture 8000-10,000 years ago enabled larger populations, permanent settlements and division of labour – and hence advanced 'civilization'. But for most of our species' time on Earth – including most of the agricultural era – humanity's natural propensity to expand has been held in check by negative feedback, e.g., food and other resource shortages, disease, and inter-group conflict.

Circumstances changed with the scientific/industrial revolution, particularly the increasingly widespread use of fossil fuels. It took 200,000 – 350,000 years for human numbers to reach one billion early in the 19th Century, but only 200 years (as little as 1/1750th as much time!) to balloon another seven-fold by early in the 21st Century. Improvements in medicine, public sanitation and population health contributed to this expansion, but coal, oil and gas made it possible. Fossil fuels are the energetic means by which humans extract, transport, and transform the prodigious quantities of food and other material resources into the products needed to support our burgeoning billions. More than any other factor, fossil fuels enabled *H. sapiens* to eliminate or reduce normal negative feedbacks. Freed from historic constraints, our species was at last able to exhibit its full potential for geometric growth (Figure 3).

Figure 3: Human population over the past 12,000 years (what goes up will come down)



Source of population graph: https://ourworldindata.org/world-population-growth

As implied above, it is not just population that has bloomed. Since 1800, propelled by a 28-fold increase in primary energy use, mostly fossil fuel, real global GDP has increased over 100-fold. World average per capita income (consumption) is up by a factor of 13, rising to 25-fold in the richest countries (Roser, 2018). As Catton (1982) famously observed, Earth is being asked to accept not only more people but ever larger people.

There is hidden irony in these data. Figure 3 shows clearly that only the most recent ten or so of literally thousands of generations of humans have experienced sufficient technological change and population growth in their lifetimes to even notice it. In short, *the period of spectacular growth and change people today take be the norm (and wish to preserve) represents the single most anomalous period in human evolutionary history*!

Figure 3 also underscores humanity's membership in the club of fractal population dynamics. The recent accelerating surge in human numbers reflects classic geometric growth – hyper-geometric, actually, since the growth-rate increased and doubling time decreased throughout the boom period until 'peak growth' in the 1960's. At peak, humanity's numbers were doubling every 33 years. (Compare the steepening human population growth curve with the geometric phases of the CoViD-19 case count and reindeer populations in Figs 1 and 2 respectively.)

Meanwhile, Earth was not getting any bigger.

Which means, of course, that membership in the club will eventually bear a price. The so-called 'environmental crisis' has little to do with the 'environment' and everything to do with excess human demands on natural systems. For several decades, *H. sapiens* has been in a state of 'ecological overshoot' – our species is exploiting even renewable resources faster than species and ecosystems can regenerate and dumping (often toxic) waste at rates well beyond nature's assimilation and recycling capacities; think plunging biodiversity, collapsing fish stocks, desertification, soil depletion, tropical deforestation, ocean pollution, contamination of food supplies, rising atmospheric greenhouse gas concentrations, resultant climate change, etc., etc. By 2016, *H. sapiens* was 68% in overshoot – i.e., acting as if Earth were 68% larger or more productive than it is (GFN, 2020).

It is worth noting that, initially, most of this damage could be traced to consumption by the wealthiest 20% of humanity who have effectively appropriated 70-75% of Earth's productive and waste assimilation capacities. However, there is an upper limit to the amount any individual can consume. Today, eco-degradation is being driven primarily by rising material demands and, more importantly, by population growth in middle and low-income countries. The world community must confront egregious inequality and population growth as separate problems.

Clearly overshoot cannot be sustained indefinitely (only economists think something can grow forever). The endogenous positive feedback that dominated the geometric phase of humanity's population growth is already being countered by exogenous negative feedback including the aforementioned ecosystems degradation and the weakening of life-support functions. With overshoot, carrying capacity declines in proportion to the loss of self-producing 'natural capital' and, with it, the ability to support even existing populations. The world community is literally financing its current population and material growth by liquidating the biophysical resources and life-support functions upon which the future of the human enterprise depends; the longer we remain in overshoot, the more we compromise the ability of future generations to thrive (red curves in Figure 4).

Keep in mind, too, that degraded ecosystems are not the only source of negative feedback on human exuberance. Food and other resource scarcities will intensify geopolitical strife which, in turn, will be exacerbated by mass migrations of people abandoning areas that have become uninhabitable because of climate change or ecosystems collapse. Disease may once again emerge as a major scourge – crowded human populations weakened by hunger and stress, no longer protected by functional public health systems, present ideal conditions for the spread of resurgent pathogens.

Or new ones. Approximately 70% of the new diseases in humans in recent decades, including CoViD-19, are zoonoses, ailments caused by pathogens transmitted from animals (the SARS-2-CoV virus jumped to people from bats or pangolins). CoViD-19, itself an exemplar of negative feedback, is at least the sixth global health pandemic since the Great Influenza of 1918 – and it may be a harbinger of worse to come. A recent report notes that there are six to eight hundred thousand unknown viruses in nature that could infect people as humans encroach ever more insistently on wildlife habitats. "Future pandemics will emerge more often, spread more rapidly, do more damage to the world economy and kill more people than CoViD-19 unless there is a transformative change in the global approach to dealing with infectious diseases..." (IPBES, 2020). Pandemics may originate from contact with animals, but their emergence is driven by human activities.

And what about our energy conundrum? Modern society is precariously suspended on a gusher of fossil fuel – despite significant advances in so-called renewable energy for *electricity* generation[7] coal, oil and natural gas still provided 84% (492.3 exajoules) of the world's primary energy in 2019 (BP 2020). The problem is that, to avoid potentially catastrophic climate change, the global economy must decarbonize by 2050. In the absence of quantitatively similar renewable substitutes, this implies significant energy (and food and other resource) shortages, shrinking GDP and a major reset of societal priorities.

Even the option of risking climate change by continued reliance on fossil fuel may be closing. Economically viable sources of oil and gas require ever greater levels of investment just to maintain supplies. Ironically, the onslaught of CoViD-19 has so deflated demand for oil and gas that the resultant glut has destroyed investment. Meanwhile, production has fallen precipitously, and low prices have bankrupted dozens of companies. Some wonder whether the industry can recover (e.g., Cho 2020) but the problem is much greater. Society as we know it cannot survive the absence of abundant cheap energy.

Where do we go from here?

A bacterial culture can quickly overwhelm and deplete its Petri dish; the SARS-2-CoV virus will continue to ravage the human population until herd immunity or a successful vaccine cuts it off. This is the way of living things, including humans – our species has expanded over the entire planet and is well on the way to depleting resources essential to its own survival. Earth is to *H. sapiens* as Petri dish is to *Bacillus* sp.

7 Wind turbines and solar PV panels are not truly renewable, merely replaceable, and their production involves mining, refining and manufacturing processes dependent on fossil fuel. Indeed, many key direct uses of fossil fuels – high-heat manufacturing, inter-urban, air and marine transportation, agriculture – are not readily electrifiable.

The analogy, or rather 'homology', goes quirkily further. When the bacterium's medium turns hostile, its cells sporulate; the resultant endospores wait in dormant state to be wafted to a more favourable environment. How does this adaptation differ functionally from NASA's inquiries into using suspended animation to facilitate human interstellar travel (Bagelley, 2017) or plans to colonize Mars to ensure that humans survive a war-ravaged or eco-degraded Earth (Solon 2018; McFall-Johnsen and Mosher 2020)?

Whether *H.sapiens* will ever reach some Earth-like planet 'x' light-years away or even successfully colonize Mars, may be entirely moot. In the best of circumstances, serious interplanetary exploration, even within the solar system, would be decades in the future and these are hardly the best of circumstances. The 'Anthropocene' is quickly becoming dominated by negative feedback induced by the already excessive scale of the human enterprise.

Not that this makes much difference to decision-makers. Despite cumulative evidence of potential disaster, the world's major governments, international development organizations, the corporate sector and probably the majority of even well-educated citizens are fully committed to maintaining the global cultural narrative of perpetual economic growth abetted by continuous technological progress. It seems that few people comprehend the physical implications of humanity's material addiction. When something is growing geometrically (e.g., plague-like) with a constant doubling period, the quantity attained at the end of any doubling period is greater than the sum of the quantities at the end of all previous doublings (e.g., $128 > \sum(64 + 32 + 16 + 8 + 4 + 2+ 1)$).[8] More or less on geometric projection, the global material footprint rose from 43 billion tonnes/year in 1990 to 92 billion in 2017 – an increase 113%. Similarly, half the fossil fuels ever used were burned in just the past 30 years (90% has been consumed since 1943). Consider, then, that with population growing at 1.0%/year and incomes in developing countries increasing even faster, the global economy will more than double again the next 30 years (i.e., >2.0% /year). Since much of that income growth will be in countries where people have yet to satisfy basic needs let alone luxury wants, we can expect parallel growth in economic energy and material throughput – the material footprint is projected to expand another 106% to 190 tonnes/year by 2060 (UN 2019).

8 Alternatively, with geometric growth, the quantity consumed during the latest doubling period is greater than the sum of quantities consumed in all previous doubling periods.

All this on a planet already 68% in overshoot; unable to control soil and landscape degradation; beginning to reel from climate change; witnessing a 68% drop in the populations of hundreds of regularly monitored vertebrate species world-wide since 1970; etc., etc. What is the likely impact of imposing an energy, material, and waste load on the ecosphere in just the next 30 years potentially greater than the sum of the loads imposed by all previous doublings since the beginning of the 19th Century?

The time has come to face biophysical reality. Contemporary data and trends suggest that global society is nearing the end of an unprecedented – *and likely one-off* – human population outbreak (Fig 1) affecting the entire planet.[9] Distasteful as it may seem to human exceptionalists, we can justifiably describe *H. sapiens* seeming dominance as a form of global plague, a description that would surely apply if we were discussing any other species (Rees, 2020).

On our present course, the likely outcome for global society is systems collapse as we run up against serious climate effects, resource shortages, and increasing geopolitical conflict in coming decades. Compare the 'overshoot' simulation in Figure 4 (red curves) with the real-world boom-bust collapse of the St Paul Island reindeer herd as it depleted its food resources (Fig. 2).

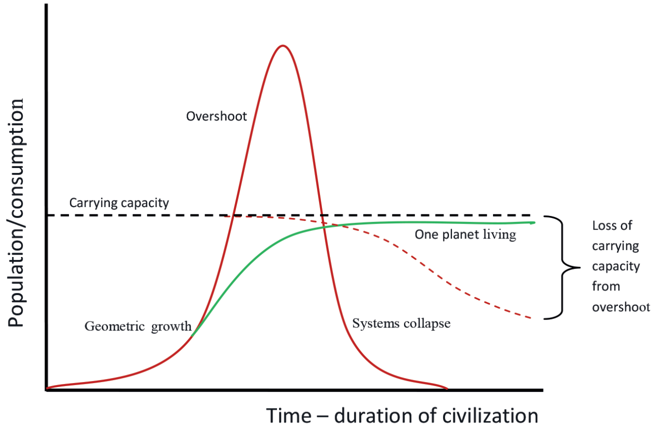
Forget about interstellar space travel or even colonizing dead-cold Mars. Humans should be focused on regenerating ecosystems and life-support functions on Earth, the planet on which we evolved, which continues to sustain us and for which we are best adapted. Despite damage wrought by *H. sapiens*, Earth remains infinitely more hospitable than the red planet; why would anyone think that efforts to terraform Mars is more likely to pay off than restoring the earth?

Epilogue – the choice before us

CoViD-19 may well exemplify the biological universal to expand that *H.sapiens* shares with all other life-forms. But humans have other unique qualities that we have yet to exercise fully in addressing overshoot. Our species is blessed with high intelligence, the capacity to reason logically from the evidence, and the ability to plan ahead in ways that could dramatically alter our future prospects.

9 "One off" because, with all readily accessible resources used up, survivors would likely be unable to resurrect a technologically advanced global civilization.

Figure 4: Alternative pathways – overshoot-to-collapse (red lines) or controlled contraction to 'one-planet living' well within Earth's human carrying capacity (green line)



It helps that we also possess a unique appreciation of our own vulnerability and mortality, no doubt heightened by the current pandemic.

The scientific evidence tells us that *some form of contraction of the human enterprise is a material necessity if we to maintain the functional integrity of the ecosphere*. It seems we have a choice: either allow nature to take its course and suffer the ugly consequences of a chaotic implosion or rise to our true potential by executing a controlled down-sizing of the human enterprise. The overall goal must be 'one-planet living' which means learning to thrive more equitably on Earth well within the carrying capacity of the ecosphere (Moore and Rees, 2013). When dealing with the human plague, this is the real meaning of 'flattening the curve' (Fig. 4).

The question is: how can the self-proclaimed most-intelligent-species-on-Earth organize socially, politically, and economically to implement a process to ensure an orderly and equitable contraction? Could there be a more riveting intellectual and practical challenge? Indeed, this, more than fear, is proving to be the real motivation for some of our best minds in dealing with our (un)sustainability crisis (see, for example the degrowth initiative at https://www.degrowth.info/en/what-is-degrowth/). If the global community does not rise fully to engage its fate, humanity proclaims itself to have no more practical intelligence or conscious moral agency when it comes to ensuring its own survival than does the CoViD-19 virus.

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PEER REVIEWED ARTICLE

Marx, population and freedom

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Abstract

Marxists have long moved beyond a perception of Marx as a Promethean ecological vandal. Yet those disputing his environmental credentials are generally united in deploring the unhappy history of population control. They implicitly accept the idea of currently forecast future population levels as consistent with a Marxist view of human emancipation. This assumption should be challenged, on the basis of what resources a truly unalienated future may require in order to achieve real freedom for each future individual.

Keywords: Marxism; environmental impact; population control; freedom.

Marxism and the environment

The time when a consensus existed that Marx was largely blind to ecological problems now seems long ago. As an all-too brief summary of events since, invidious in its choice of authors amidst a plethora of work, eco-socialist critics such as André Gorz (1994), Ted Benton (1989, 2001), James O'Connor (1988, 1998), Joel Kovel (2002) and Daniel Tanuro (2003), many in the *journal Capitalism, Socialism, Nature,* as well as eco-feminists such as Merchant (1992, 2005, 2012) and Ariel Salleh (1997, 2012) broadly agreed that Marx's undeniable emphasis on human labour implicitly denigrated the importance of the biosphere. In response, whilst largely agreeing in terms of objectives, contesting terms and even collaborating

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(Kovel & Löwy, 2001), Marxists concerned with the environment – notably Paul Burkett (1999, 2014) John Bellamy Foster (2000, 2009, 2011, 2014), and Michael Löwy (2017) constructed new theories of Marxist ecology, aiming to render the Marxist theory of surplus value more compatible with environmental concerns. And more recently, a comprehensive assessment of Marx's 'ecological turn' in later life leads at least to questioning whether Marx himself, at least, recognised the close relationship between human and planetary welfare, even if many of those subsequently acting in his name did not (Saito, 2016, 2017).

There is however a paradox at the centre of all these efforts to integrate Marxism and environmental politics. Whilst there is great concern over what kind of planet people should enjoy, there is a relative neglect of how many people there might need to be in order for a specifically Marxist ecological politics to succeed. Answering this question raises the question of the relationship between population, ecology and human freedom, which Marxism has generally eschewed.

Marxist theory of population

The reason Marxists have been suspicious of population control lies in the 'archaeology' of Marxism. Marx and Engels themselves were highly critical of Thomas Malthus's early account of scarcity and population (Jones, 2020, p.101). Whilst population is a critical determinant of the ability of underdeveloped societies to affect their external environment, Marx suggested that 'this reproduction of labour-power forms, in fact, an essential part of the reproduction of capital itself. Accumulation of capital therefore entails an increase of the proletariat'. (Marx, 2015 [1867], p.435); Perelman, 1987, p.30). That being Marx's own view, the predominant Marxist view of population control has always therefore been that it is at worst rebarbative, at best unnecessary, and largely irrelevant in a wider economic and political context, as population levels will be determined historically, first by capitalist, and subsequently by socialist social relations. The practically universal assumption has been made that Marxism need not, indeed should not, address questions of population, whether in relation to the achievement of socialism or their possible role in ending alienation and creating universal freedom. These questions had been 'solved' by Marx.

Marxists have therefore argued from the fact that technology has always risen to the challenge of production for a growing population, leaving only a very real question of distribution. There is evidence that this overall approach is reasonable, if not always accurate. Generally, as wealth increases, fertility rates naturally fall as families invest more resources in fewer children. There is an empirically observable tendency that even in the absence of socialism, as people, especially women, gain education and income, fertility rates decline (Williams, 2010, n.p.), albeit unevenly. If so, we need not worry: economic growth and rising prosperity, even under capitalism, will solve the problem of overpopulation by itself. As one Marxist author, following the well-trodden path of environmentalists such as George Monbiot (2007) and Naomi Klein (2014) who argue that capitalism and the health of the planet are incompatible, summarised the Marxist response: population is not the problem, capitalism is, so 'Higher population growth rates are a product of hunger, not its cause' (Williams, 2010, n.p.). Marxists are not alone: the entire field of social reproduction theory too has placed the conflict between capitalism and reproductive freedom at its centre (Bhattacharya, 2020). This then leaves the problem of hunger as fundamentally one of distribution; the Food and Agriculture Organisation of the United Nations has stated plainly (FAO, 2005), and repeatedly (Martin-Shields & Stojetz 2018; FAO, 2019), that global conflict is the main cause of global hunger, and that the world has plenty of food if only it could be rationally distributed. Unfortunately, capitalism prevents that very effectively, not only through conflict but also by ensuring that international grain markets are directed at animal feed rather than food consumption (Cohen, 2017, p.38).

