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Ecological economics for humanity's plague phase

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ABSTRACT

The human enterprise is in potentially disastrous 'overshoot', exploiting the ecosphere beyond ecosystems' regenerative capacity and filling natural waste sinks to overflowing. Economic behavior that was once 'rational' has become maladaptive. This situation is the inevitable outcome of humanity's natural expansionist tendencies reinforced by ecologically vacuous growth-oriented 'neoliberal' economic theory. The world needs a more ecologically-informed economics yet, despite its self-description, contemporary 'ecological economics' does not adequately reflect key elements of human evolutionary and behavioral ecology. How should the discipline develop? This paper briefly considers some of the missing pieces that are particularly relevant to humanity's econo-ecological predicament: competitive displacement of non-human species through habitat and resource appropriation; humans as exemplars of the maximum power principle; the implications of 'far-from-equilibrium' thermodynamics; and evidence that *H. sapiens* is in the plague phase of a global population cycle. I then describe some of motivational and cognitive roots of crisis denial that extend even into the 2015 Paris climate accord. The paper concludes with: a) a list of principles for ecological economics consistent with the analysis and; b) a minimal set of policy actions necessary for the global community to achieve a more equitable steady-state economy and stable population within the biocapacity of nature.

1. Introduction: establishing context

This paper explores underused theory for ecological economics and suggests how the discipline might contribute more effectively to human well-being in coming decades. There is no doubt that new economic thinking is required. At the end of the second decade of the 21st Century scientists—if not politicians—have declared anthropogenic climate change an existential threat (Spratt and Dunlop, 2017, 2019; IPCC, 2018). Formal climate agreements have had little effect and "….even if the [2015] Paris Accord target of a 1.5 °C–2.0 °C rise in temperature is met, we cannot exclude the risk that a cascade of feedbacks could push the Earth System irreversibly onto a 'Hothouse Earth' pathway" (Steffen et al., 2018, p. 3). Meanwhile, a million non-human species face extinction from the human-induced decline of natural systems (IPBES, 2019); the pollution of air, land and oceans continues unabated; soil erosion and land degradation directly threaten two-fifths of the human population (Watts, 2018), etc., etc. On the socio-political front, we are witnessing growing civil discontent with wide-spread political corruption and increasingly egregious income disparity, elevated global tension over diminishing water and energy resources, and continuous energy-related war(s) in the Middle East (Castelo, 2018; Klare, 2014). No one should be surprised at the accompanying surge in international political and environmental refugees.

What all these trends have in common is a clear connection to the material economy and related economic processes. In this age of financialization we need reminding that, to the majority of people, the 'economy' still refers mainly to the production, distribution and consumption of *physical* goods. It is the (un)economic over-exploitation of biophysical systems that results in pollution (including GHG emissions/climate change), fisheries collapses, land degradation, etc. A cascade of data shows that the human enterprise is in ecological overshoot, consuming nature's goods and services faster than ecosystems can regenerate and dumping (often toxic) wastes beyond nature's processing/recycling capacity (Wackernagel et al., 2002; IPBES, 2019; Pearce, 2019). In short, we are currently 'financing' economic growth by liquidating the biophysical systems upon which humanity ultimately depends. There are too many people competing for the same diminishing quantity of essential resources.

Meanwhile, the benefits of growth are not equitably distributed; even in high-income capitalist economies the income gap is expanding. Neo-liberal economics scorns regulation and considers markets the arbiter of social value. In these circumstances, interest bearing money, mergers and acquisitions, regressive taxation and regulatory corruption ensure that an increasing proportion of national wealth flows to the already wealthy (Kennedy, 1995). In the United States, the rich-poor income gap has widened for several decades as neoliberal policies have

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taken hold. Since 1989 the share of national income going to wealthiest 1 % has almost doubled while the share going to families in poverty has stagnated. By 2017, the average annual income of the wealthiest 1 % averaged 39 times that of the bottom 90 % and "an estimated 43.5 percent of the total U.S. population (140 million people) [were] either poor or low-income" (Inequality.org, 2019).

These data are extreme for an OECD country, but egregious inequality is a global phenomenon. Even quasi-capitalist China recently passed the US to join the club of the world's most unequal nations (Jain-Chandra, 2018).[1] India may not be far behind. Our leaders need reminding that income inequality anywhere is negatively correlated with various measures of population health (Wilkinson and Pickett, 2010); extreme inequality foments discontent and is a precursor to civil disorder.

1.1. The economics of planetary unraveling

> A story is a choreographed hallucination that temporarily displaces reality…. By telling stories, early humans could obscure, revise and mythologize truth; they could dwell in alternative worlds of their own making (Jabr, 2019, p. 40).

Modern humans easily match their Paleolithic ancestors as storytellers. The economic paradigms that run our lives are made-up stories, complex social constructs conceived in language and massaged into accepted theory through academic debate, social discourse and practical experience. However, just because some economic model has become received wisdom does not mean it accurately represent either actual human behavior or that of the ecological systems with which the economy interacts in the real world. A serious mismatch can be problematic.

In fact, as a "choreographed hallucination", the neoliberal paradigm contributes significantly to planetary unraveling. Neoliberal thinking treats the economy and the ecosphere as separate independent systems and essentially ignores the latter. The foundational model in mainstream analysis is the circular flow of exchange value (money) from households to firms (expenditures on goods, services and investments) and back again (wages, salaries, and dividends), in which each "self-renewing, self-feeding" cycle can be larger than the last (see Heilbroner and Thurow, 1981, p. 127). Thus, the goal of mainstream economists and most governments since the 1950s has been to maximize the growth of this cycle of production and consumption. True believers have such overweening confidence in human technological ingenuity that so-called 'factors of production' — manufactured capital, labor, knowledge, natural capital (land and natural resources/processes) — are considered inter-substitutable. In effect, the world is in thrall to a mythic construct of perpetual material growth abetted by technological progress in which even "exhaustible resources do not pose a fundamental problem" (Dasgupta and Heal., 1979, p. 205). (Many production functions omit resources altogether.) What could possibly go wrong?

Plenty, as it turns out. Ecosystems, social systems, and real economies are actually tightly connected, complex dynamic systems characterized by opaque multi-layered relationships, temporal lags and behavioral thresholds. Because they ignore this connectivity, interdependence and complexity, simplistic quasi-mechanical economic models are unable to capture the complex space, time and behavioral dynamics of real-world natural and social systems *including even the economy* (see Christensen, 1991). Dysfunction is inevitable.

[1] China's Gini coefficient has risen 15 points since 1990 to 50 compared to low 40s for the US (On the Gini scale, '0' indicates perfect equality — everyone has the same income — while a score of 100 means one individual gets all the income.)

1.2. In search of economic realism

Ecological economics (ecol-econ) was framed as a more realistic alternative to neoliberal economics (Costanza, 1991; Daly and Farley, 2010). Ecol-econ sees the economy as a fully contained, dependent, prone-to-grow subsystem of the non-growing ecosphere. Ecological economists recognize that: a) the economy is dynamically connected to the rest of nature through resource extraction/consumption and waste production and; b) all economically-relevant energy and material transformations are subject to biophysical laws, particularly the laws of thermodynamics (Georgescu-Roegen, 1971; Martinez-Alier, 1991). Thus, the most important economic flows are the unidirectional irreversible *throughputs* of energy and material rather than the self-inflating circular flows of abstract money value.

Significantly, humanity's growth-driven ecological predicament is generally predictable from the assumptions of ecological economics (which tends to validate the assumptions). Ecol-econ therefore shifts the developmental policy emphasis from promoting growth and efficiency toward enhancing well-being and social equality. Emphasizing qualitative improvement (getting better) over quantitative increase (getting bigger) essentially negates the neoliberal vision — changing the story changes everything.

2. Losing our grip on reality (and what's needed to get it back)

Or maybe not. In the half-century since the theoretical foundations of ecological economics were laid down, and after more than three decades of sustainable development rhetoric, expansionist neoliberal thinking has colonized virtually the entire world. Ecological economics has had little discernible effect.