Marxists have therefore largely worried that concentrating on population confuses symptoms with causes, as well as failing to distinguish between absolute levels and rates of change, while simultaneously validating apologists for the system—and in some cases actively updating and perpetuating Malthusian anti-poor, nationalist, and racist arguments. Although there have been exceptions, the majority of Marxists have followed Bernstein on the Right and Luxembourg on the Left (Petersen, 1988, p.87) in being stridently opposed to population control, ably summarised in the argument that: 'The majority of the world's people don't destroy forests, don't wipe out endangered species, don't pollute rivers and oceans, and emit essentially no greenhouse gases' (Butler & Angus, 2011, n.p.). The point has also been made that: 'Capitalism's drive for growth isn't a drive for more customers – it is a drive for more profit' (Angus & Butler, 2013,n.p.).

It is noticeable that such criticism of population control often focuses on the contested liberal terrain of 'human rights' (Angus & Butler, 2013). The problem here is that the rights of the current generation may come at the expense of successive generations to follow – including those who will eventually inherit the Earth when capitalism has finally been ended. At the time the one-child policy was first introduced, the Chinese Government appeared to be groping uncertainly for this kind of concept. No doubt they made mistakes, ably and enthusiastically seized upon by opponents of population control (Mosher, 2008). And it may be readily conceded that policy directed at achieving a specific level of population must inevitably strike a balance between investment in the future of humanity and individual liberty in the short-term, at least so long as that liberty is conceived in terms of liberal 'rights' to personal procreation and not unshakeably connected to hope in the future. Similar trade-offs of course exist in the restriction of personal freedoms throughout the realm of government.

Unfortunately, also, however justified his arguments against Malthus, Marx did not 'solve' the question of population forever. Nor, although it is perhaps ironic for Marxists to argue it, is it necessarily the case that capitalism will necessarily come to the rescue of women everywhere and enable fertility rates to decline. Although Angus & Butler (2011) suggest that the argument that rising incomes are strongly correlated with declining population growth is irrefutable, and it is certainly generally the case, recent evidence from Nigeria, where population growth rates have remained steady for decades, is surely sufficient to disprove this as a universal hypothesis. Just as importantly, whilst global population growth rates have undoubtedly declined, that is of scant use to the underprivileged of Bangladesh, for example, where although the rate of growth of population is declining, the country still adds over 1.5m of predominantly very poor people annually. As a result, the question of at what level global population will peak, even that it actually will, is not yet settled. More importantly, it is definitely not clear what kind of population density will be the case when it does: all we can be certain of is that it will certainly be greater than that which prevails in advanced Western democracies such as Australia and the United States, even Europe.

Yet there seems to be no alternative for Marxists but to join their political adversaries in hoping that all will turn out well. It would seem that Marxists should welcome a growing global population, but unless socialism can be achieved in the process, only if they remain poor, surely an entirely unwelcome paradox. Either way, by relegating questions of population to an increasingly distant communist future, Marxists appear to have marginalised themselves politically on this issue as on many others. Something has gone wrong here.

Three components of human freedom

What has been neglected throughout the development of the relationship between Marxism and population are the psychological, geographical and temporal dimensions.

In relation to the psychological dimension, the trail leads back to the debates over the role of the individual within Marxism and the debate between Marxist humanism and structural Marxism almost half a century ago. For Marx, alienation and capitalism were inseparable. Yet tragically, 'free conscious activity constitutes the species-character [*Gattungswesen*] of man' (Marx, 2009 [1844], p.81]). Overcoming capitalism entails a future in which human beings can and do participate in human society through free, cooperative activity, through which individual human beings can realise their freedom. For Marx, freedom means 'the conscious shaping by humans of the social conditions of their existence and so the elimination of the impersonal power of alienated, reified social forces' (Walicki, 1988, p.13). As a result, for Marxism, individual freedom cannot and certainly should not ever be defined in the liberal sense; it must remain 'social, collective and positive' (Brenkert, 2013, p.88). To be free, individuals must become ends-in-themselves, and not subject to such constraints in their actions that their time is used up in unwelcome, repetitive labour within a capitalist economy, even if an improvement over primitive conditions prior to the control of Nature (Marx, 2010 [1894], p.593]). The world Ayn Rand envisaged cannot deliver human freedom for all. Certainly, working conditions in many parts of the world are far better than the 19th Century capitalism that Marx saw first-hand, although by no means everywhere. Nevertheless, Marx's original criticism, that labour under capitalism denies human self-realisation, remains a forceful, relevant and valid one for the majority of human labour (Sayers, 1998, p.39), even in the 21st Century, and even in developed countries.

Subsequent theorists took up the argument and placed the individual at the centre of the Marxist project. A first example: the leading Marxist humanist Adam

Schaff recognised that socialist societies are not free from alienation, but one of the chief causes was that neglect of the problem of the human individual had in the 20th Century to the theoretical impoverishment of Marxism and its practical distortion (Schaff, 1967, p.143). In his view, personality is and always will be: 'the defining factor of a real individual, peculiar to the individual' (Schaff, 1970 [1965], p.94). Schaff's view that elimination of private property is an essential step towards the flourishing of individual personality points both to his fidelity to the Marxist tradition, but also to his implicit recognition of the sheer complexity of the multiple prerequisites for freedom in a Marxist sense, many of which will inevitably be severely circumscribed by the diminishing allocation of natural resources to individuals that a growing population inevitably entails.

A second example: Erich Fromm, who if not entitled to the appellation of Marxist himself was certainly closely associated with the Marxist tradition (Wilde, 2000, p.55), took the view that separation from nature is the basic human trauma, creating a sense of emptiness that is often addressed negatively, through the pursuit of power, wealth or fame, or through engagement in relations of dominance and subordination, but which can also be addressed positively, through the pursuit of human solidarity and through love and care for others. Love and solidarity are basic human needs that are consistently frustrated by capitalism. This created the need for a decentralised socialist society based on cooperation and self-management. Fromm's position hardly changed over two decades: in his later work he again complained that whilst 'industrial society has contempt for nature' (Fromm, 1976, p.17), a new form of humanity is possible, as 'Having and being as two different forms of human existence are at the centre of Marx's ideas' (Fromm, 1976, p.156).

Third example: in developing a theory of the human personality within Marxism, Lucien Sève, although himself opposed to Marxist humanism, argued for the formal characterisation of the problem caused by the absence of learning and development activity within the capitalist workforce of as a falling rate of progress in individual development over time, expressed in 'the general tendency of personalities to stagnation and ossification as the years pass' (Sève, 1978 [1974], p.360). Sève later advanced the example of successful retirement in Western society, surely beyond doubt a resource-intensive activity from which few as yet can benefit, as potential liberation from this downward spiral (Sève, 2008, p.417). It must be conceded that Sève's view did not go without challenge within the Marxist tradition. Louis Althusser went so far as to argue for the rejection of the conscious subject as an 'absolutely ideological conceptual device' (Althusser, 1971, p.157) From this theoretical debate, the paradox within Marxism therefore stands ready to emerge. Collectivist regimes may be more willing to use the tools historically associated with population targets, but their reasons, such as Mao's pragmatic concern with managing city size through migration (Lampton, 1974, p.687) are largely tactical, and by no means necessarily directed at the freedom of actual, living individuals. Whereas, Marxist humanists may have a much stronger strategic focus on the potentially negative implications of population growth for individual freedom, they are much more cautious in respect of the potential use of political tools to curb it and the balance between present and future individual freedom.

The second dimension is geographical, urban geography in particular. For a Marxist, true freedom cannot be found in endless multiplication of private spaces. Hence when Engels considered housing problems in the big cities of his day, he visualised that expropriation can end overcrowding (Engels, 1872). This rendered him open to the criticism that 'the problems of the city are displaced by the problems of revolution' (Merrifield, 2002, p.47). Today's Marxists are committed to a struggle against capitalist social relations, as well as economic ones: the contemporary city, as Marxists have persistently argued, has become a metaphor for the hopelessness of radical struggle and the location of huge inequalities. Poverty, overcrowding and resultant poor health and low life expectancy in major global cities have become unwelcome but recurrent reminders of the failure of capitalism to provide living conditions for the majority, lived environments in which individuals recognise that their freedom is permanent jeopardy (Jaffe et al., 2020, p.1015). The conclusion Marxists should draw is that individual freedom becomes progressively harder as population density passes a point that places psychological pressure on the individual. One example of this is the choice of location in Western cities: collectively, well-designed high-rise apartments with emphatic collective spaces are kinder on the environment and more conducive to interpersonal communication. Urban planners with Marxist leanings should however remember that many seek the suburbs because the prospect of apartment living fills them with dread. The result is urban sprawl, dreadful for the environment (Dietz & Rosa, 1997) and scarcely satisfying as a mode of living. It is no accident that the cities and countries that consistently win prizes for liveability are those with lower population densities, or that one of the almost inevitable corollaries of personal wealth is the accumulation of living space, often in multiple locations. No Marxist can want this to continue indefinitely.

But in developing responses, it is no use for Marxists to pretend that in making the world anew, they can ignore the reality of urban geography. High-density living and urban sprawl are physical, geographical facts as well socio-economic ones (Gonzalez, 2005, p.344). Yet Marxists of every stripe have always seemed largely determined to ignore the fact that the elimination of capitalism will not automatically remove geographical and natural constraints, nor instantly make the urban environment anew. Even when a Marxist recognises that human overpopulation 'is the single most important factor contributing to human destruction of the environment' (Andrews, 2013, n.p.), the focus is on environmental damage, although his analysis of the consequences of allowing all land to be shared comes very close to the point. That is, socio-economic change is of no use if the end-result is crippled by too many people – and there may already be too many people for individuals to be properly free, in a Marxist sense.

Caution and balance notwithstanding, the third dimension of the Marxist view of human freedom remains hope for the future. The freedom that is to be fought for now is that of generations to come. There is good reason to avoid potentially sterile Marxist exegesis. But if Marx's own words are to be cited, arguably the text that should be at the forefront of any debate over population and Marxism is in fact this well-known assertion:

> 'in communist society, where nobody has one exclusive sphere of activity but each can become accomplished in any branch he wishes, society regulates the general production and thus makes it possible for me to do one thing today and another tomorrow, to hunt in the morning, fish in the afternoon, rear cattle in the evening, criticise after dinner, just as I have a mind, without ever becoming hunter, fisherman, herdsman or critic' (Marx & Engels, 1970 [1846], p.53).

Traditionally, this paragraph has been considered solely as a metaphor for the end of the division of labour. But at least arguably it implies that the end of capitalism is simply no use if after its welcome demise, people are prevented from exercising those new-found freedoms from the division of labour by the size of human population. Problems posed by population for the exercise of human freedom as properly understood are no doubt endemic to capitalist society, but they will undoubtedly also persist after its demise. Marxists should certainly not ignore them.

Three neglected dimensions of genuine, unalienated freedom – and all of them with potential implications for the population policy Marxists should advocate.

What should Marxists do?

The fundamental confusion for Marxists over population policy has been between the technical and the economic. At the root of the problem is an understandable, but nevertheless unforgiveable, confusion between two different causes with the same result. Marxists are right to lay the blame for the appalling conditions under which many people still live on capitalism. But Engels was equally right when he speculated that at some future point, the number of people might become so great that limits will have to be set to their increase. Engels suggested 'population control from the center' (Hollander, 2011, p.149):

> 'The abstract possibility that mankind will increase numerically to such an extent that its propagation will have to be kept within bounds does, of course, exist. But should communist society ever find itself compelled to regulate the production of humans in the same way as it has already regulated the production of things, then it, and it alone, will be able to effect this without difficulty. In such a society it would not, or so it seems to me, be particularly difficult to obtain deliberately a result which has already come about naturally and haphazardly in France and Lower Austria. At all events, it's for those future people to decide whether, when and how it's to be done and what means they wish to use. I don't consider myself qualified to supply them with suggestions and advice about this. Indeed, they will, presumably, be every bit as clever as we are' (Engels, 2010 [1881], pp.57-58]).

When Engels mused over population control, as with agricultural production, he was convinced that the issue would only ever be likely to confront humanity under communism, when society as a whole would solve the complex problem of making rational decisions in the interests of all existing and future people equally. In reality, it now seems exceptionally likely – indeed, throughout the world it has already been the case – that population policy will continue to be shaped under capitalist economic conditions. There is nothing unusual in that – the same applies to a multitude of issues of global concern, including gender relations and environmental controls more broadly. In no case are Marxists excused from taking a policy position on the ground that the founders of Marxism expected such issues to be resolved within the context of a socialist or even communist society. The time for endless apologies over the excesses of States propounding Marxist-Leninist ideologies is now firmly over as well.

Revisionism has never carried positive connotations within Marxism. Yet accommodation with the capitalist State is constantly necessary, whether to fight for workers' rights, campaign against injustice, or to protect the environment. Attitudes to population policy should be no exception. Much as revision to Marx need not always involve any kind of hypothetical exegesis, it does seem entirely unreasonable to leave Marx's debate with Malthus as the last word of Marxists in regard to population. This is especially so given that Marx himself throughout his work recognised the need to accept scientific advance as a cornerstone of economic and political change. At the very least the question should be left open.

The difficulty lies therefore not in accepting the principle of population policy within the context of a capitalist State. However many difficulties there have been historically, this may be not only desirable but entirely necessary for improved environmental outcomes essential to the eventual achievement of space and freedom for future generations of humanity, something on which Marxists may agree with many others. Rather, it is a complex question of political decision-making. It may be that global population of seven to ten billion is eventually perceived as inconsistent with human freedom and personal development, and population policy aimed at reducing this total in the long term is eventually adopted. This may occur whilst societies continue to be capitalist, in which case Marxists and others on the Left will have an important role to play in determining the practical way in which it is implemented. Under such circumstances, continued opposition would simply perpetuate the perception of Marxism as an outlying, outdated political tradition. Rather, the essential task of Marxists will be to criticise the privatisation of reproductive rights, for example to exercise scepticism towards any entirely market-driven solutions, such as the all-too plausible route of competitive auctions (Tobin, 1970, p. 271) or the lesser evil of equally allocated but tradeable reproduction rights (Lianos, 2018, p.93). Marxists should argue instead for socially determined population targets and the protection of the vulnerable, as the Left argues against private health and education. Victory in such a potential conflict may itself even play an important role in the wider political struggle against capitalism itself.

Conclusion: the revival of the human project

The conclusion to be drawn is surely this: Marxism – and socialism more widely – has always claimed to have at its centre, the theory and practice of human emancipation. Putting humanity at the centre of a political and environmental project will achieve much more than relegating it to the periphery, but only if by humanity we understand what Marx meant by it at the level of the individual. There is a need to shift away from silence over how capitalism can sustain ever larger global population, whilst at the same time criticising the consequence of environmental depredation that capitalism has continued to bring in its wake. Marxists would be better to look to the intersection of psychology, geography and hope to help shape their response to the challenge of global population growth and the population density it implies. The combination of a Marxist theory of human freedom, and practical politics based on realistic appreciation of how such freedom can best be promoted in the future, could well turn out after all to be the best prospect for the survival of the planet and the flourishing of humanity as a whole.

If so, in arguing for human freedom, Marxists cannot shirk the responsibility for advocacy of population policy, should it prove necessary – which will eventually be a technical question at the intersection of psychology, geography and forecasting, not a speculative matter for philosophy or a question of political slogans. This may yet turn out to be Marx's greatest legacy: to create real freedom, it may not only be necessary to surpass capitalism, but also to ensure that those future people who will benefit from its abolition are able to do so without crippling resource constraints, so that they can indeed hunt in the morning and fish in the afternoon, and not be forced to just criticise all day.

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COMMENT

Humanity's environmental problems can only be fixed by changing the system. The coronavirus offers a chance.[1]

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Abstract:

Societies need to introduce much more radical emissions reductions targets than those agreed in Paris if they are to successfully slow the pace of change. Covid-19 makes this possible. By forcing aviation and other transportation businesses to downsize emissions have started to fall. By paying people to stay at home governments have shown that they can support them during a transition. Societies should grasp this unique chance for radical social and economic reform.

Keywords: COVID-19 pandemic; alternative economic systems; climate change; population growth; reforming democracy.

Partly because of the chaotic response by so many governments, it is easy to imagine that the virus which is causing such widespread and prolonged misery around the world is rare, if not unique. Yet it is only the most recent example of a relatively new and worrying trend. While the economic and social impact has been greater this time, Coronavirus SARS-CoV-2 is just the latest in a series of

1 This article is based on *A Chicken Can't Lay a Duck Egg* by Graeme Maxton and Bernice Maxton-Lee (2021).

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zoonotic viruses to have passed from other species to humans in recent decades. Others include HIV, SARS, MERS, Zika and Ebola.

The reason these diseases are being transmitted to humans more frequently is simple: too many people are encroaching onto the territory of other species. In areas where natural systems have been badly degraded by human activity, the number of animals hosting such diseases, such as bats and rats, is 250% higher than before, while the proportion of animals carrying the pathogens which cause them is 70% greater (Gibb et al, 2019).

Without any change, the number of these diseases passing to humans will grow, as will their economic and social impact. Put simply, unless humans learn to respect nature more, they face a series of healthcare crises, some of which will be as serious as that caused by Covid-19.

Changing the way humans interact with nature is easier said than done, of course. It will not come about simply by encouraging people to treat the world around them with greater respect. The imperative to endlessly increase economic output makes that impossible, even before patterns of individual behaviour and the rising human population's need for more land are taken into account. To work, the change in human behaviour needs to be fundamental. This is doubly so because the consequences of humanity's damaging impact on nature are not restricted to the problem of zoonotic diseases. They are much more widespread.

Another consequence of human activity is accelerated species loss. According to the UN, millions of animals, plants, insects, fish and birds are dying every year because of habitat loss, pollution and climate change, with species die-off 10,000 times the natural rate (Gibb et al, 2019). It is also accelerating.

UN – SPECIES EXTINCTION RATES 'ACCELERATING'

- Three-quarters of the land-based environment and about 66% of the marine environment have been significantly altered by human actions.