There are many reasons for this failure including major weaknesses in disciplinary development. Paradoxically, ecol-econ does not adequately reflect key aspects of human evolution and behavioral ecology. The facts are that *H. sapiens* is an evolved species; human resource-getting and allocation (i.e., 'economic') behavior has been shaped, in part, by natural selection. These facts should help shape ecological economics.

2.1. Competitive displacement or 'the demise of nature'

Intra-and inter-specific competition for scarce habitat and food is a powerful selection pressure in the evolution of most life forms.[2] Two innate tendencies that humans share with other species are predispositions to expand to occupy all accessible habitats and to use all available resources.[3] In fact, *H. sapiens* is classified as a reproductive K-strategist because human populations historically tended to press up against the carrying capacities ('K') of their habitats. K-strategists are generally long-lived, slowly reproducing species with extensive parental care and relatively high rates of offspring survival. Thus their populations grow until their habitats 'push back'—negative feedback may include spatial crowding, disease, food shortages, ecosystems degradation, etc.[4] Humans are archetypal K-strategists, but have a competitive 'leg-up' in the game because technological advances tend to increase resource availability and therefore short-term carrying

[2] This does not discount the role of cooperation. However, to the extent that a tendency to cooperate increases the fitness (survival and reproduction) of cooperating individuals above that of non-cooperators, *cooperation* can be interpreted as a winning tactic in the *competition* for essential resources.

[3] And sometimes unavailable resources. If one thinks of money income as modern humans' basic resource, then credit enables people to consume beyond their means, i.e., to consume resources they don't really have.

[4] Indigenous peoples, who seem to live in harmony with nature, often achieve that uneasy balance only after a population crash, having first over-harvested their ecosystems sometimes to the point of driving prey species to extinction (see Flannery, 1994).

capacity.

Humanity's competitive superiority has been well documented. In a comparative study of ecologically similar species, Fowler and Hobbs (2003) test (and reject) the hypothesis that contemporary humans fall "within the normal range of natural variation observed among species for a variety of ecologically relevant measures" (p. 2579). They found that, in 22 of 31 tests, humans lie outside the 99 % confidence limits for variation among other species and that our technology-aided demands on exploited ecosystems often dwarf those of competing species. For example, the human population is two orders of magnitude greater than the upper 95 % confidence limits of populations of 63 similar-sized mammal species; human aggregate consumption of biomass from the biosphere exceeds the upper 95 % confidence limits for biomass ingestion by 95 nonhuman mammal species by two orders of magnitude and; humanity's geographic range exceeds the upper 95 % confidence limit for the ranges of 523 other mammal species by a factor of ten.

As human populations expand they necessarily appropriate ecological space required by other species. Human 'competitive displacement' of non-human organisms from their habitats and food sources is now the greatest contributing factor to plunging biodiversity (Pimm and Raven, 2000; Smil, 2011, 2013). Consider that with only 0.01 % of total Earthly biomass, *H. sapiens*' expansion has eliminated 83 % of wild animal and 50 % of natural plant biomass. From a fraction of 1 % ten millennia ago, humans now constitute 36 %, and our domestic livestock another 60 %, of the planet's much expanded mammalian biomass compared to *only* 4 % *for all wild species combined*. Similarly, domestic poultry now comprise 70 % of Earth's remaining avian biomass (data from Bar-On et al., 2018; see also Smil, 2011). Meanwhile, commercial fishing depletes the oceans at the expense of rapidly declining marine mammals and birds. Seabirds are the most threatened bird group, with a 70 % community-level population decline between 1950 and 2010 (Grémillet et al., 2018).

Overall, the World Wildlife Fund reports an "astonishing" 60 % decline in the populations of mammals, birds, fish, reptiles, and amphibians in just over 40 years (WWF, 2018). Using very conservative assumptions, Ceballos et al. (2015) found that the average rate of vertebrate extinctions over the last century is up to 100 times higher than the (mainly pre-industrial) background rate. Even insects are experiencing "Armageddon" (and systemically-linked insect-dependent birds, mammals and amphibians are not far behind) (Lister and Garcia, 2018; Hallmann et al., 2017).