- More than a third of the world's land surface and nearly 75% of freshwater resources are now devoted to crop or livestock production.

- The value of agricultural crop production has increased by about 300% since 1970, raw timber harvest has risen by 45% and approximately 60 billion tons of renewable and non-renewable resources are now extracted globally every year – having nearly doubled since 1980.

- Land degradation has reduced the productivity of 23% of the global land surface, up to US$577 billion in annual global crops are at risk from pollinator loss and 100-300 million people are at increased risk of floods and hurricanes because of loss of coastal habitats and protection.

- In 2015, 33% of marine fish stocks were being harvested at unsustainable levels; 60% were maximally sustainably fished, with just 7% harvested at levels lower than what can be sustainably fished.

- Urban areas have more than doubled since 1992.

SOURCE: UN (2019)

Another problem is water pollution. According to the same UN report, between 300 million and 400 million tons of heavy metals, solvents, toxic sludge and other waste from industrial facilities are being dumped into the world's waterways each year. Fertiliser run-off has created 400 'dead zones' in the world's oceans where nothing can survive. There are also vast quantities of untreated human waste flowing into many of the world's rivers, the radioactive water from Japan's Fukushima nuclear power plant is leaking into the Pacific Ocean, and hormone, narcotic and other pharmaceutical residues are being flushed away in cities around the world every day. As with species loss, water pollution is on a steadily upward trend. This is disrupting natural food-chains and reducing the volume of clean water available to all living things, as well as future generations.

The steady accumulation of micro- and nano-plastics is also creating a wide range of problems for many animals, birds and aquatic creatures, as well as damaging human immune systems, bringing the prospect of declining fertility and higher cancer rates. Though the impact of this plastic waste is not fully understood, it has been described as the 'number one threat' to humankind (Bluewater, 2019).

The world's rainforests are also being destroyed at an increasing rate, while efforts to cut air pollution have largely failed. Though the particles produced today are much smaller than they used to be, and so less visible, they are often more deadly. According to the World Health Organisation, '9 out of 10 people breathe polluted air ' today. It kills seven million people a year, with respiratory problems the third biggest cause of human mortality (WHO, 2018a, 2018b).

Humanity's environmental impact has become so serious largely because the population has grown so quickly. It has more than doubled in the last 60 years and is eight times greater than it was a century ago. Even after taking the deaths caused by Covid-19 into account, the number of people on the planet is growing by a billion every 12 years – a billion more needing food, water, housing, clothing and waste management. With the push for ever greater economic output requiring ever more energy, land and raw materials, as well as rising levels of urbanization, the accumulated environmental impact of humanity's activities has simply become overwhelming. This is especially so when it comes to climate change, which is by far the most serious environmental problem of all.

It's easy to get confused about climate change. The endless headlines can be as numbing as the endless inter-governmental reports. The problem is presented as urgent and yet people are also told that the most serious consequences are decades away. There is a great deal of misinformation out there too, with fossil fuel firms and others deliberately sowing seeds of doubt about the science or denying there is a serious problem.

The truth, unfortunately, is that everything that societies are currently doing in response to climate change is not working. All those investments in wind farms, solar energy, electric cars, and recycling are not having any meaningful effect. Though the annual volume of greenhouse gases fell slightly in 2020, thanks to the economic slowdown caused by the coronavirus, it was still much too great for nature to reabsorb. So the pace of global warming has continued to accelerate, with the surface of the planet now warmer than at any time in the last 3 million years.

If the concentration of greenhouse gases continues to grow at the current rate (and there is no reason to think otherwise right now) the world will reach a catastrophic tipping-point in the mid-2030s. If this is breached, a chain-reaction will begin which will make further warming impossible to control. The polar ice will melt faster, reducing the planet's ability to reflect some of the sun's heat, accelerating the pace of warming. The permafrost in Siberia and northern Canada will also melt more extensively and many of the world's forests will gradually die. Both of these changes will release even more greenhouse gases, as will the rising number of wildfires, increasing the pace of warming even more. By the middle of the century the average temperature will have reached its highest level in 10 million years. By 2100, the Earth will be on track to become as hot as it was 45 million years ago.

If this happens, it will take many centuries for the temperature to return to how it was before the industrial revolution. Many parts of the planet will become uninhabitable in the second half of this century, with almost all of it uninhabitable long term, putting the survival of up to 95% of the human population at risk (Spratt and Dunlop, 2017)[3]. By 2050, more than 500 cities will have to be depopulated because of rising sea levels, while many countries around the Mediterranean, as well as much of Australia and large parts of the United States will be too hot and too dry for people to live. This is also what will happen if all of the conditions of the 2015 Paris Climate Accord are met, by the way. What has been agreed by governments so far will not avoid this catastrophe, nor delay it one second.

A large number of people are working to avoid this outcome, of course, and make societies more sustainable. Green groups around the world are also pushing governments and businesses to invest in renewable energy. Even so, none of these activities will achieve anything like the change needed in the time available. Even if *everyone* in America – all 330 million people – had some sort of green epiphany tomorrow and lived without generating any damaging gases for the next decade, it would only delay the start of the atmospheric chain-reaction by a couple of years. The US is responsible for only 15% of emissions, which is a lot, as it has just 4% of the global population, but if those responsible for the other 85% continue as now, America's efforts alone would not avert disaster.

3 Kevin Anderson, former Director of the Tyndall Centre for Climate Change Research, considers that "a 4°C future [relative to pre-industrial levels] is incompatible with an organised global community, is likely to be beyond 'adaptation' "If you have got a population of nine billion by 2050, and you hit 4°C, 5°C or 6°C, you might have half a billion people surviving" (Spratt and Dunlop, 2017).

The only way to avoid the chain-reaction is if almost everyone *reduces* their greenhouse gas emissions by at least 7% a year (UNEP, 2019). In practical terms, this means 20% fewer cars in three years, as well as 20% fewer planes, 20% fewer coal-fired powered stations, and 20% fewer ships. In the following three years there needs to be another 20% reduction. And the longer societies take to begin this process, the steeper the cuts will have to be. To work, emissions must be at least 60% lower in 2030 compared to today (Breakthrough, 2020). By 2040 they need to be zero - and not "net-zero" as some fossil fuel companies, airlines, and governments suggest is okay. Trying to offset emissions in some way, such as planting trees, which take decades to grow, will not have anything like enough impact on what is happening, just as taking exercise cannot offset the effects of a 20-a-day cigarette habit when someone has been diagnosed with lung cancer.

Societies also need to stop all deforestation and change the way they grow food. They will also need to build thousands of carbon capture and storage plants across the world and run them at full-blast for more than a century to bring the CO2 concentration in the atmosphere back to safer levels. Even then, having done all this, humanity's chance of avoiding that chain-reaction will be little better than 50:50.

It will also, unfortunately, take time before societies can be sure that their efforts have paid off, because what will happen to the temperature in the next 25 years is already largely locked-in (Breakthrough, 2020). Cutting emissions now, no matter how sharply, will take decades to show any visible impact.

Reducing emissions on the scale necessary requires a radical change in how humanity thinks about development and progress. Societies have to dismantle vast swathes of the current industrial system, regardless of the short-term cost, with almost everyone changing the way they live, whether they want to or not. The most polluting businesses - fossil fuel firms and cement companies - have to be closed quickly, most flights have to be permanently cancelled, and vehicle use has to be hugely curtailed.

Until recently, a change on this scale was thought to be impossible, because the economic disruption it would cause in the short term would be too great. Covid-19 has shown, however, that such radical change *is* actually possible.

The Coronavirus has shown societies that it *is* possible to cut emissions, downsize the aviation industry, reduce vehicle use, and support people financially during a crisis. When it comes to dealing with the climate problem, of course, the changes would have to be much larger and made permanent. It requires a structural transformation. Until Covid-19 however, there was a widespread belief that the changes needed to cut emissions had to be financially attractive. Covid-19 has shown that this is wrong.

Of course, the virus has brought enormous social upheaval, a deterioration in the mental health of many people and rising political tensions. Yet this also shows societies what they need to focus on if they are to slow the pace of climate change successfully. The difficulties have shown governments how hard it will be to close all the unnecessary, wasteful, and polluting industries, and support people financially.

Covid-19 has taught people how much they need to invest in the transition if they are to do what is necessary. Before, societies did not really understand what they were up against. They did not understand the consequences of cutting emissions sharply or know how hard those who want to maintain the status quo would fight back. Now they do. That is a huge step forward.

Thanks to the virus, societies have a unique opportunity to change. Rather than seeing the current economic crisis as a problem, they should look on it as the greatest chance for a radical transformation they have had in decades. Instead of bailing out polluting companies such as airlines and car manufacturers, as they presently are, governments should close them. Instead of trying to return economies to their past levels of output, societies should permanently downsize them. Instead of being wedded to the outdated goal of maximising economic growth, people should focus instead on building an entirely different development system, which can coexist with nature. Instead of expecting everyone to be financially independent, governments should pay a basic income to everyone during the transition, even if this is for many years. They should retrain people to work in the new economic sectors which will be needed, such as materials recovery, emissions capture, repairing, sharing, and recycling. To pay for the transition, governments can print money, just as they did after the 2008 financial crisis. While there is a risk that this could lead to currency crises or even state bankruptcy, these problems will be much easier to handle than runaway climate change.

Covid-19 also gives countries a unique opportunity to come together and work cooperatively, to create a better and more sustainable future for everyone. Unlikely as this might seem, there is now the small chance (albeit a very small one) that governments will learn to work together for the benefit of all. It is, after all, the only way they will eradicate the virus and respond to climate change effectively.

Whatever societies do, there *will* be a transition to another system of human development within the next decade, because the many failures of the current economic system, the impact of climate change, and the planet's other many environmental troubles will come together and force change.

Covid-19 offers humanity the chance to choose the path we take.

Graeme Maxton's latest book, *A Chicken can't lay a duck egg: How Covid-19 can solve the climate crisis*, written with Dr Bernice Maxton-Lee, was published at the end of 2020.

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EDITOR REVIEWED ARTICLE

Achieving a post-growth green economy

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Abstract

A transformation in human values in a 'post-materialist' direction by middle-class youth around the world may be setting the stage for a new reality of near-zero economic growth and a sustainable and healthy global biosphere. Evidence from the World Values Survey suggests that a global expansion of post-material values and experiences leads to (1) a reduction in consumption-oriented activities, (2) a shift to more environmentally friendly forms of life that include living at higher, more energy efficient urban densities, and (3) active political support for environmental improvement. Such behavioral shifts provide a foundation for a turn to a slow-growth or even no-growth economy in comparatively affluent countries to the benefit of a healthier global biosphere. To set the stage for a 'post-growth green economy' that features climate stability and a substantially reduced ecological footprint, the timing is right for a 'Green New Deal' that focuses on de-carbonizing the global economy and has the side-benefit of fostering an economic recovery from the Covid-19 global recession currently underway. The financing of global decarbonization by the world's wealthiest countries is affordable and could stimulate much needed economic improvements in developing countries by creating within them modern, efficient clean energy systems that can serve as a basis for increased economic prosperity. Such prosperity will in turn accelerate declines in population fertility and result ultimately in reduced global population growth.

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Keywords: post-materialism; post-growth economy; green economy; population growth; sustainability.

Introduction

In this day and age of existential threats to global social and economic tranquility from the likes of climate change, rising economic inequality, emerging authoritarian populism, and, now, a Covid-19 pandemic, to think about prospects for the future may seem naïve. But the future will come and hope springs eternal. Potentially, Covid-19 will teach us that global problems, climate change in particular, cannot be ignored and that new approaches are needed to arrive at a more just and environmentally friendly world. The purpose of this article will be to suggest a possible path forward by thinking seriously about interconnections between two phenomena: the 'post-material silent revolution' as a key historical event; and a 'post-growth green economy' as a solution to the global environmental crisis. The central thesis offered here is that these phenomena blend together comfortably as a framework for thinking about our economic and environmental future.

The 'post-material silent revolution' amounts to a sea-change in values among middle-class youth around the world away from giving high social priorities to materialist, economic social goals and towards non-economic social purposes such as advancing freedom of expression and increasing social tolerance. This change is accompanied by less emphasis on the pursuit of wealth and material possessions and more emphasis on seeking cultural and social experiences that take place outside the sphere of economic transactions or within the economic arena but for non-economic purposes. We will see that such a shift in outlook and activity brings forth a less entropic and more environmentally friendly way of living and greater political support for sustaining a healthy natural environment that together may well lead to big changes in the way we think about the economy.

A 'post-growth economy' refers here to the empirical phenomena of affluent economies experiencing a slowing of growth in both per-capita incomes and population as they mature and attain a threshold of material affluence. Post-growth is achieved when those economies attain a no-growth status, or even slow decline. Japan in recent years comes close to this status with a 0.8% annual growth in GDP per capita (2000–2018) and 0.0% annual population growth (World Bank, 2019c, 2019e).

Worried about serious degradation of the earth's natural environment by an ever-expanding global economy, ecological economists have begun to consider the somewhat heretical idea of a 'post-growth economy' as essential for halting the over-exploitation of the biosphere caused by the excessive extraction of energy and material resources, damaging emissions of waste materials and gases, and the degrading and destruction of natural habitats. The post-growth idea is heretical simply because continuous global economic growth is taken as a given in the modern corporate-capitalist reality and as a fundamental requirement for bringing the good life to all the peoples of the world. The necessity of economic growth for living well and the compatibility of growth with a sustainable global biosphere has been challenged by a number of authors, challenges nicely summarized a few years ago in Peter Victor's, *Managing Without Growth* and more recently by Tim Jackson's *Prosperity Without Growth* (Jackson, 2017; Victor, 2008 pp.170-174). Simply put, no growth in the world's highly developed countries is essential to halting dangerous degradations of the earth's environment, and a post-growth economy is perfectly compatible with a decent life once a certain threshold of prosperity is achieved. Other than for committed environmentalists, a post-growth economy never has had a substantial political constituency in the past, but with the emergence of increasing numbers of post-materialists around the world, the absence of such a constituency is no longer the case. Post-materialism provides a real-world value-foundation and form of life for a materially and environmentally stable, 'post-growth green economy'. This is the key proposition to be explored in the pages to follow.

The post-material silent revolution

The future spreading of a post-material silent revolution around the world, I will now argue, provides an economic and political foundation for a post-growth green economy, an outcome that may well be essential to prevent the existential threat of climate change to the global biosphere (more on this in the next section). The silent revolution will assist in bringing about such an economy for the following reasons: (1) first and foremost, post-materialists likely consume relatively less over their life-time than materialists with similar economic opportunities; (2) post-material forms of living and experiences tend to be less entropic than materialist ways of life; and most important of all (3) post-materialists are more supportive of environmental protection than others in both their attitudes and political actions.

Post-materialists are individuals whose quest in life has shifted away from the acquisition of material possessions and towards the pursuit social goals and experiences valued for their own sake largely outside the realm of market transactions (Booth, 2018a). This quest is enabled by having grown up in social environments of reasonable physical and material security that permit a lifetime focus on higher ordered purposes at the upper reaches of the hierarchy of human needs (Inglehart, 1971; Maslow, 1987). Such individuals are less interested than others in gaining riches and material possessions and achieving publicly recognized personal success according to analyses of World Values Survey, Wave 6 (2010-2014) data covering 60 countries and more than 85,000 respondents worldwide (Booth, 2018a; World Values Survey Association, 2015). Post-materialists also possess a universalist outlook meaning they desire to take positive actions to the benefit of society as a whole and for the protection of nature and the earth's environment. Adding this all up infers that post-materialists are prone to consume less in the way of material possessions over their lifetime than others with similar economic opportunities. Thus, the silent revolution in post-material values likely serves to dampen life-time consumption and the material throughput that goes with it.

Having attained a basic threshold of economic security and material possessions, post-materialists not only limit their overall demand for material goods, but as a matter of taste seek a comparatively low-entropy, form of life placing less demand on energy and materials flows to the benefit of the environment. Post-materialists are more inclined than others to reside in larger, denser cities that are more energy efficient and thus less entropic than the spread-out suburban areas so attractive to their older peers after World War II (Booth, 2018b). Energy efficiency increases with human density for such reasons as reduced human travel distances; less use of energy inefficient private motor vehicles and more use of energy efficient public transit; and lower per person consumption of private dwelling space and associated heating and cooling energy requirements (New York City, 2007; Newman & Kenworthy, 1999, 2015). In the USA a return to downtown living has been driven in part by Millennials choosing to live in high-density urban neighborhoods as opposed to spread out low-density suburbs (Birch, 2005, 2009). Even in already densely populated countries such as Germany, center-city, dense neighborhoods recently experienced a relative surge in population growth driven by younger generations (Brombach, Jessen, Siedentop, & Zakrzewski, 2017).

Complementary to higher-density living by younger generations in the USA, the rate of car ownership and the miles of driving undertaken by Millennials is less than their older peers (Polzin, Chu, & Godrey, 2014). Higher urban densities support more of the publicly shared experience opportunities afforded by parks, libraries, public squares, museums, art galleries, entertainment and sports venues, spaces for group meetings and public demonstrations, street cafes, and more that provide opportunities for a post-material mode of living (Markusen, 2006; Markusen & Gadwa, 2010; Markusen & Schrock, 2006).

In addition to being oriented to a less entropic form of life, post-materialists exhibit greater support for the environment than others in terms of both their attitudes and actions in the world (Booth, 2017; Inglehart, 1995). This support is not just a matter of personal preferences but includes such overt actions as contributing to environmental groups, attending environmental protests, and in Europe giving support to the Green Party movement.

To summarize, the long-term trend to post-materialism around the world fueled by generational replacement is a good thing for the global biosphere by fostering more energy efficient, less entropic forms of living, taking the pressure off of growing demand for material possessions that threatens the global biosphere, and increasing active political support for protecting the global biosphere. This trend lends support to the emergence of a 'post-growth green economy' as a foundation for stabilizing the global climate in particular and increasing the health of the biosphere in general.

The post-growth green economy

The concept of a post-growth green economy is inspired by the recognition that a global economic system functioning within a fixed biosphere cannot expand forever without doing substantial harm to the latter (Daly, 1991, 2018). The biosphere receives energy but only miniscule amounts of materials from the solar system of which it is a part. The economic system is totally dependent on the biosphere for both energy and matter. The laws of thermodynamics tell us that, while neither energy nor matter can be destroyed, their quality declines with human use. The economic system extracts high quality energy and materials from the biosphere and returns waste heat and low-quality waste materials back to it. The supply of energy and matter is ultimately limited as is the capacity of the biosphere to absorb resulting wastes without undue harm to biotic functioning. Accounting for this limitation, a post-growth green economy is founded on the principle that energy and materials flows in particular, and the environmental scale of the economy in general, should be capped at sustainable amounts consistent with an ecologically healthy biosphere (Booth, 1998).

Paradoxically, the problem with a post-growth green economy is not so much attaining zero growth but realizing a green economy such that energy and material flows and waste emissions are capped at sustainable levels consistent with the maintenance of global ecosystem health. The next section will focus on bringing waste emissions down to environmentally sustainable levels within the context of a post-growth economy, and the current section will address the seeming inevitability of realizing a post-growth economy.

For those countries at the upper-end of the human development hierarchy, the notion of a zero-growth economy is quickly coming to fruition. If we look at the world's high-income countries, their population fertility rate has already reached 1.6 children per female and their annual population growth rate is down to 0.64% per year and will eventually turn negative (Table 1). For the most affluent countries of the world, zero population growth or even population decline will be a fact of life in the not too distant future assuming an absence of a significant upsurge in immigration. Moreover, for this same group of countries, real GDP growth per capita is slowing as well and is down to 1.2% a year between 2000 and 2018 from 2.4% between 1980 and 2000, a 50% drop (World Bank, 2019c). With zero or even negative population growth and with the GDP annual growth rate per capita closing in on 1% or less, a no-growth economy looks to be on the way for the world's most affluent countries.

This prospect leaves us with important unresolved questions: Why are the wealthiest economies in the world tending towards zero economic growth? Is this a problem for human well-being in wealthy countries? In a world where many countries need human development and expansion of their economies to achieve a minimum threshold income necessary for the good life, is there a path to forestalling excessive climate change by mid-century and ultimately attaining sufficient economic security for all the world's citizens that would enable a global post-growth green economy?

Growth in constant dollars GDP divides into two factors: (1) growth in population, and (2) growth in real GDP per capita. Growth in population ultimately depends on the fertility rate, the number of births per female, of which the population replacement level is approximately 2.1. Over the long-run, fertility rates above this number result in population growth and below it in population shrinkage. Fertility rates appear to be heavily dependent on the level of human and economic development. Basically, as material affluence increases, fertility diminishes as shown in the data in Table 1. Approximately half the world's population (High Income plus Upper Middle Income, Table 1) now possesses a fertility rate below replacement levels at approximately 1.81 and the other half (Lower Middle Income plus Low Income, Table 1) has a fertility of approximately 3.0. With global fertility at 2.4, long-run population stability is within reach. By roughly doubling the GDP per capita for the lower half of the world's population, their fertility rate can probably be driven below 2.1. Doing so would result in an average GDP per capita for the lower half at least equal to the GDP per capita of the upper-middle income ($8,537) countries who currently possess a fertility rate of 1.9, which is below the population replacement level (Table 1). At the current GDP per capita growth rate for the lower half, a more than doubling of GDP per capita will occur in less than 30 years.

As shown by Table 1 data, in both high-income and OECD countries, GDP per capita is growing at a historically modest rate just above 1% annually. Such growth theoretically occurs from a combination of increases in the number of hours worked per capita and in output per hour worked (constant $ GDP/hours worked). Between 2000 and 2018, OECD hours worked per capita remained unchanged, while output per hour (labor productivity) has grown 1.2% annually (OECD, 2019a, 2019b, 2019c). Growth in GDP per capita is consequently due entirely to productivity growth, but at a rate that over the long run has been in decline for wealthy countries. As Tim Jackson notes, labor productivity in the world's most advanced economies has fallen steadily from a high in the 4% range just after World War II to around 2% in the 1980s and 1990s, and now to less than 1% since the turn of the century. As he also notes, the reasons for this are a matter of some contention and include a slowing in the pace of technological innovation placing a drag on the supply side of the economy and stagnant growth on the demand side of the economy dampening productivity improving investment in new production facilities (Jackson, 2017 pp. 43-46). Slower growth on the demand side of the economy is driven in part by growing economic inequality, a lack of real wage growth, and the disruptions of the 2008–2009 Great Recession (Alvaredo, Chancel, Piketty, Saez, & Zucman, 2017; Saez, 2009; Stiglitz, 2010; Wisman, 2013). A shift in the structure of modern post-industrial economy in the direction of services and away from goods can make a difference as well. Face-to-face human services intrinsically lack opportunities for labor productivity improvements, meaning that overall productivity growth is likely to shrink as the service sector expands relatively (Jackson, 2017, 170-174). In addition, since many service jobs are low-paying, a relative expansion of services can place a drag on earnings at the lower end of the social class structure (Storm, 2017) adding to economic inequality. These reasons for slower growth in productivity imply that modern capitalism possesses critical inner flaws that taken together will ultimately bring economic growth as we know it to an end.

A slowing of growth in the world's most affluent economies could also be occurring for positive reasons below the radar as a matter of public choice, and not entirely as the result of dis-functional economic arrangements. The post-material silent revolution described above amounts to a turning away from the pursuit of more material possessions to other purposes once a threshold of material security is achieved. For the total World Values Survey, Wave 6 sample, 31% of the respondents selected a majority of post-material social options for the questions behind the construction of the Inglehart post-materialism index instead of economically focused materialist options (Booth, 2018a; World Values Survey Association, 2015). This number rises to 39.8% for affluent countries in the top 25% of the human development hierarchy as measured by the Human Development Index (United Nations Human Development Program, 2018). A substantial proportion of the population in wealthy countries subscribes to post-materialist social goals, and many of those same individuals participate in post-materialist experiences outside the arena of market transactions. Engaging in such experiences likely dampens consumer spending and could well lead to a slowdown in aggregate demand growth and in economic expansion. The point is a simple one; achieving a decent and satisfying life is contingent on a minimum threshold of material wealth but 'not' on continuous economic growth once that minimum is achieved.

Table 1: Global population, gross domestic product, fertility, and carbon emissions data

Countries	Population: 2018 Millions (% World)	GDP per Capita: 2018 Constant 2010 US $	GDP: 2018 Constant 2010 US Trillion $ (% World)	Population Fertility: 2017 Births per female	Population Annual Compound Growth Rate %: 2000–2018	GDP per Capita Annual Compound Growth Rate %: 2000–2018	$C0_2$ Emissions: 2014 Million metric tons	80% $C0_2$ Decarbonization Cost per year over 30 yrs. At $32 per mt./yr Bil. US $ (% 2018 GDP)
World	7,594	10,891	82.7	2.4	1.21	1.61	36,138	925.1 (1.1%)
High Income	1,210 (15.9%)	43,559	52.7 (63.7%)	1.6	0.64	1.20	12,940	331.3 (.6%)
Upper Middle Income	2,656 (35.0%)	8,537	22.7 (27.4%)	1.9	0.75	4.50	16,827	430.8 (1.8%)
Lower Middle Income	3,023 (39.8%)	5,198	15.7 (5.3%)	2.6	1.16	4.10	4,185	107.1 (1.6%)
Low Income	705 (9.3%)	740	.5 (0.6%)	4.6	2.66	2.30	196	5.0 (0.9%)
OECD	1,304 (17.2%)	39,974	52.1 (62.9%)	1.7	0.67	1.10	9,551	244.5 (0.5%)
USA	327 (4.3%)	54,579	17.8 (21.5%)	1.7	0.83	1.11	5,254	134.5b (0.76%)
China	1,393	7,753	10,799	1.7	0.54	8.55	10, 292	263.5 (2.2%)

SOURCES: (HEAL, 2017; WORLD BANK, 2019A, 2019B, 2019C, 2019D, 2019E)

This is exactly the same point made by both Jackson and Victor in their separate works on no-growth economics (Jackson, 2017; Victor, 2008). Both note that neither happiness nor genuine social progress necessarily occurs as a consequence of GDP growth. Happiness does increase with income up to a certain minimum, but after that the rate of increase flattens out. A minimum country-level GDP per capita threshold is required to achieve relatively high life expectancy and a decent education, both essential to life-satisfaction. Beyond this threshold, post-materialists shift gears towards supporting non-economic social goals such as freedom of self-expression, having more say in all of life's arenas, and supporting a more humane society based on ideas rather than money. Post-materialism around the world bears a strong positive correlation to such basic values as being creative and doing something for the good of society and the environment (Booth, 2018a). Those who engage in post-materialist experiences desire connections with others in voluntary organizations, creative and independent activity in their work, and active political participation in the pursuit of valued social goals. These are 'intrinsic' purposes, as opposed to materialist 'extrinsic' ends sought in market transactions, and bear a strong relationship to the intrinsic values of "self-acceptance, affiliation, and a sense of belonging in the community" mentioned by Jackson as important for flourishing in a prosperous world where economic growth ceases to be a fundamental social premise (Jackson, 2017). In support of a basic human desire for realizing intrinsic values, Jackson points to a 'quiet revolution' of people accepting lower incomes to leave room in life for the simple pleasures (reading, gardening, walking, listening to music), getting involved in the *voluntary simplicity* movement, or taking part in creative and engaging activities characterized by a sense of flow (a state of heightened focus). These are exactly the kinds purposes sought by those possessing post-material values and engaging in post-material experiences, phenomena that find substantial empirical support in the World Values Survey (Booth, 2018a, 2018b).

To sum up, the world's richest countries are tending towards annual rates of economic expansion in per capita income below 1% and annual rates of population growth likely to fall below zero in the not too distant future absent significant immigration. Potential explanations for the decline in per capita income growth include a mix of structural problems on both the demand and supply side of the economy. Alternatively, the decline may not be a problem at all but simply reflect a movement by a portion of the population beyond extrinsic materialist pursuits in life to more satisfying post-materialist intrinsic purposes. Future population declines follow from fertility rates below replacement levels that have in turn resulted from relatively high rates of affluence and human development.

Climate change and achieving a green global economy

An essential environmental virtue of a post-growth economic system is the stabilizing of the extraction of energy and materials from, and waste emissions into, the global biosphere. A post-growth economic system has other environmental benefits as well including limitations on the human damage to ecosystem functioning required for both human and nonhuman species survival. Such stability in energy and materials throughputs and ecological harms doesn't necessarily mean a healthy and sustainable biosphere since existing (stable) rates of human environmental intrusions may well lead to continuing ecological degradation. In other words, certain human-caused environmental harms will have to be reduced below existing levels for a healthy and sustainable biosphere in a post-growth economy. A simple steady state in the human use of the environment will not be enough. The Global Footprint Network, for example, reports that the worldwide ecological footprint in terms of hectares of land needed to supply the world with the 2016 volume of ecological resources consumed on a sustainable basis is approximately 1.7 times the amount of land available globally. In brief, this rate of consumption is above the sustainable level, and the earth's resources will continue to degrade under steady-state consumption at the 2016 rate (Global Footprint Network, 2020). For future reference, note that if the global economy were 80% decarbonized as will be describe below, then worldwide ecological footprint would decline to approximately 0.9 times the amount of land available based on the 2016 numbers. Decarbonization would in effect eliminate the huge land requirements for carbon absorption and bring the ecological footprint into sustainability.

The most threatening of all human induced environmental harms clearly is the unsustainability of waste greenhouse gases being emitted into the global atmosphere. Even in a global no-growth economy, such emissions would continue at climate threatening rates, although these would slowly diminish over time because of improvements in energy efficiency and resulting reductions in

CO_2 emissions per unit of global GDP (currently approximately 0.6% per year) (Jackson, 2017 p.97). Currently, worldwide CO_2 emissions stand at around 36 billion metric tons annually (Table 1). To drive these emissions down by 80% at mid-century over a thirty-year period would require an annual rate of decline of approximately 5.2%. Without any concerted action to cut emissions further, no-growth global economy emissions would only decline by about 20% over 30 years to 29 billion at a 0.6% annual rate. In brief, a no-growth economy globally would not be enough to come anywhere near decarbonizing the economic system as a whole. A global no-growth economy would be a help, but it is not the final solution to the existential threat of a warming global climate. In a no growth economy, a 4.6% (5.2 - 0.6) annual reduction in emissions will be needed for 80% decarbonization in 30 years. This is indeed less than required in a 'normal-growth' global economy with GDP per capita projected to expand over the next 30 years at a rate of around 1.3% per year and population projected to grow at 0.8% per year (Jackson, 2017, p. 97). In this case the annual percent decline in emissions would need to be 6.7% per year (5.2-0.6+1.3+0.8) to achieve 80% decarbonization.

While there is nothing new or unfamiliar in the Table 1 statistics, a number of interesting messages can be gleaned from them. First, as just noted, if current trends continue the world's high-income countries are on track to be 'no-growth economies' with GDP per capita income growth trending towards zero and population growth moving into negative territory. Second, population fertility remains above the magic 2.1 stabilization rate for roughly the poorest half of the world's countries, and an annual GDP per capita above $8,500 apparently results in fertility dropping below this number. Simply put, per capita income growth of 2% per year or more over the next 30 years for the poorest half of the world's population appears to be a feasible route to bringing fertility down to population stabilizing levels. Because of the age structure of populations in low income countries, actually reaching population stability will take time and could be accelerated with a greater current commitment to family planning efforts (Sachs, 2008). Growth in per capita income for the poorest half would also be a help in getting to a basic economic security threshold capable of bringing on a shift to the pursuit of post-material values and experiences as opposed to further acquisitions of material possessions. Third, an 80% decarbonization of the global economy in the next 30 years appears to be a relative bargain, costing a bit more than 1% of global GDP per year. Setting China aside as capable of paying its own way, high-income countries could finance 80% decarbonization for the entire world (excluding China) at a cost of roughly 1.3% of their GDP per year for 30 years.[2]

The term 'Green New Deal' originated in the UK with a proposal to tackle the 2008 'Great Recession' with a large-scale program of public investments and economic reforms to expand employment, reduce economic inequality, and to create a clean energy sector for the purpose of bringing climate change to heel (Green New Deal Group, 2008). More recently, in reaction to the Trump administration's attack on USA environmental regulations and with the return of the Democratic Party to power in the House of Representatives in 2018, a Green New Deal resolution with similar purposes passed the House (U.S. House of Representatives, 2019). While the global economic future after the Covid-19 pandemic at this point is murky, the global economy will most likely enter an economic recession or even a depression with a dramatic decline in economic activity as a result of business shutdowns to bring spreading of the virus under control. To foster an economic recovery will surly require an unprecedented global economic stimulus of which investment in clean energy and other forms of decarbonization could be quite popular given that a second crisis in the form of climate change and its devastating consequences will be staring at everyone on the horizon. The beauty of a Green New Deal is its probable high degree of political acceptability. It gives environmentalists and post-materialists a project around which they can coalesce and gain political momentum; it will create large numbers of well-paying working-class jobs and potentially bring working-class disaffected populists on board

2 The decarbonization cost estimates are based on numbers for the USA in (Heal, 2017). Heal estimates 30-year decarbonization costs to fall in a best-case to worse-case range from $1.3 trillion to $4 trillion. Using the worst-worst-case figure this equals about $952 per mt for 4.2 million mt USA emissions reduction over 30 years, or about $32 per ton annually. These cost figures are likely to be similar to those faced by other high-income economies. Costs are likely to be somewhat less for countries with lower wage rates such as China. China is included in the World Bank, Upper Middle-Income country category, but that country possesses a sophisticated clean energy equipment industry already and can likely afford to achieve decarbonization using its own resources. China is already a major exporter of solar panels and other clean energy equipment and will thus benefit substantially from a global decarbonization effort. Looking at the cost estimate as a percentage of the current year GDP means that the annual cost in absolute terms will increase annually by the growth rate of GDP more than accounting for GDP related possible growth in emissions.

weaning them away from a currently emergent anti-environment authoritarian populism (Norris & Inglehart, 2019) in the process; and, last but not least, such a project could bring the majority of global business interests (fossil fuels excepted) on board by causing the global economy to flourish with a boom that creates a new clean energy sector and brings about economic recovery. The process of replacing fossil fuel with clean energy will create jobs on two counts: First, clean energy alternatives such as solar and wind will be more labor intensive than the fossil fuels they are replacing, meaning that employment in the energy sector will permanently increase as a result of the shift; and secondly, the initial investment in clean energy facilities will mean a temporary boom in employment and a surge in economic growth lasting over the transition period (Garrett-Peltier, 2017; Wei, Patadia, & Kammen, 2010).

My primary purpose here is to comment on the possible role of a Green New Deal in setting the stage for a stable and healthy global biosphere. Others have done a good job in describing how Green New Deal decarbonization can be implemented (Heal, 2017; Sachs, 2019). First and foremost, a global decarbonization project could set us on track for climate stabilization at an affordable cost, one that could easily be fully borne by the world's high-income countries, setting them back about 1.3% of their annual GDP as noted above. The financing of a global Green New Deal by high-income countries would have to be coordinated globally, perhaps through the Green Climate Fund established by the Paris Climate Accord (Green Climate Fund, 2019). An obvious virtue of such an approach to financing would be to foster greater economic equity at a global level between rich and poor as well as gaining support for decarbonization from all low and middle-income countries.