There are several lessons here for ecological economists: 1) The data show what should be self-evident on a finite planet—humanity's appropriation of an ever-greater proportion of the energy and material flows through the ecosphere can have only dire impacts on competing life-forms. Contrary to politicians' assertions that economic growth can be compatible with conserving 'the environment', a core principle of ecological economics should be that, beyond a certain scale (long-since exceeded), there is an absolute conflict between the economy and ecosystem integrity. (This consideration is not even visible to neoliberal models); 2) While mainstream economists see 'the economy' and 'the environment' as virtually separate systems (and believe the former is further decoupling from the latter) ecological economists can assert that *H. oeconomicus* is the most ecologically significant macro-consumer organism (both herbivore *and* carnivore) in all the major terrestrial and most marine ecosystems on Earth; 3) Finally, the data highlight a double-barrelled behavioral challenge to sustainability—*H. sapiens*' genetic predisposition to expand is being reinforced by a socially constructed cultural meme, the neoliberal growth ethic, as most dramatically expressed through global capitalism. Nature and nurture, the latter abetted by technology, conspire against human society living within safe planetary boundaries. The central question is how can ecol-econ contribute to neutralizing this potentially fatal confluence? Subsidiary questions (admittedly anthropocentric) are, what level of biodiversity is necessary, and what percentage of ecosystem area should be left unexploited (or restored), to ensure the continued functioning of essential life-support services as necessary for human survival?

2.1.1. Just what is nature worth?

These questions are not likely to be satisfactorily answered by 'putting a price on nature' (Spangenberg and Settele, 2010; Rees, 2006). Ecol-econ has dedicated considerable attention to the commoditization of so-called natural capital on grounds that knowing its money value should discourage depletion. This effort has done little to retard degradation, in part because monetization is a relapse into neoliberal market thinking, displaces other approaches and leaves no room for a fall-back position. A major problem is that many species have no market value or valid shadow price—their contributions, if any, to eco-integrity are simply unknowable until they disappear. Similarly, various life-support services may be transparent to detection, rendering monetary valuation impossible (Vatn and Bromley, 1994).

These technical limitations alone can invalidate cost-benefit analysis—undervalued natural capital gives way to competing profitable development. Ecological economists must therefore accept that conventional economic logic is an unreliable ally in protecting nature. Mainstream valuation can never fully capture the ultimate worth of most species or so-called ecosystems services. In short:

> …to the dismay of all those conservationists who have joined the valuation bandwagon in the hope it would play a preservationist tune, pure economic reasoning generally resonates more with the prevailing symphony of destruction […] Absent a crisis, the perceived value of biodiversity is likely always to be less than the measurable value of development. [In the circumstances,] the valuation exercise becomes a mere formality that turns against biodiversity by rationalizing its destruction (Rees, 2006).

If it is theoretically impossible to monetize life-forms and eco-processes, then ecological economists must devise and champion some other approach to valuing life. We need "value articulating processes which involve open deliberative judgment rather than instantaneously stated preferences, concealed expert opinion and global cost-benefit analysis" (Spash, 2008).

2.2. H. sapiens as maximum power archetype—accelerating eco-destruction

> We use 30 percent of all the energy… That isn't bad; that is good. That means we are the richest, strongest people in the world and that we have the highest standard of living in the world. That is why we need so much energy, and may it always be that way (US President Richard Nixon, November 1973, p. 980).

Ecological economists should be more creative in exploring the role of energy in both human evolution and economic progress. Physicist Ludwig Boltzmann (the father of statistical thermodynamics) famously speculated as early as 1886 that the Darwinian struggle for existence is really a competition for available energy. Subsequently, ecologists Alfred Lotka (1922) and later Howard Odum formulated what is now known as the 'maximum power principle': Successful systems are those that evolve in ways that maximize their use of available energy per unit time in the performance of useful work (growth, self-maintenance and reproduction) (see Hall, 1995). In the Anthropocene, no other species comes close to challenging humanity's energy hegemony. As President Nixon implicitly understood, 'maximum power' is a fundamental organizing force in both ecosystems and socioeconomic systems.