Second, in a Covid-19 economic recovery, debt-financed expenditures on decarbonization will help high income countries get back to their original levels of economic activity and also foster economic expansion in the world's middle and low-income economies.[3] The recovery of high-income economies will be advanced by producing much of the world's clean energy equipment, and the middle and low-income economies will be boosted by not only the work of installing such equipment, but by the creation of a modern energy sector that for many countries did not previously exist and can serve as a point of departure for other development projects. For the world's developing countries, decarbonization and a global Green New Deal can help push per capita GDP towards thresholds necessary to bring about zero population growth and provide enough economic security to make a 'post-material silent revolution' globally feasible.

Conclusion

The essential hypothesis here is this: The 'post-material silent revolution', enabled by the attainment of a critical level of material and physical security that permits lives less-focused on further economic achievements, sets the stage for a 'post-growth economy' that ultimately can bring the global economic system into a sustainable balance with the global biosphere. Currently, this is just a hypothesis, but one that is consistent with a shift by a significant share of the global population beyond an emphasis on materialist to post-materialist values and modes of life. This hypothesis is also consistent with, but not necessarily the entire cause of, a reduction in economic growth rates to 1% or less for many of the world's most affluent economies. Paradoxically, a Green New Deal is proposed here that will actually stimulate worldwide economic growth in the short-run and at the same time put humanity on a path to bring a halt to the existential threat of climate change. Such a stimulus will help foster recovery of the global economy from the Covid-19 economic downturn and set developing economies on a path to reasonable material security for all of humanity. More importantly, if 80% global decarbonization had already occurred, the ecological footprint as measured in

3 To finance the *Green New Deal*, high-income countries would be advised to issue long-term government backed debt-obligations to avoid the drag on economic recovery that tax-financed spending would bring. Once recovery has occurred, then debt-obligations could be slowly retired, perhaps funded by a small 'automated payment transactions' tax that would be progressive and at the same time would dampen overall financial transactions and thus contribute to sustaining a 'post-growth economy' (Feige, 2000). Such a tax would likely have a mild negative effect on consumer expenditures but could well diminish the volume of financial transactions significantly, especially those undertaken for speculative purposes. Since the bulk of payment transactions are undertaken in association with financial assets disproportionately held by the wealthy, the redistributive effects of payments transactions tax would probably be progressive.

2016 would actually have been about 0.9 rather than 1.7 due to the reduction in requirements for carbon absorption, bringing the footprint into sustainability. Whatever the level of the ecological footprint turns out to be in 2050, it will be substantially less than otherwise because of decarbonization. In brief, short-run green economic growth is needed to set the stage for a green post-growth economy consistent with a stable and healthy global biosphere. Hope does spring eternal.

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COMMENT

We know how many people the earth can support

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Abstract

A quarter century after Joel Cohen asked the essential question "How Many People can the Earth Support?", this article offers an answer, based on new science and geographical analysis, and asserts that we have long ago exceeded our planet's long term ecological carrying capacity that optimistically can only support 3 billion modern industrialized humans. While agreeing that strategies based on reducing consumption are sorely needed to live within our planet's carrying capacity, the impending explosion of the global middle class promises to render consumption-only strategies inadequate, in the face of runaway population growth and the accumulation of massive ecological debt. Noting recent studies that project global population to begin to decrease in 2064 after peaking at 9.7B, it is asked why we don't act now to accelerate this already inevitable trend with enhanced investment in women's empowerment, education, and access to family planning technologies. This paper calls for a goal of achieving 1.5 total fertility rate (TFR) by 2030 to bend the global population curve, begin relieving the ecological burden humanity has foisted on our planet, and to decrease human population as we approach 2100 to something closer to the long term ecological carrying capacity of our planet.

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Keywords: carrying capacity; ecological debt; runaway population growth; women's empowerment.

There is absolutely no doubt that runaway population growth, and our ever growing human footprint have led us to overshoot our planet's long term ecological carrying capacity. Our industrialization of the Earth's surface has systematically deleted ecosystem goods and services that our species, and all other species, rely on. As we add 80 million humans to the planet each year – the equivalent of ten New York Cities – each additional human places even more demand on our planet for resources. All the while, we steadily increase the volume and geographic spread of humanity's persistent and accumulating wastes, further burdening our ever diminishing, and already beleaguered ecological resources. Not only have we exceeded our planet's carrying capacity, but we have managed to incur an ecological debt that will take generations to pay down, if ecological catastrophe does not exact its toll on us first.

Yet, we still tend to do little but admire the global population curve as it progresses ever upwards, occasionally bantering about when it might level off, as though fertility is completely out of our collective power to affect. Before we annihilate the planet from which we evolved, and which fundamentally sustains our species, perhaps we need to change how we approach the subject of population.

The way the world once was

All of our assumptions about population today are so utterly modern. It is sometimes hard to envision how the world once was. For millennia before the industrial revolution, infant mortality was so high that despite high fertility rates, global population grew at a mere 0.04% between 10,000 BCE and 1750 AD, hovering barely above replacement level (Volk and Atkinson, 2013). Roughly, this led to a doubling of the world population, or less, every thousand years or so - until the most recent millennium. Before the dawn of our ever-improving agricultural and technical skills, humanity was just able to eke out an existence, holding well below 10 million individuals for hundreds of thousands of years. The combined power of the agricultural, industrial, and scientific revolutions transformed human existence, and led to a steady decrease in infant mortality (and maternal mortality), while decreases in fertility lagged considerably, resulting in a population explosion that we have admired as a centerpiece of modernity – part of what we rightly call 'progress'. This progress broke the stability feedback loop, allowing runaway population growth which has decimated the ecosystems that support our species, and undermined our planet's carrying capacity. Of course, we have recognized that in recent decades, the most developed nations have seen their fertility taper off without conscious policy making on the matter, in places where women have been empowered, educated, integrated into the workforce, and achieved access to family planning technologies. This, of course, raises the question why small, educated, and prosperous families are not held up as the hallmark of modernity and progress, instead of runaway population growth.

How many people can the earth support?

Joel Cohen's 1995 question is the most important question that every citizen and leader should be asking themselves and each other, every single day (Cohen, 1995). Yet, a quarter century has gone by, and we have collectively failed to take it seriously. For a variety of reasons that have been exhaustively covered elsewhere, population growth has not been a mainstream topic of discussion since the 1970s. The doubling of the world population since 1900 was openly discussed as we approached the first Earth Day in 1970 (e.g., 1.6 billion to nearly 3.7 billion). Since this first Earth Day, a half century ago, we have become transfixed by an endless stream of ecological catastrophes and human tragedies, somehow remaining silent on what has become yet another doubling of the world population from nearly 3.7 billion to more than 7.7 billion. We have refused to publicly discuss how these catastrophes and tragedies are in many ways simply symptoms of the runaway population growth that has undermined our planet's long term ecological carrying capacity.

How many people can the Earth support? In my book *A Planet of 3 Billion* (www.Planet3Billion.com), I offer my analysis, including a review and critique of a variety of approaches to calculating the Earth's carrying capacity (Tucker, 2019a). In that book, I invite everyone to differ with my analysis – if only you will show your data and your math. For the sake of this article, I will forgo a defense of my calculation, which I consider a very optimistic assessment. It is easy not to take issue with less optimistic assessments that come in lower than 3 billion. Higher assessments tend to demonstrate gaping blind spots regarding certain dimensions of humanity's vast and variegated ecological footprint.

In rough terms (give or take a billion) we actually have a very good sense of how many people the Earth can support. We know that we have overshot our planet's long term ecological carrying capacity. Even if we achieved a carbon-neutral (or even carbon-negative) society, the larger human footprint we would continue to exert on our planet, if population growth continued unchecked, would still have us exceeding our planet's carrying capacity.

Scientists' warning

The climate change community struggled for decades to gain widespread acceptance of its scientific findings. While fighting tooth and nail to get people to accept that human carbon emissions are driving climate change, this community remained largely silent on the obvious reality that the addition of more humans increases the volume of these carbon emissions. There was a cultural predisposition to blame consumption over population growth for our ever growing carbon footprint – in part to avoid inappropriately blaming poorer nations for a carbon footprint that has been overwhelmingly driven by rich nations. This all changed in November 2019, when 11,000+ scientists signed on to the "Scientists' Warning on Climate Change" in the journal BioScience – and for the first time called for the stabilization and then decrease of human population if we are to avert climate catastrophe – even assuming we were able to materially reduce consumption in the developed world, and stem growing consumption in the developing world as billions race to join the global middle class (Ripple, et.al., 2019). Some climate action advocates will no doubt take a bit of time to incorporate this scientific consensus into their orthodoxy and their calls for action. But, the seal has been broken, and runaway population growth is now a mainstream concern within the climate science, climate action, and climate restoration communities.

Unfortunately, the carbon emissions driving climate change are just one small portion of the larger human footprint. Our human footprint is much larger - perhaps 10 times larger. As I like to say, "What if climate change were twice as bad as the worst projections, and still only 1/10th of the problem that humanity has foisted on our planet?" (Tucker, 2019b). This makes the urgency of ending runaway population growth many times more urgent than that communicated in the 'Scientists Warning'.

Bending the global population curve

As we quickly approach 8 billion, adding 80+ million additional souls (again, the equivalent of 10 New York Cities) to our planet each year, so many are confused by basic statistics. Whether it is journalists or their editors, the rampant confusion over a decline in the rate of population growth versus a decline in population continues to muddy these issues in the popular mind. When icons such as Elon Musk and Jack Ma take the world stage and warn of population collapse, while we are actually facing runaway population growth, the average citizen cannot be expected to keep things straight (Clifford, 2019).

While the global Total Fertility Rate (TFR) does indeed continue to decline little by little,[2] even modest percentages of annual growth atop the existing enormous global population base means massive increases in total numbers, and massive increases in the crushing weight of humanity's ecological footprint. TFR will need to drop from the existing (2020) TFR of 2.448 (Macrotrends, 2020) to a replacement level fertility of 2.1 TFR before global population stops growing.

A recent (July 2019) Lancet article projects that we will reach this TFR of 2.1 by 2064, with global population peaking at 9.7 billion (Vollset, 2020). While somewhat controversial, this article was novel in how it broke down the factors driving population growth. This study team determined that improvements in access to modern contraception and the education of girls and women have progressed, in effect, ahead of schedule, leading fertility to decline more quickly than previously assumed. Their model has population declining to 8.8 billion by 2100 – some 2 billion lower than some of the UN Population Division's estimates.

When interviewed regarding this Lancet article, the head of the UN Population Division, John Wilmoth, characterized the bending of the global population curve as a 'problem', and surmised that it is a problem that nations' leaders will intervene to avert (Gladstone, 2020). It appears that the United Nations community has not yet made a connection between our failure to meet UN Sustainable Development Goals (SDGs) and runaway population growth. Or they, too, have been bamboozled by the cult of perpetual growth.

2 The fertility rate for World in 2019 was 2.458 births per woman, a 0.41% decline from 2018 (Macrotrends, 2020).

Interestingly, there has been no discussion about how this already inevitable bending of the global population curve might be accelerated. If it can happen by 2064, why not sooner? The Lancet analysis clearly shows how access to modern contraception and the education of girls and women can drive a decline in fertility, to below replacement level. Thus, it provides a clear roadmap to how this inevitable trend (e.g., the bending of the global population curve) might be accelerated. How much investment in access to modern contraception and the education of girls and women would be required (and in which geographies) to accelerate this inevitable trend? However, this was not the research question driving the Lancet article. Perhaps their follow up work will help answer this question.

1.5 by 2030

Of course, we are left to ask ourselves, if this curve is actually something of our own making, and not some inexorable process handed down by the gods, what should our collective goal be? If indeed, our planet's carrying capacity can support a mere 3 billion modern industrialized humans, as billions are now racing to join the global middle class, then what TFR could get us to that lower, more sustainable population plateau?

It is important to note how small changes in complex systems can lead to profound change, very quickly. And, given the urgency we face with climate change, and the threshold of 1.5C temperature rise that climate scientists and biodiversity experts have settled on as a line that should not be crossed, many have concluded that 2030 is the time horizon by which carbon emissions must end. Flattening the global population curve would not end carbon emissions. However, bringing the population curve below replacement level on the way to 2030 and beyond would certainly help alleviate the carbon burden on our planet, along with the 9 other forms of human footprint currently undermining our planet's ecological carrying capacity.

Not only could we accelerate the bending of the global population curve now, and begin alleviating the population pressure on our planet on or before 2030, but bringing the global TFR down to 1.5 would set us on a course to achieve to a global population of around 3 billion much sooner than current projections anticipate.

As such, we should ask ourselves, what would it take to bring the global TFR down to 1.5 by 2030? In truth, this is not that big a change. And again, it would simply be the acceleration of an inevitable trend that we already predict for later in the century. People need to remember that in many urban areas around the world, a TFR of 1.5 or lower is the norm. Further, all predictions indicate that a vast majority of humanity will move into urban environments over the coming decades. Investing further in the humane, ethical, and empowering strategies outlined by the Lancet report could bend the global population curve by 2030, bringing global TFR to 1.5, and perhaps even help us avert a temperature increase of 1.5C or more. Small, educated, prosperous families living in urban communities would become the species wide norm.

Pick your challenge

When faced with a challenging proposal, it is easy to throw up one's hands, and be overwhelmed by the difficulty of the task. However, we are already challenged by calls for epic, planetary-scale policy initiatives intended to bend the curve of carbon in our atmosphere and our oceans – which runaway population growth only serves to exacerbate. Similar proposals seek to bend the curves driving loss in natural habitat and biodiversity, fresh water resources, and the diminishment of so many other elements of our world ecology. Of course, runaway population growth is at the heart of all of these exasperating trends. In a very real sense, bending the global population curve makes the realization of so many of our goals so much more plausible.

We could educate more women more quickly. That is called education policy. We could integrate more women into the workforce more quickly. That is called labor policy, (micro-) finance policy, and economic policy more generally. We could empower more women more quickly, by investing in access to family planning technologies, norm shifting media interventions, and civil society initiatives. We could encourage small, educated and prosperous families. None of these policies are controversial. Many of these goals are already called out in our Sustainable Development Goals. But the order and sequencing with which we undertake these policies matters. It seems clear that an 18th SDG should be added, as a capstone, that calls for an end to the runaway population growth that is undermining our accomplishment of the other 17 SDGs.

Perhaps the 18th SDG should call for 1.5 TFR by 2030.

Empowering future generations to save our planet and our species

Without malice of forethought, we have exceeded our planet's carrying capacity. In doing this, we have put future generations in the crosshairs of ecological catastrophe and human tragedy. But, we could very easily achieve a more sustainably and equitably prosperous global society that enables everyone to live the good life within our planetary boundaries. We could even do this very quickly, through humane, ethical, and just policies. We must simply stop acting as if population growth is some unfathomable process that humanity could never craft to its own advantage, and to the benefit of the planet that gives us life.

It is entirely feasible to achieve a more just and sustainable planet – one where small, educated and prosperous families think deliberately about their impact on each other and the ecosystems that give them life. We need not force future generations to embrace the fear and uncertainty posed by the ecological calamity that awaits if we refuse to change. We need only build bridges to the rest of our brethren, across the globe, to accelerate already inevitable trends, and bend the global population curve by collectively investing in humane, ethical, and empowering strategies that will leave our world and our society better off than when we entered it.

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PEER REVIEWED ARTICLE

Population effects of increase in world energy use and CO_2 emissions: 1990–2019

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Abstract

This paper analyses population effects of increase in world energy use and CO_2 emissions between 1990–2019 following a decomposition framework with interaction effects. The analysis has also been carried out for the 44 countries which accounted for most of the increase in world energy use and CO_2 emissions during 1990–2019. Population growth was found to have a significant effect on both the increase in energy use and CO_2 emissions at the global level, although the contribution of population growth to these increases has varied widely across countries. There is a need for integrating population factors in the sustainable development processes, particularly efforts directed towards environmental sustainability.

Keywords: population; energy use; global CO_2 emissions.

Introduction

The impact of human activity on the environment can be conceptualised in terms of the use of natural resources and resulting wastes generated. The environment provides natural resources necessary for human activity. It also serves as the repository of wastes generated as a result of natural resource use. The quantum

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of natural resource use is determined by the extensiveness and intensity of natural resource use while the extent of wastes generated is determined by the efficiency of natural resource use, in addition to the extensiveness and intensity of natural resource use. The relationship between extensiveness, intensity and efficiency in deciding the quantum of natural resource use and extent of wastes generated is multiplicative, not additive. Implications of human activity on the environment, therefore, should be analysed in terms of extensiveness, intensity and efficiency of natural resource use. Such an analysis requires quantifying natural resource use and measuring its extensiveness, intensity and efficiency. Extensiveness of natural resource use can be measured in terms of the number of human beings or population size. Other things being equal, the larger the population the more the natural resource use. Intensity, on the other hand, can be measured in terms of per capita natural resource consumption. Finally, efficiency can be measured in terms of wastes generated per unit of natural resources used. Population, in this conceptualization, is an integral component of any analysis of the environmental impact of human activity. However, there is a conspicuous silence in recent years about the role of population in the debate on environmental sustainability. For example, the United Nations 2030 Agenda for Sustainable Development pays only a passing attention to population related issues and concerns in the quest to secure environmental sustainability (United Nations, 2015). Kopnina and Washington (2016) have discussed at length why population growth has been ignored in setting priorities for environmental sustainability. They conclude that without giving due attention to the population dimension of environmental sustainability, the probability of securing an ecologically sustainable future will be vanishingly small.

Concern about the implications of size and growth of population on the use of natural resources is not new and dates back to time immemorial. In ancient times, Chinese philosophers attempted to formulate an ideal proportion between land and population to ensure survival of mankind and for the development and well-being of society. The question of 'optimum population' in the context of ideal conditions for the development of the full potential of an individual was also discussed by Greek Philosophers Plato and Aristotle. Similar echoes may also be found in *Arthashastra* written by *Kautilya* in India (United Nations, 1973). During the Medieval period, availability of natural resources necessary for sustaining life was argued to be a key factor in population growth (Batero, 1589). The view prevalent at that time was that 'resources' determined population'. More than two centuries later, Malthus was the first to argue that misery and vice would result from the differential pace of growth between population and the productivity of agriculture necessary to support it (Malthus, 1960 [1798]). In the 1940s the concern about population growth shifted to natural resources, particularly energy supplies, whereas in 1950s, especially in the less developed countries, this concern revolved round physical capital (Preston, 1994). The negative effects of population growth on the environment have also been highlighted in a number of studies carried out in 1960s and 1970s (Ehrlich, 1968; Forrester, 1971; Meadows et al, 1972). In recent years, concern about the environmental impact of population growth has focused on the wastes generated as a result of natural resource use. It is argued that excessive use of natural resources is causing irreparable damage to the environment with emissions of greenhouse gasses such as carbon dioxide (CO_2) being the most glaring example of the irrational use of natural resources (Chaurasia [Ranjan], 2009).

Ehrlich (1968) was the first to propose a simple analytical framework, known as IPAT (*Impact* = *Population* x *Affluence* x *Technology*) framework, for an *ex post* analysis of the environmental impact of human activity. This framework describes how natural resource use can be explained in terms of extensiveness (*population size*), intensity (*per capita natural resource use*) and efficiency (*wastes generated per unit of natural resource use*). This simple yet straightforward analytical framework has been criticized for a number of perceived flaws (O'Neil and Chen, 2002), but it has almost become the norm in analysing population effects of the environment. The framework illustrates the multiplicative nature of relationship among driving factors of natural resource use as each factor amplifies changes in other factors. A small change in population induces a small absolute impact on natural resources use in a country with low-income and low intensity of natural resources use but much greater effect in a high-income country where intensity of natural resources use is high (O'Neil and Chen, 2002).

There have been efforts to improve the simple *IPAT* framework. Notable among these efforts is the stochastic version of the framework known as STIRPAT framework (Dietz and Rosa, 1994; Dietz, Rosa and York, 2007; Chertow, 2001). Another framework is the *ImPACT* framework which divides the affluence component of the *IPAT* framework into two components separating energy use per capita from income per capita (Waggoner and Ausubel, 2002). In this framework, which is based on the Kaya identity (Kaya, 1990), population, per capita income, natural resource use per capita and waste generated per unit of natural resource use determine the impact of human activity on the environment. I have previously used this framework to analyse the change in natural resource use and waste generated in the world during 1990–2000 and found that although the main driver of the environmental impact of human activity was the increase in per capita income or affluence, the effect of population growth on the environment was quite substantial. The debate about the environmental impact of population growth, however, remains inconclusive. Different perspectives on the effect of population size on the environment have been discussed by Weber and Sciubba (2019) who have argued that one reason for the prevailing inconclusiveness is the approach of these analyses. Most of the population-environment impact analyses are based on cross-country data which suffer from high level of dissimilarity and strong collinearity among factors that influence both increase in natural resource use and resulting wastes generated. Onanuga (2017) has analysed population elasticity of CO_2 emissions in 26 African countries on the basis of time series data for the period 1971–2013 and observed that the response of emissions to population growth has a limiting effect in some countries but a contributory effect in others. Shi (2003) found a direct relationship between population change and CO_2 emissions in 93 countries during 1975–1996. A similar result has also been obtained by Cole and Neumayer (2004).

In this paper, I carry out an *ex post* analysis of the contribution of population change to the change in energy use and CO_2 emissions in the world and in its 44 countries during 1990–2019. The 44 countries included in the present analysis account for nearly all the increase in world energy use and CO_2 emissions. The paper also carries out country-specific analyses to highlight population effect of the environment as reflected through the increase in energy use and CO_2 emissions. The paper separates the direct effect of population change from its indirect effect that works through the change in the intensity and efficiency of natural resources use. The findings of the analysis emphasise the need for population factors to be integrated in efforts directed towards securing environmental sustainability.

The paper is organised as follows. The next section of the paper outlines the methodology. I use a decomposition framework with interaction effects to estimate the contribution of organized population change to the change in energy use and CO_2 emissions. Section three describes the data source. The analysis is based on the data made available by EnerData, an independent research and consulting firm. Section four presents a snapshot of the trend in energy use and CO_2 emissions along with the trend in population, consumption and technology. Results of the decomposition analysis are presented in section five. The last section discusses policy implications in the context of sustainable development.

Analytical framework

Let *E* denote the total energy use and *P* denote population size. Then, total energy use may be written as at product of population size and per capita energy use

$$E = P * \left(\frac{E}{P}\right) \tag{1}$$

It is well-known that there is a linear relationship between per capita income and per capita energy use (Cole et al, 1997; Suri and Chapman, 1998). If *G* denotes the real gross domestic product (GDP), then equation (1) may be extended as

$$E = P * \left(\frac{G}{P}\right) * \left(\frac{E/P}{G/P}\right) = P * A * U \tag{2}$$

where *A*=*G*/*P* is the per capita real GDP which is a commonly used indicator of per capita income and the ratio *U*=(*E*/*P*)/(*G*/*P*)=(*E*/*G*) is the ratio of per capita energy use to per capita real GDP. It is known as the energy intensity of GDP.

Extending the above arguments further, total CO_2 emissions, as a result of energy use may be written as

$$C = E * \left(\frac{C}{E}\right) = P * \left(\frac{E}{P}\right) * \left(\frac{C}{E}\right) = P * \left(\frac{G}{P}\right) * \left(\frac{E/P}{G/P}\right) * \left(\frac{C/P}{E/P}\right) = P * A * U * T \tag{3}$$

where *T*=(*C*/*P*)/(*E*/*P*)=(*C*/*E*) is CO_2 emissions per unit energy use and is termed as carbon intensity of energy use. The change in energy use and CO_2 emissions between two points in time $t_2 > t_1$, can be captured in relative terms and in absolute terms. In relative terms, the change in energy use and CO_2 emissions can be written as

$$r_E = \left(\frac{E_2}{E_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{A_2}{A_1}\right) * \left(\frac{U_2}{U_1}\right) = r_P * r_A * r_U \tag{4}$$

$$r_C = \left(\frac{C_2}{C_1}\right) = \left(\frac{P_2}{P_1}\right) * \left(\frac{A_2}{A_1}\right) * \left(\frac{U_2}{U_1}\right) * \left(\frac{T_2}{T_1}\right) = r_P * r_A * r_U * r_T \quad (5)$$

Equations (4) and (5) may also be written as

$$a_E = a_P + a_A + a_U \quad (6)$$

$$a_C = a_P + a_A + a_U + a_T \quad (7)$$

where a_E=ln(r_E), etc. Equations (6) and (7) are true by definition which means that naive regression or correlation approaches, that ignore the sum constraint, are potentially problematic in explaining how inter-country variation in a_P, a_A, and a_U influences inter-country variation in a_U and inter-country variation in a_P, a_A, a_U, and a_T influences inter-country variation in a_C. To overcome this problem, Preston (1996) has suggested to decompose the inter-country variation in a_E or a_C in terms of inter-country variation in a_P, a_A, a_U and a_T. The inter-country variance in a_E can be decomposed as

$$Var(a_E) = [Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U)] + [Var(a_A) + Cov(a_A, a_P) + Cov(a_A, a_U)] + [Var(a_U) + Cov(a_U, a_P) + Cov(a_U, a_A)] \quad (8)$$

where *Var* denotes the variance and *Cov* denotes the covariance. The contribution of the change in population to the change in energy use may now be measured in terms of the proportion of the inter-country variance in a_E explained by the inter-country variance in a_P:

$$V_{P/E} = \frac{Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U)}{Var(a_E)} \quad (9)$$

Similarly, the inter-country variance in a_C can be decomposed as:

$$Var(a_C) = [Var(a_P) + Cov(a_P, a_A) + Cov(a_P, a_U) + Cov(a_P, a_T)]$$

$$+[Var(a_A) + Cov(a_A, r_P) + Cov(a_A, r_U) + Cov(a_A, r_T)]$$

$$+[Var(a_U) + Cov(a_U, r_P) + Cov(a_U, a_A) + Cov(a_U, a_T)] + [Var(a_T) +$$

$$Cov(a_T, r_P) + Cov(a_T, a_A) + Cov(a_T, a_U)] \qquad (10)$$

and the inter-country variance in a_C attributed to the inter-country variance in a_P to the inter-country variance in a_C may be obtained as

$$V_{P/C} = \frac{Var(a_P)+Cov(a_P,a_A)+Cov(a_P,a_U)+Cov(a_P,a_T)}{Var(a_C)} \qquad 11$$

It may be noted that the contribution of inter-country variance in a_P to the inter-country variance in a_E or a_C may be small for two reasons. First, the contribution of inter-country variance in a_P to the inter-country variance in a_E or a_C may be small because a_P varies little across countries so that the corresponding variance and covariance terms in equation (8) and (10) are small. Second, even if a_P varies substantially across countries, the contribution of inter-country variance in a_P to the inter-country variance in a_E or a_C may still be small because covariance terms in equations (8) and (10) are negative so that the algebraic sum of variance and covariance terms is small. In this case, equations (9) and (11) may not reflect the true importance of inter-country variance in a_P in explaining the inter-country variance in a_E or a_C. To circumvent this problem, it is suggested to use absolute values of covariance in equations (9) and (11) (Horvitz et al, 1997; Rees et al, 2010: Rees et al, 1996). In other words, the importance of the inter-country variance in a_P to the inter-country variance in a_E can then be obtained as

$$I_{P/E} = \frac{Var(a_P)+|Cov(a_P,a_A)|+|Cov(a_P,a_U)|}{S} \qquad (12)$$

where S is the sum of the absolute values of the terms on the right-hand side of equation (8). Similarly, the relative importance of the inter-country variance in a_P to inter-country variance in a_C may then be obtained as

$$I_{P/C} = \frac{Var(a_P)+|Cov(a_P,a_A)|+|Cov(a_P,a_U)|+|Cov(a_P,a_T)|}{V} \quad (13)$$

where V is the sum of the absolute values of the terms on the right-hand side of equations (11).

On the other hand, the absolute change in the energy use between two points in time $t_2>t_1$ can be decomposed as:

$$\begin{aligned} d_E = E_2 - E_1 &= (P_2 * A_2 * U_2) - (P_1 * A_1 * U_1) \\ &= \big((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U)\big) - (P_1 * A_1 * U_1) \\ &= (d_P * A_1 * U_1) + (P_1 * d_A * U_1) + (P_1 * A_1 * d_U) + (d_P * d_A * U_1) \\ &\quad + (d_P * A_1 * d_U) + (P_1 * d_A * d_U) + (d_P * d_A * d_U) \\ &= \partial P + \partial A + \partial U + \partial P \partial A + \partial P \partial U + \partial A \partial U + \partial P \partial A \partial U \end{aligned} \quad (14)$$

where $\partial P=(P_2 - P_1)$, etc. The first three terms on the right-hand side of equation (14) reflect the main effects, the next three terms reflect the first order or two-way interactions while the last term reflects the second order or three-way interaction among population, per capita real GDP and energy intensity of GDP. The advantage of the decomposition given by equation (14) is that it shows both direct and indirect effects of the change in population, per capita real GDP and energy intensity of GDP as they affect the change in the energy use. Although, interaction effects are difficult to interpret (Preston, Heuveline, Guillot, 2001), yet they provide useful insights into how population growth (increase in extensiveness of natural resources use) interacts with the change in per capita real GDP and the change in the energy intensity of GDP in influencing the change in natural resource use. The change in per capita GDP and the change in the energy intensity of GDP, in combination, determine the intensity of natural resource use.

Similarly, change in CO2 emissions can be decomposed as

$$d_C = C_2 - C_1 = (P_2 * A_2 * U_2 * T_2) - (P_1 * A_1 * U_1 * T_1)$$

$$= \big((P_1 + d_P) * (A_1 + d_A) * (U_1 + d_U) * (T_1 + d_T)\big) - (P_1 * A_1 * U_1 * T_1)$$

$$= (d_P * A_1 * U_1 * T_1) + (P_1 * d_A * U_1 * T_1) + (P_1 * A_1 * d_U * T_1)$$

$$+ (P_1 * A_1 * U_1 * d_T) + (d_P * d_A * U_1 * T_1) + (d_P * A_1 * d_U * T_1)$$

$$+ (d_P * A_1 * U_1 * d_T) + (d_P * d_A * d_U * T_1) + (d_P * d_A * U_1 * d_T)$$

$$+ (d_P * A_1 * d_U * d_T) + (P_1 * d_A * d_U * d_T) + (d_P * d_A * d_U * d_T)$$

$$= \delta P + \delta A + \delta U + \delta T + \delta P\delta A + \delta P\delta U + \delta P\delta T + \delta A\delta U + \delta A\delta T + \delta U\delta T +$$

$$\delta P\delta A\delta U + \delta P\delta A\delta T + \delta P\delta U\delta T + \delta A\delta U\delta T + \delta P\delta A\delta U\delta T \qquad (15)$$

In order to estimate total effect of population change on the change in energy use and CO_2 emissions, it is necessary to distribute the interaction effect across interacting factors. Kim and Strobino (1984) have applied Goldfield's rule (Durand, 1948, p.220) of "allocating interactions to different individual factors on the principle of equal distribution of all factors involved in each interaction" to allocate interaction effects to individual factors. In contrast, I have previously applied principal component analysis to determine relative weights of factors involved in interaction term (Chaurasia, 2017). Alternatively, weights may also be determined on the basis of the relative increase in factors involved in different interaction terms. For example, weight for the change in population in the interaction term $\partial P\partial A$ in equation (14) may be estimated as

$$w_{P/A} = \frac{\left|\ln\left(\frac{P_2}{P_1}\right)\right|}{\left(\left|\ln\left(\frac{P_2}{P_1}\right)\right| + \left|\ln\left(\frac{A_2}{A_1}\right)\right|\right)} \qquad (16)$$

weights for other factors involved in different interaction terms may also be obtained in a similar manner.

The change in energy use and CO_2 emissions between two points in time $t_2 > t_1$ may also be decomposed as

$$d_E = \frac{d_E}{a_E} a_E = \frac{d_E}{a_E} a_P + \frac{d_E}{a_E} a_A + \frac{d_E}{a_E} a_U \qquad (17)$$

and

$$d_C = \frac{d_C}{a_C} a_C = \frac{d_C}{a_C} a_P + \frac{d_C}{a_C} a_A + \frac{d_C}{a_C} a_U + \frac{d_C}{a_C} a_T \qquad (18)$$

The decomposition given by equations (17) and (18) is known as logarithmic mean Divisia index (LMDI) factor decomposition. It is one of the index decomposition analysis (IDA) approaches widely used in energy and environmental economics (Chen et al, 2020; Hammond and Norman, 2012; Kumbaroglu, 2011). This decomposition was proposed by Ang and Liu (2001) and further developed by Ang (2004; 2005; 2015). Bacon and Bhattacharya (2007) have applied this approach to analyse the impact of growth on CO_2 emissions during 1994-2004 in 70 countries of the world. The decomposition given by equations (17) and (18), however, provides little insight into direct and indirect effects of change in factors of energy use and CO_2 emissions. In fact, decomposition given by equations (17) and (18) is actually an arithmetic manipulation of equations (6) and (7). Like equations (6) and (7), equations (17) and (18) also treat different factors as independent of each other when analysing the change in energy use and CO_2 emissions.

Based on equation (14), the population effect of the change in energy use can be estimated as

$$P_E = \partial P + \omega_{P/A} \partial P \partial A + \omega_{P/U} \partial P \partial U + \omega_{P/AU} \partial P \partial A \partial U \qquad (19)$$

Similarly, the population effect of the change in CO_2 emissions can be estimated as

$$P_C = \delta P + \nu_{P/A} \delta P \delta A + \nu_{P/U} \delta P \delta U + \nu_{P/T} \delta P \delta T + \nu_{P/AU} \delta P \delta A \delta U +$$

$$\nu_{P/AT} \delta P \delta A \delta T + \nu_{P/UT} \delta P \delta U \delta T + \nu_{P/AUT} \delta P \delta A \delta U \delta T \qquad (20)$$

Data source

The analysis is based on estimates of total energy use, CO_2 emissions and energy intensity of GDP for the world and for 44 countries for the period 1990–2019 prepared by Enerdata, an independent information and consultancy firm (Enerdata, 2020). In addition, estimates of population prepared by the United Nations Population Division (United Nations, 2019) have been used in the present analysis. The energy use has been defined as the balance of the primary energy production, external energy trade, marine bunkers and stock changes including biomass. Estimates of energy use for the world include marine bunkers also but they are not included while estimating energy use in different countries (Enerdata, 2020).

On the other hand, estimates of CO_2 emissions are confined to emissions from fossil fuel combustion (coal, oil and gas) only. They have been estimated following the methodology proposed by the United Nations Framework Convention for Climate Change (UNFCCC, 2009). Moreover, the energy efficiency of GDP has been calculated as the ratio of total energy use to real GDP which has been measured in terms of 2015 US$ purchasing power parity while carbon intensity of energy use is measured as CO_2 emissions per unit energy use. The 44 countries that have been included in the present analysis accounted for more than 86 percent of the world energy use, almost 92 percent of the world CO_2 emissions and around 72 per cent of the world population in 2019. Collectively, they primarily determine the level and trend in world energy use and CO_2 emissions.