That said, humanity's power supremacy had a long gestation period. Anatomically modern humans have existed for about 200,000 years but it wasn't until we committed to fossil-fuels only 200 years ago that we came fully to exercise our 'maximum power' muscle. The 19th Century shift to coal, oil and natural gas marked humanity's fateful transition from mainly endosomatic or 'within body' renewable energy (animal and human labor, including slavery), to dependence on an entirely exosomatic but depletable energy source (buried stocks of stored ancient solar energy). Modern society was birthed by, and remains precariously balanced on, a gusher of petroleum.[5]

Contemporary analysts rarely acknowledge what a uniquely remarkable transition this has been. For most of humanity's at least 200,000 year history, population growth was negligible and attributable mainly to expansion out of Africa during the past 60 millennia. Even with agriculture and the boost in food production 10,000 years ago, it took 99.9 % of human history for the population to top one billion early in the early 1800s.

Then, in just 200 years—1/1000th as much time required to reach the first billion—the population ballooned over 7-fold to 7.4 billion by 2016. The principal enabler was the 1300-fold increase in global fossil energy use that energized industrialization between1800 and 2016.[6] Fossil power facilitated a 100-fold increase in real global GDP and a factor 13 (rising to 25-fold in the richest countries) surge in average per capita incomes (Roser, 2019). In short, fossil energy, along with access to the land and resources of the 'new-world' and improving population health, suppressed natural negative feedback (e.g., disease, food/land/resource shortages) and freed *H. sapiens* to express its innate capacity to expand exponentially (sometimes super-exponentially; Fig. 1).

Of course, it is these parallel (and on-going) increases in energy supply, population, resource consumption and waste production that are driving climate change and the precipitous degradation of the ecosphere. And 'precipitous' is precisely the right word. It is a quirk of exponential growth that half the fossil energy ever used (and half the fossil CO_2 ever produced), has been burned (emitted) *in just the past 35 years!*[7] (The same for many other industrially important minerals and metals and waste generation/pollution.) During the 20th Century, humanity's 'maximum power' leverage elevated our species to superiority not only as the dominant ecological entity on Earth but also as the major geological force changing the face of the planet. Ironically, maximum power success may be our downfall. The economics facilitating this rise to power dominance ignores the biophysical laws governing every energy and material transformation!

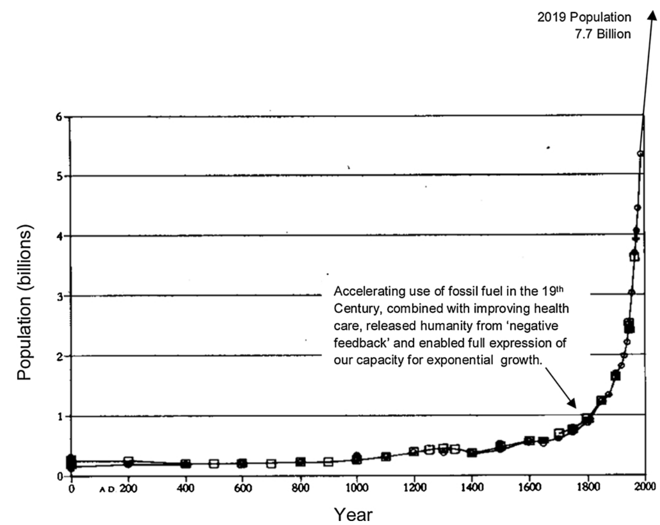

Fig. 1. The unsustainable, oil-based exponential growth of the human enterprise on a finite planet—the growth spurt that recent generations assume to be the norm marks the single most anomalous period in human history.

2.3. Raising humanity far-from-equilibrium, disordering the ecosphere)

> Every process, event, happening—call it what you will; in a word, everything that is going on in Nature means an increase of the entropy of the part of the world where it is going on (Schrödinger, 1945)

All energy and material transformations are subject to the second law of thermodynamics, the entropy law. The second law dictates that any spontaneous change in an isolated system—a system that can exchange neither energy nor material with its environment—increases the system's entropy (where 'entropy' is a measure of disorder or randomness). Each successive change in an isolated system creates greater disorder; concentrations disperse, gradients disappear and energy dissipates. In simple language, the second law states that things naturally run down, wear out and crumble away. Eventually, "a permanent state is reached, in which no observable events occur" (Schrödinger, 1945). This is a state of local 'thermodynamic equilibrium', or maximum entropy, in which no further change is possible.