Global trend in energy use and CO_2 emissions

Total energy use in the world increased by more than 64 percent during 1990–2019, from 8756 million of tonnes of oil equivalent (Mtoe) in 1990 to 14378 Mtoe in 2019 whereas CO_2 emissions increased by more than 61 percent, from 20311 miillion tonnes (Mt) in 1990 to 32741 Mt in 2019. The world population increased by almost 45 percent during this period, from 5.327 billion to 7.713 billion, per capita real GDP at 2015 US$ purchasing power parity increased by almost 80 percent, from 9440 to 16982, energy intensity of GDP decreased by almost 37 percent, from 0.174 to 0.110 and carbon intensity of energy use decreased by less than 2 percent, from 2.320 to 2.277 between 1990 and 2019 (appendix table 1). The trend in energy use and CO_2 emissions and factors that determine them has, however, not been linear but changed frequently as revealed through "joinpoint" regression analysis (Kim et al, 2000) which studies the variation in trends over time. It identifies the time point(s), or joinpoint(s), at which the trend in the variable of interest changes and then estimates the trend between two joinpoint(s) in terms of annual percent change. The Joinpoint Trend Analysis software developed by National Cancer Institute of United States of America (NCI, 2013) has been used for carrying out the joinpoint regression analysis.

Application of joinpoint regression analysis reveals that the trend in world energy use changed three times during 1990–2019 (appendix table 2). The annual percent change in the world energy use was 1.401 percent during 1990–2001 but increased to 3.289 percent during 2001–2006. After 2006, the annual percent change decreased to 1.877 percent during 2006-2012 and to 1.184 percent during 2012–19. On the other hand, the trend in global CO_2 emissions changed four times. The annual percent change in global CO_2 emissions was just 0.120 percent during 1990–1992 but increased to 1.579 percent during 1993–2002 and to 4.396 percent during 2002–05. After 2005, the annual percent change in CO_2 emissions decreased to 2.219 percent during 2005–2012 and to only 0.683 percent during 2012–2019. Similarly, the trend in all the factors of energy use and CO_2 emissions also changed frequently. The trend in population changed five times; the trend in real per capita GDP changed three times; the trend in energy intensity of GDP changed five times; and the trend in carbon intensity of energy use changed two times. The annual percentage change in population decreased in every time period whereas the annual percentage change in real per capita GDP was the highest during 2003–2006. The decrease in energy intensity of GDP, as reflected in annual percentage change, was very rapid during 2004–2007 and again during 2010–2019. Finally, the carbon intensity of energy use increased during 1999–2013 but decreased quite rapidly thereafter.

The change in both energy use and CO_2 emissions varied widely across the 44 countries included in the present analysis (Table 3). The energy use and CO_2 emissions did not increase in all countries included in the present analysis. There are 11 countries where energy use decreased and 13 countries where CO_2 emissions decreased during the period under reference. The decrease in both energy use and CO_2 emissions has been the most rapid in Ukraine while the increase in both energy use and CO_2 emissions has been the most rapid in Malaysia. Among factors of energy use and CO_2 emissions, population increased in all but four countries – Poland, Romania, Russia and Ukraine – whereas per capita real GDP increased in all but three countries – Ukraine, Venezuela and United Arab Emirates. By comparison, energy intensity of GDP decreased in 36 countries while carbon intensity of energy use decreased in 30 countries.

More than two thirds of the global increase in energy use during 1990-2019 has been confined to only five countries – China, India, United States of America, South Korea and Iran. These five countries accounted for more than 43 percent of the world population in 2019. On the other hand, more than 80 percent of the global increase in CO_2 emissions was confined to only four countries – China, India, Iran and Indonesia. These four countries accounted for almost 41 percent of the world population in 2019. China, the most populous country of the world and accounting for almost 19 percent of the world population in 2019, was responsible for almost 43 per cent of the global increase in the energy use and more than 60 per cent of the global increase in the CO_2 emissions during 1990-2019. India, the second most populous country of the world and accounting for almost 18 percent of the world population in 2019, accounted for around 11 percent of the increase in world energy use and around 13 per cent of the global increase in CO_2 emissions.

The decomposition of the inter-country variance in the increase in energy use and CO_2 emissions is presented in table 4 (see appendix). The primary contributor to inter-district variance in the change in both energy use and CO_2 emissions is found to be inter-country variance in the change in per capita real GDP followed by the change in the energy intensity of GDP. The inter-country variance in population change has been found to be responsible for around 20 per cent of the inter-country variance in the change in both energy use and CO_2 emissions. A more revealing observation of table 4 is that inter-country variance in the change in carbon intensity of energy use is found to be responsible for only around 7 per cent of the inter-country variance in the change in CO_2 emissions.

Population effects of energy use and CO_2 emissions

Table 5 (see appendix) decomposes the increase in world energy use and CO_2 emissions into its different factors in conjunction with equations (14) and (15). Between 1990 and 2015 total energy use in the world increased by 5622 Mtoe. Population growth accounted for an increase of 3933 Mtoe whereas increase in real per capita GDP accounted for an increase of 6664 Mtoe. However, decrease in energy intensity of GDP resulted in a decrease of 4975 Mtoe in the world energy use during this period. Similarly, population growth accounted for an increase of 8962 Mt in CO_2 emissions while increase in per capita real GDP accounted for an increase of 15181 Mt. By comparison, decrease in energy intensity of GDP resulted in a decrease of 11336 Mt while decrease in carbon intensity of energy use resulted in a decrease of only 377 Mt during 1990–2019.

The contribution of the change in different factors to the change in energy use (appendix table 6) and CO_2 emissions (appendix table 7) has varied widely across 44 countries. Ukraine is the only country where all factors contributed to the decrease in energy use and CO_2 emissions. On the other hand, Brazil is the only country where all factors contributed to increase in energy use and CO_2 emissions. There are 12 countries where energy intensity of GDP decreased but carbon intensity of energy use increased; 6 countries where energy intensity of GDP increased but carbon intensity of energy use decreased. This leaves only 24 countries where both energy intensity of GDP and carbon intensity of energy use decreased during 1990–2019.

An idea about the effect of population on the environment may be made by relating the change in energy use attributed to population change to the change in the energy use attributed to change in energy intensity of GDP. This relationship may be captured by calculating the population effect coefficient of the change in energy use (PEC_E) as

$$PEC_E = \begin{cases} -\left(\dfrac{d_P}{d_U}\right) \; if\ P\ and\ U\ change\ in\ opposite\ directions \\ \left(\dfrac{d_P}{d_U}\right) \; if\ P\ and\ U\ change\ in\ the\ same\ direction \end{cases}$$

The PEC_E reflects the proportion of the decrease in energy use attributed to the decrease in the energy intensity of GDP which is offset by the increase in energy use attributed to the increase in population irrespective of the change in energy use attributed to the change in per capita real GDP when population increases but the energy intensity of GDP decreases. Arguing in the same manner, the population effect coefficient of the change in CO_2 emissions (PEC_C) may be defined as

$$PEC_C = \begin{cases} -\left(\dfrac{d_P}{d_U + d_T}\right) \; if\ P\ and\ (U+T)\ change\ in\ opposite\ directions \\ \left(\dfrac{d_P}{d_U + d_T}\right) \; if\ P\ and\ (U+T)\ change\ in\ the\ same\ direction \end{cases}$$

Table 8 (see appendix) gives the population effect coefficient of the change in energy use and CO_2 emissions for the world and for 44 countries. For the world as a whole, the population effect coefficient is 0.802 for energy use and 0.771 for CO_2 emissions. This means that more than 80 per cent of the decrease in energy use resulting from the reduction in the energy intensity of GDP has been offset by the increase in population. Similarly, over 77 per cent of the reduction in CO_2 emissions resulting from the decrease in the energy intensity of GDP and the decrease in the carbon intensity of energy use has been offset by the increase in population.

The population effect coefficient of energy use varies widely across 44 countries. The energy intensity of GDP decreased in 32 countries between 1990 and 2019 and the population effect coefficient, in these countries, ranged from just 0.047 in Czech Republic to 5.345 in Malaysia. A population effect coefficient of 0.047 implies that the increase in energy use as a result of the increase in population offset only 4.7 per cent of the decrease in energy use as a result of the decrease in energy intensity of GDP. Similarly, a population effect coefficient of 5.345 implies that that increase in energy use as a result of population increase is more than five times the decrease in energy use as a result of the decrease in energy intensity of GDP.

On the other hand, the energy intensity of GDP increased in eight countries and the population effect coefficient, in these countries, ranged from 0.677 in Iran to 24.011 in United Arab Emirates. This means that the increase in energy use as a result of population growth in Iran was almost 68 per cent of the increase in energy use as a result of the increase in energy intensity of GDP but 24 times higher in United Arab Emirates. Finally, in four countries, both population and energy intensity of GDP decreased during 1990-2019. In these countries, population effects coefficient ranged from 0.002 in Poland to 0.250 in Ukraine which means that the decrease in energy use as a result of decrease in population is almost negligible compared to the decrease in energy use as a result of the decrease in the energy intensity of GDP in Poland but 25 per cent in Ukraine. There is no country where population decreased but energy intensity of GDP increased during the study period. A similar pattern may also be observed in the population effect coefficient of CO_2 emissions with the only difference being that the variation of the population effect coefficient across different groups of countries is even wider.

Discussions and conclusions

The present analysis highlights the substantial impact of population growth on the increase in energy use and CO_2 emissions in the world during 1990-2019. The impact of population growth is further compounded because of the increase in per capita real GDP which is universally recognised as one of the key monetary indicators of social and economic development and of quality of life. The analysis also shows that, at the global level, the positive environmental effects of the decrease in energy intensity of GDP and carbon intensity of energy use can offset only a part of the negative environmental effects of population growth and increase in per capita real GDP. The positive environmental effect of the decrease in carbon intensity of energy use has, however, been marginal compared to the positive environmental effect of the decrease in the energy intensity of GDP.

The analysis suggests that reducing and ultimately achieving zero population growth can contribute significantly towards environmental sustainability by considerably decelerating the increase in energy use and CO_2 emissions in the world. However, such an option does not appear to be strategically viable in the context of United Nations 2030 Sustainable Development Agenda (United Nations, 2015) which characterises sustainable development in terms of economic growth, social inclusion and environmental sustainability. It is well known that population growth is an important contributor to economic growth (Peterson, 2017; Chaurasia, 2020). In India, for example, population growth during 2001-2011 accounted for almost 22 percent of the increase in the output of Indian economy (Chaurasia, 2019). Moreover, a low or zero population growth leads to an ageing population and insufficient people of productive age to support the economy (Pace, 1971). A certain minimum threshold of population growth, therefore, is necessary to lessen the burden of supporting a large number of old people (Peterson, 2017). At the same time, continued very low population growth for a long period of time may still lead to substantial increase in population (Piketty, 2014). For example, population growth at an average annual rate of 0.8 percent during 1700 to 2015 resulted in about 12 times increase in the world population (Maddison, 2001; World Bank, 2017).

Reducing population growth to very low levels will also have implications for the social inclusion component of United Nations 2030 Sustainable Development Agenda. The economic analysis of inequality indicates that lower population growth will lead to increased global and national income inequality (Peterson, 2017). When the rate of return to capital is greater than the economic growth rate, the likely result is the concentration in the ownership of capital leading to increasing inequality (Piketty, 2014). The future, economic growth is likely to be slower than the rate of return on capital because the demographic component of economic growth will grow very little in the coming years (Piketty, 2015). Obviously, reducing and ultimately achieving zero population growth may not be a strategically viable option for realising the United Nations 2030 Sustainable Development Agenda.

The present analysis highlights the need of integrating population as a factor in environmental sustainability in the United Nations 2030 Sustainable Development Agenda. This integration must recognise that extensiveness, intensity and efficiency of natural resource use interact with each other to determine the extent of natural resource use and wastes generated. This integration is all the more important because the three factors of natural resource use are very much country specific. Unfortunately, the United Nations 2030 Sustainable Development Agenda pays only lop-sided attention to these interactions which are the key to sustaining life on the planet Earth.

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Appendix

Table 1: Energy use, CO_2 emissions, population, per capita real GDP, energy intensity of GDP and carbon intensity of energy use in the world, 1990–2019

Year	Energy use (Mtoe)	CO_2 emissions (Mt)	Population (000)	Per capita real GDP (2015 US$ PPP)	Energy intensity of GDP	Carbon intensity of energy use
1990	8756	20311	5327231	9440	0.174	2.320
1991	8811	20445	5414289	9399	0.173	2.320
1992	8821	20382	5498920	9415	0.170	2.311
1993	8911	20486	5581598	9439	0.169	2.299
1994	8980	20585	5663150	9577	0.166	2.292
1995	9209	21063	5744213	9752	0.164	2.287
1996	9437	21526	5824892	9988	0.162	2.281
1997	9536	21896	5905046	10244	0.158	2.296
1998	9582	22054	5984794	10361	0.155	2.302
1999	9788	22193	6064239	10581	0.153	2.267
2000	10015	22836	6143494	10938	0.149	2.280
2001	10103	23194	6222627	11055	0.147	2.296
2002	10321	23511	6301773	11222	0.146	2.278
2003	10685	24563	6381185	11500	0.146	2.299
2004	11167	25708	6461159	11953	0.145	2.302
2005	11471	26624	6541907	12360	0.142	2.321
2006	11813	27454	6623518	12850	0.139	2.324
2007	12132	28389	6705947	13364	0.135	2.340
2008	12279	28597	6789089	13578	0.133	2.329
2009	12177	28332	6872767	13364	0.133	2.327
2010	12843	29918	6956824	13891	0.133	2.330

2011	13040	30699	7041194	14274	0.130	2.354
2012	13245	31184	7125828	14570	0.128	2.354
2013	13416	31748	7210582	14891	0.125	2.366
2014	13595	31811	7295291	15236	0.122	2.340
2015	13637	31759	7379797	15571	0.119	2.329
2016	13720	31704	7464022	15903	0.116	2.311
2017	13970	32099	7547859	16309	0.113	2.298
2018	14287	32805	7631091	16698	0.112	2.296
2019	14378	32741	7713468	16982	0.110	2.277

Table 2: Annual percent increase in energy use and CO_2 emissions in the world, 1990–2019.

Energy use		CO2 emissions		Population		Per capita real GDP		Energy intensity of GDP		Carbon intensity of energy use	
Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase	Period	Annual % increase
1990–2001	1.401	1990–1993	0.120	1990–1992	1.612	1990–1993	-0.077	1990–1996	-1.179	1990–1999	-0.198
2001–2006	3.289	1993–2002	1.579	1992–1996	1.453	1993–2003	2.035	1996–2001	-1.881	1999–2013	0.255
2006–2012	1.877	2002–2005	4.396	1996–2001	1.328	2003–2006	3.745	2001–2004			
2012–2019	1.184	2005–2012	2.219	2001–2010	1.246	2006–2019	2.163	2004–2007			
		2012–2019	0.683	2010–2015	1.187			2007–2010			
				2015–2019	1.109			2010–2019			
1990–2019	1.770	1990–2019	1.651	1990–2019	1.285	1990–2019	2.047	1990–2019			
Number of joinpoints											
3		4		5		3		5		2	

SOURCE: AUTHOR'S CALCULATIONS

Table 3: Energy use, CO_2 emissions, population, real per capita GDP, energy intensity of GDP and carbon intensity of energy use in 44 countries of the world 1990 and 2019.

Country	Energy use (Mtoe)		CO2 emissions (Mt)		Population (000)		Per capita real GDP (2015 US$ PPP)		Energy intensity of GDP		Carbon intensity of GDP	
Year	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019
Algeria	22	62	53	147	25759	43053	10998	14547	0.078	0.099	2.388	2.368
Argentina	46	82	101	171	32619	44781	12146	19071	0.116	0.097	2.195	2.070
Australia	86	136	261	395	16961	25203	30276	47873	0.168	0.113	3.034	2.910
Belgium	48	55	107	98	10007	11539	33281	47270	0.144	0.100	2.224	1.790
Brazil	141	288	194	410	149003	211050	11045	15340	0.085	0.089	1.377	1.422
Canada	211	295	430	569	27541	37411	32504	46086	0.236	0.171	2.036	1.927
Chile	14	39	31	86	13275	18952	9146	23245	0.115	0.089	2.209	2.205
China	874	3284	2257	9729	1176884	1433784	1572	17907	0.472	0.128	2.582	2.963
Colombia	24	40	46	83	33103	50339	8254	14535	0.089	0.055	1.902	2.059
Czech Republic	50	43	147	100	10341	10689	22026	37486	0.219	0.108	2.960	2.311
Egypt	32	95	78	215	56134	100388	6299	12173	0.091	0.077	2.432	2.272
France	225	241	365	302	56667	65130	32854	44472	0.121	0.083	1.627	1.250
Germany	351	296	953	673	79054	83517	34247	50042	0.130	0.071	2.714	2.277
India	306	913	523	2222	873278	1366418	2035	7541	0.172	0.089	1.710	2.433

Table 3: Continued

Country	Energy use (Mtoe)		CO2 emissions (Mt)		Population (000)		Per capita real GDP (2015 US$ PPP)		Energy intensity of GDP		Carbon intensity of GDP	
Year	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019	1990	2019
Indonesia	99	269	148	581	181413	270626	4940	12875	0.110	0.077	1.498	2.159
Iran	69	258	181	638	56366	82914	12137	17346	0.101	0.179	2.615	2.476
Italy	147	149	398	318	57048	60550	33259	38375	0.077	0.064	2.711	2.131
Japan	440	421	1040	1045	124505	126860	32398	42034	0.109	0.079	2.362	2.483
Kazakhstan	73	89	236	266	16384	18551	13907	27200	0.322	0.176	3.217	3.000
Kuwait	9	36	28	94	2095	4207	40480	70181	0.107	0.120	3.081	2.659
Malaysia	21	93	51	244	18030	31950	11274	30986	0.104	0.094	2.391	2.624
Mexico	124	178	264	433	83943	127576	14193	18703	0.104	0.074	2.135	2.441
Netherlands	67	71	163	170	14965	17097	34378	54727	0.129	0.076	2.455	2.398
New Zealand	14	20	22	33	3398	4783	24675	40476	0.163	0.104	1.582	1.624
Nigeria	66	168	28	87	95212	200964	3589	5655	0.194	0.148	0.426	0.518
Norway	21	27	28	40	4247	5379	40412	61722	0.123	0.082	1.323	1.471
Poland	103	103	356	302	37960	37888	10937	31799	0.248	0.085	3.450	2.939
Portugal	17	22	40	48	9895	10226	22699	33031	0.075	0.065	2.371	2.154
Romania	62	34	163	75	23489	19365	11754	27046	0.224	0.065	2.630	2.213

Russia	879	779	2189	1754	147532	145872	20362	25450	0.293	0.210	2.491	2.251
Saudi Arabia	58	207	156	534	16234	34269	45603	51680	0.078	0.117	2.684	2.582
South Africa	90	135	252	447	36801	58558	10573	12837	0.231	0.180	2.808	3.301
South Korea	94	298	243	650	42918	51225	12157	39545	0.180	0.147	2.591	2.180
Spain	90	125	205	240	39203	46737	25500	38603	0.090	0.069	2.281	1.920
Sweden	47	47	53	39	8567	10036	32754	51311	0.168	0.091	1.113	0.835
Taiwan	48	110	115	280	20479	23774	8173	24389	0.285	0.189	2.412	2.555
Thailand	42	142	81	271	56558	69626	7106	18381	0.104	0.111	1.929	1.905
Turkey	51	147	133	377	53922	83430	12532	27754	0.076	0.063	2.576	2.563
Ukraine	252	89	690	177	51463	43994	11268	8689	0.435	0.232	2.739	1.990
United Arab Emirates	20	69	52	199	1828	9771	119987	71246	0.093	0.100	2.553	2.868
United Kingdom	206	171	556	346	57134	67530	28945	43190	0.125	0.059	2.700	2.023
United States	1910	2213	4866	4920	252120	329065	39199	60544	0.193	0.111	2.548	2.223
Uzbekistan	46	37	116	89	20398	32982	3298	7299	0.689	0.152	2.509	2.440
Venezuela	40	39	94	87	19633	28516	15613	6608	0.129	0.205	2.368	2.237

Table 4: Decomposition of the inter-country variance in the rate of change in energy use and CO_2 emissions, 1990–2019

Particulars	Variance and covariance		Variance explained		Relative importance
			Total	Percent	
Energy use (E)					
Var (*E*)			0.349	100.00	100.00
Var (*E*) explained by *P*			0.113	32.47	19.63
	Var (*P*)	0.091			
	Cov (*PA*)	-0.032			
	Cov (*PU*)	0.054			
Var (*E*) explained by *U*			0.124	33.54	37.35
	Var (*U*)	0.176			
	Cov (*UP*)	0.054			
	Cov (*UA*)	-0.106			
CO_2 emissions (C)					
Var (*C*)		0.475	0.475	100.00	100.00
Var (*C*) explained by *P*			0.136	28.61	19.42
	Var (*P*)	0.091			
	Cov (*PA*)	-0.032			
	Cov (*PU*)	0.054			
	Cov (*PT*)	0.023			
Var (*C*) explained by *A*					
	Var (*A*)	0.249	0.133	28.08	39.86
	Cov (*AP*)	-0.032			
	Cov (*AU*)	-0.106			
	Cov (*AT*)	0.022			

Table 4: Continued

Particulars	Variance and covariance		Variance explained		Relative importance
			Total	Percent	
Var (*C*) explained by *U*			0.131	27.50	33.41
	Var (*U*)	0.176			
	Cov (*UP*)	0.054			
	Cov (*UA*)	-0.106			
	Cov (*UT*)	0.007			
Var (*C*) explained by *T*			0.076	15.82	7.32
	Var (*T*)	0.024			
	Cov (*TP*)	0.023			
	Cov (*TA*)	0.022			
	Cov (*TU*)	0.007			

SOURCE: AUTHOR'S CALCULATIONS

Table 5: Decomposition of the change in energy use and CO_2 emissions in the World during 1990–2019

Particulars	Energy use				CO_2 emissions			
			Total	%			Total	%
Total change during 1990–2019			5622				12430	
Change attributed to population			4186	74.47			9541	76.76
Direct		3922				9098		
Indirect		264				443		
Through A	1212				2810			
Through U	-645				-1497			
Through T					-159			
Through A and U	-302				-701			
Through A and TT					-50			
Through U and T					27			
Through A, U and T					13			
Change attributed to per capita real GDP			6991	124.36			15929	128.15
Direct		6997				16229		
Indirect		-5				-300		
Through P	1922				4459			
Through U	-1448				-3359			
Through T					-288			
Through P and U	-479				-1112			
Through P and T					-80			
Through U and T					60			
Through P, U and T					20			

Table 5: Continued

Particulars	Energy use				CO_2 emissions			
			Total	%			Total	%
Change attributed to energy intensity of GDP			-5556	-98.83			-12659	-101.84
Direct		-3237				-7508		
Indirect		-2319				-5151		
Through P	-804				-1866			
Through A	-1138				-2640			
Through T					132			
Through P and A	-377				-61487			
Through P and T					33			
Through A and T					47			
Through P, A and T					16			
Change attributed to carbon intensity of energy use							-382	-3.07
Direct						-371		
Indirect						-10		
Through P					-8			
Through A					-9			
Through U					5			
Through P and A					-3			
Through P and U					1			
Through A and U					2			
Through P, A and U					1			

SOURCE: AUTHOR'S CALCULATIONS

Table 6: Population effects of energy use (Mtoe) in 44 countries, 1990–2019

Country	Increase in energy use during 1990–2015	Increase in energy use attributed to increase in population	Decomposition of population effect				
			Direct	Indirect	Decomposition of indirect effect		
					Through *A*	Through *U*	Through *A* and *U*
Algeria	39.771	21.334	14.894	6.440	3.112	2.695	0.633
Argentina	36.435	18.831	17.175	1.656	4.040	-1.833	-0.551
Australia	49.764	43.759	41.864	1.896	11.281	-6.858	-2.528
Belgium	6.864	7.441	7.335	0.106	0.891	-0.629	-0.156
Brazil	147.614	72.947	58.579	14.368	11.722	2.185	0.461
Canada	84.423	77.575	75.637	1.938	14.770	-10.119	-2.713
Chile	25.191	7.265	5.992	1.273	2.552	-0.793	-0.486
China	2409.378	248.865	190.820	58.044	148.820	-18.268	-72.507
Colombia	16.229	13.426	12.614	0.813	4.084	-2.232	-1.039
Czech Republic	-6.646	1.693	1.677	0.015	0.069	-0.038	-0.016
Egypt	62.331	32.043	25.416	6.627	11.110	-2.999	-1.484
France	16.703	33.823	33.552	0.271	3.737	-2.837	-0.629
Germany	-55.551	20.010	19.821	0.189	1.156	-0.748	-0.219
India	607.539	215.983	172.616	43.367	118.953	-33.724	-41.862
Indonesia	170.426	58.361	48.516	9.844	22.952	-7.676	-5.432

Iran	188.271	53.197	32.638	20.559	7.276	10.121	3.162
Italy	2.275	9.008	9.008	0.000	0.407	-0.371	-0.036
Japan	-19.416	8.348	8.329	0.019	0.166	-0.126	-0.021
Kazakhstan	15.142	10.043	9.717	0.326	1.451	-0.751	-0.375
Kuwait	26.406	14.307	9.180	5.126	3.764	0.948	0.414
Malaysia	71.623	24.345	16.380	7.965	10.350	-1.401	-0.984
Mexico	53.846	64.100	64.287	-0.187	12.312	-10.142	-2.358
Netherlands	4.574	9.668	9.475	0.193	1.249	-0.783	-0.273
New Zealand	6.507	5.813	5.568	0.244	1.457	-0.870	-0.342
Nigeria	101.351	82.049	73.785	8.264	26.398	-12.969	-5.166
Norway	6.139	5.767	5.614	0.153	1.060	-0.688	-0.218
Poland	-0.340	-0.197	-0.197	0.000	-0.001	0.000	0.000
Portugal	5.324	0.566	0.561	0.005	0.021	-0.014	-0.002
Romania	-28.185	-11.649	-10.882	-0.767	-2.663	1.040	0.857
Russia	-99.337	-9.896	-9.883	-0.013	-0.119	0.092	0.014
Saudi Arabia	148.933	94.900	64.439	30.461	7.355	20.628	2.478
South Africa	45.590	52.188	53.043	-0.855	8.011	-7.589	-1.277
South Korea	204.168	21.129	18.187	2.941	5.344	-1.553	-0.850
Spain	34.707	17.932	17.315	0.617	2.649	-1.607	-0.425
Sweden	-0.132	8.255	8.093	0.162	1.195	-0.761	-0.272

Table 6: Continued

Country	Increase in energy use during 1990–2015	Increase in energy use attributed to increase in population	Decomposition of population effect				
			Direct	Indirect	Decomposition of indirect effect		
					Through *A*	Through *U*	Through *A* and *U*
Taiwan	61.945	8.361	7.683	0.678	1.831	-0.690	-0.463
Thailand	100.515	13.117	9.692	3.426	2.760	0.492	0.174
Turkey	95.578	35.218	28.152	7.066	12.119	-3.300	-1.753
Ukraine	-163.247	-30.605	-36.579	5.974	3.151	3.409	-0.586
United Arab Emirates	49.065	65.457	88.714	-23.257	-27.488	6.157	-1.926
United Kingdom	-35.148	38.073	37.476	0.598	5.434	-3.601	-1.236
United States	303.544	594.345	582.897	11.449	120.589	-80.495	-28.645
Uzbekistan	-9.713	31.639	28.604	3.035	13.079	-5.379	-4.665
Venezuela	-0.824	18.131	17.878	0.252	-3.121	4.717	-1.343

SOURCE: AUTHOR'S CALCULATIONS

Table 7: Population effects of the increase in CO_2 emissions (Mt) in 44 countries, 1990–2019

Country	Increase in CO_2 emissions	Population effects of CO2 emissions									
		Total	Direct	Indirect	Indirect effect through						
					A	U	T	AU	AT	UT	AUT
Algeria	93.727	50.522	35.566	14.956	7.432	6.434	-0.293	1.511	-0.062	-0.053	-0.013
Argentina	69.611	39.320	37.706	1.615	8.870	-4.025	-1.821	-1.209	-0.472	0.206	0.065
Australia	134.061	127.836	127.025	0.811	34.230	-20.808	-4.718	-7.670	-1.340	0.812	0.305
Belgium	-8.522	15.265	16.316	-1.050	1.981	-1.399	-1.262	-0.346	-0.269	0.191	0.054
Brazil	216.278	103.499	80.685	22.814	16.145	3.010	2.411	0.635	0.503	0.091	0.020
Canada	139.600	150.748	153.999	-3.250	30.071	-20.602	-7.003	-5.524	-1.489	1.016	0.281
Chile	55.474	16.017	13.238	2.779	5.638	-1.751	-0.028	-1.074	-0.012	0.004	0.002
China	7472.341	706.149	492.605	213.544	384.179	-47.159	42.868	-187.178	53.941	-6.383	-26.722
Colombia	37.221	27.322	23.994	3.328	7.769	-4.247	1.665	-1.976	0.593	-0.322	-0.155
Czech Republic	-47.689	4.878	4.965	-0.087	0.204	-0.113	-0.129	-0.046	-0.031	0.019	0.008
Egypt	136.417	73.255	61.806	11.449	27.018	-7.292	-3.646	-3.610	-1.688	0.440	0.227
France	-63.627	50.646	54.573	-3.926	6.078	-4.614	-4.368	-1.023	-0.881	0.704	0.179
Germany	-279.773	52.218	53.789	-1.571	3.138	-2.031	-2.063	-0.595	-0.360	0.258	0.082
India	1699.515	465.911	295.197	170.714	203.426	-57.672	69.834	-71.590	71.657	-18.513	-26.428
Indonesia	433.168	109.761	72.680	37.081	34.384	-11.499	16.756	-8.137	11.953	-3.418	-2.959
Iran	456.534	132.448	85.356	47.092	19.028	26.469	-3.978	8.270	-0.943	-1.332	-0.422

Table 7: Continued

Country	Increase in CO_2 emissions	Population effects of CO2 emissions									
		Total	Direct	Indirect	Indirect effect through						
					A	U	T	AU	AT	UT	AUT
Italy	-80.184	23.395	24.418	-1.023	1.104	-1.006	-1.036	-0.098	-0.108	0.109	0.013
Japan	4.817	19.997	19.676	0.321	0.393	-0.298	0.275	-0.050	0.017	-0.013	-0.002
Kazakhstan	29.525	30.895	31.259	-0.364	4.669	-2.416	-1.348	-1.205	-0.289	0.149	0.077
Kuwait	66.353	38.962	28.289	10.673	11.599	2.921	-3.204	1.277	-1.423	-0.339	-0.158
Malaysia	192.851	63.262	39.171	24.091	24.750	-3.350	3.275	-2.353	2.272	-0.286	-0.217
Mexico	169.200	151.650	137.282	14.368	26.293	-21.657	14.881	-5.034	3.153	-2.630	-0.637
Netherlands	7.130	23.264	23.263	0.001	3.066	-1.922	-0.464	-0.669	-0.069	0.044	0.015
New Zealand	11.147	9.425	8.811	0.615	2.305	-1.376	0.218	-0.542	0.060	-0.036	-0.014
Nigeria	58.606	41.013	31.453	9.560	11.253	-5.528	5.371	-2.202	2.085	-1.000	-0.419
Norway	12.142	8.221	7.427	0.793	1.402	-0.911	0.573	-0.289	0.135	-0.087	-0.029
Poland	-53.642	-0.678	-0.679	0.001	-0.002	0.001	0.001	0.001	0.000	0.000	0.000
Portugal	7.830	1.309	1.330	-0.021	0.049	-0.033	-0.031	-0.005	-0.004	0.002	0.000
Romania	-88.213	-28.010	-28.621	0.611	-7.005	2.735	2.396	2.254	0.951	-0.387	-0.332
Russia	-434.364	-24.413	-24.618	0.205	-0.297	0.229	0.238	0.035	0.020	-0.017	-0.003
Saudi Arabia	378.647	245.472	172.959	72.514	19.741	55.366	-6.247	6.652	-0.718	-2.035	-0.245
South Africa	194.715	165.537	148.958	16.578	22.498	-21.313	19.392	-3.586	3.170	-3.048	-0.534

South Korea	406.441	49.771	47.129	2.642	13.849	-4.024	-3.784	-2.203	-1.950	0.439	0.315
Spain	34.130	37.548	39.493	-1.944	6.042	-3.665	-3.156	-0.970	-0.740	0.417	0.128
Sweden	-13.237	8.381	9.011	-0.630	1.331	-0.848	-0.799	-0.303	-0.226	0.154	0.061
Taiwan	165.149	21.057	18.531	2.526	4.415	-1.663	0.795	-1.118	0.251	-0.090	-0.064
Thailand	190.465	25.003	18.696	6.307	5.324	0.949	-0.220	0.335	-0.066	-0.011	-0.004
Turkey	244.303	90.270	72.523	17.747	31.220	-8.502	-0.363	-4.516	-0.158	0.043	0.023
Ukraine	-513.545	-77.606	-100.171	22.565	8.628	9.336	9.020	-1.605	-1.336	-1.814	0.336
United Arab Emirates	147.118	186.243	226.522	-40.278	-70.188	15.721	26.072	-4.918	-8.204	1.814	-0.576
United Kingdom	-210.520	93.609	101.196	-7.586	14.673	-9.723	-9.304	-3.336	-2.438	1.856	0.686
United States	54.310	1387.020	1485.056	-98.036	307.226	-205.079	-125.223	-72.979	-32.792	22.419	8.393
Uzbekistan	-26.905	77.318	71.770	5.548	32.817	-13.498	-1.868	-11.705	-0.884	0.367	0.319
Venezuela	-7.023	40.888	42.342	-1.454	-7.392	11.171	-2.033	-3.182	0.391	-0.579	0.170

SOURCE: AUTHOR'S CALCULATIONS

Table 8: Population effect coefficient in the world and in 44 countries.

World/Country	Population effect coefficient	
	Energy use	CO2 missions
World	0.754	0.732
Algeria	2.598	2.661
Argentina	1.797	1.393
Australia	0.964	0.889
Belgium	0.381	0.250
Brazil	11.352	6.482
Canada	0.940	0.816
Chile	1.393	1.385
China	0.070	0.071
Colombia	0.841	0.963
Czech Republic	0.046	0.039
Egypt	4.546	3.308
France	0.367	0.228
Germany	0.093	0.078
India	0.547	0.845
Indonesia	1.084	23.785
Iran	0.612	0.649
Italy	0.316	0.148
Japan	0.058	0.066
Kazakhstan	0.185	0.171
Kuwait	9.851	22.766
Malaysia	8.224	46.963
Mexico	1.255	1.942
Netherlands	0.240	0.231
New Zealand	0.726	0.760
Nigeria	3.141	8.501

Norway	0.557	0.713
Poland	0.001	0.002
Portugal	0.236	0.142
Romania	-0.176	-0.160
Russia	0.035	0.028
Saudi Arabia	2.169	2.306
South Africa	1.950	5.006
South Korea	0.826	0.456
Spain	0.636	0.397
Sweden	0.253	0.188
Taiwan	0.299	0.331
Thailand	4.002	4.816
Turkey	2.802	2.744
Ukraine	0.351	0.239
United Arab Emirates	41.380	15.822
United Kingdom	0.229	0.180
United States	0.462	0.382
Uzbekistan	0.328	0.324
Venezuela	0.792	0.889

SOURCE: AUTHOR'S CALCULATIONS

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