Of course, many real-world systems from single-celled amoebae to the entire ecosphere are neither crumbling nor slipping toward equilibrium; in fact, all living systems persist in a state of thermodynamic *disequilibrium*. The ecosphere, for example, is a self-organizing system of mind-numbing complexity and multi-layered structure comprising steep material gradients, millions of distinct species, thousands of ecosystems and incalculable accumulations of energy-rich biomass. Moreover, over billions of years of evolution, on average, all these qualities have been increasing—i.e., the ecosphere has been moving ever *further* from equilibrium. Indeed, distance from equilibrium may well be the measure of life: it is "…an essential parameter in describing nature, much like temperature is in standard equilibrium thermodynamics" (Prigogine, 1997).

While living things seem to violate the second law, they are actually subject to the same inexorable processes of entropic decay as everything else. However, because they are open rather than isolated systems, organisms, ecosystems (and economies) are able to extract energy and concentrated matter ('negentropy') from their 'environments' which they use to maintain themselves, grow and reproduce; they simultaneously inject resultant waste heat and degraded materials (entropy) back into their surroundings.[8] Because living systems survive by continuously degrading and dissipating low entropy energy and matter they are called 'dissipative structures' (Prigogine, 1997).

Nicholas Georgescu-Roegen was among the first economists to understand (and be rejected for understanding) the implications of the second law for the economy. He observed repeatedly that "…in a finite space there can be only a finite amount of low entropy and, second, that low entropy continuously and irrevocably dwindles away" (e.g., Georgescu-Roegen, 1975, p. 359). This observation is the more relevant in light of the structural/functional relationships described by SOHO (self-organizing holarchic open) systems theory (see Kay and Regier, 2001). Living systems, including the human enterprise, exist in overlapping nested hierarchies in which each component sub-system (holon) is contained by a higher level in the system, and itself hosts a complex of linked sub-systems at lower levels. (Think of Russian nesting dolls). Within the

[5] Remarkably, most people seem unconsciousness that abundant cheap energy is the means by which we produce all the food and other resources required to grow and maintain techno-industrial civilization

[6] The contribution from coal grew from just 97 terawatt hours in 1800 to 43,403 TWh in 2016; petroleum and natural gas were not used at all until later in the 19th century, but by 2016 they were contributing 50,485 and 36,597 TWh respectively to global energy supplies (Ritchie and Roser, 2019).

[7] Anything growing exponentially has a constant doubling time. For example, a population growing at just 2% will double every 35 years. If something is growing super-exponentially, then the rate of increase is increasing and the doubling time shrinking. Curiously, even with simple exponential growth, the number attained at the end of each doubling period is larger than the sum of the corresponding numbers for all previous doublings.

[8] Schrödinger (1945) originally put it this way: "[The living organism] can only keep aloof from [death and decay], i.e. alive, by continually drawing from its environment negative entropy […]. After utilizing it they return it [to the environment] in a very much degraded form".

hierarchy each holon thrives—maintains itself far-from-equilibrium—by extracting low entropy energy and material from its host system one level up and exporting resultant degraded energy and material wastes (entropy) back into that host. In short, living organisms create and increase their local structure and complexity at the expense of increased global disorder and decay (Schneider and Kay, 1994, 1995).

SOHO relationships should reframe all economists' understanding of humans-in-nature. It is true that both the human enterprise and the ecosphere are self-producing far-from-equilibrium dissipative structures. However, while the ecosphere evolves and maintains itself in dynamic steady-state by dissipating an extra-terrestrial source of negentropy, sunlight, the human sub-system to date can grow and complexify (i.e., raise itself ever further from equilibrium) *only* by dissipating its host system, the ecosphere.

That said, there was nothing inherently unstable or unsustainable about energy and material dynamics within the pre-industrial SOHO hierarchy. Ecosystems self-produce, indefinitely powered by solar energy; anabolism marginally exceeds catabolism so biomass accumulates; the recycling process—nature's 'waste' sink—is capacious. Thus, for 99.9 % of human history our species functioned within thermodynamically 'healthy' limits. Indeed, net primary production by producer species (mostly green plants) has been more than adequate to sustain not only humans but also the world's entire complement of millions of other consumer species.

2.4. *H. sapiens as plague species*

Serious problems emerged only in the fossil fuel age. Coal, oil and natural gas have helped raise the human enterprise so far-from-equilibrium that (rising) demand for negentropy to maintain and grow the economy exceeds the productive and assimilative capacities of host ecosystems. The resultant entropic disordering of the ecosphere is evident in biodiversity loss, dissipation of soils and material resources (including fossil fuels), accumulating GHGs/climate change, ocean dead zones, etc., all signature symptoms of overshoot and apparent gross human ecological dysfunction.

I say 'apparent' because the root cause is natural. Recall that all species populations have a predisposition to expand exponentially. When exposed to a temporary abundance of some limiting resource, many respond with an explosive population outbreak. Some species in simple ecosystems exhibit regular cycles of outbreak followed by collapse in which the outbreak is referred to as the 'plague phase' of the cycle (e.g., CSIRO, 2019). The plague continues until negative feedback—food shortages, disease, predation, etc., depending on species and circumstances—knocks the population back (Korpimäki et al., 2004).

As exemplary 'K'-strategists, humans are as prone to population outbreaks as any similar species (only the time scales differ). When fossil-fueled technology reduced normal negative feedback by providing access to all necessary food and other material resources, humanity embarked on a 200+ year global population outbreak now well into plague phase (Fig. 1) with all the negative consequences for the ecosphere described above.

This raises an important question for all economists: can—or should—the human plague phase be extended indefinitely or will it wind down, either through controlled implosion, gradual unraveling or catastrophic collapse? The answer is suggested by examination of energy consumption by country and region as of 2018 (Fig. 2). The horizontal line at '0' represents global average energy consumption per capita remembering that energy use is tightly correlated with GDP/capita. Relatively rich OECD countries representing only 17 % of the world's population consume 2.4 times as much energy per capita as world average citizen and 3.4 times as much as non-OECD citizens (83 % of the world's population) (Fig. 2).

To address equity concerns and bring the present non-OECD population to just *average* 2018 OECD levels—still low compared to high-end users such as Norway, Canada and the US—would require increasing global energy consumption by 140 %. At a global energy-use growth rate of 2.0 %/year, total primary energy use would double in just 35 years—scarcely over $^{2}/3^{rds}$ of the way to 140 %—and more energy and other resources would be consumed/dissipated during that doubling than the total to date since 1800! Are there adequate fossil energy supplies? What would this mean for CO_2 emissions? Could the already stressed ecosphere cope with the attendant massive entropy injection? And what about the expected additional billions of people? Meanwhile, the IPCC 1.5 C degree special report demands nearly 50 % lower emissions by 2030 and complete decarbonization by 2050, i.e. 6 % annual *reductions* beginning immediately.

This conundrum will not soon be resolved by the much-heralded shift to 'green' alternative energy. The hype over wind, solar and other 'green' energy sources notwithstanding, no fully adequate substitutes for fossil fuels are available (IER, 2019; Mills, 2019) and absolute decarbonization is not occurring (Schröder and Storm, 2018). Global energy demand grew by 2.9 % in 2018 led by natural gas; carbon emissions grew by 2.0 %. Renewables did contribute about a third of the growth in electrical power generation—solar now produces about 585 TWh and wind 1270 TWh globally (total = 1850 TWh). However, the global *increase* in demand for electricity in 2018 was 938 TWh, 60% more than the *total* output of all existing solar photovoltaic installations. Just two years of electricity demand increase absorbs the entire contribution from more than three decades of wind and solar power development (data from BP, 2019).

Even if the world were successfully to engineer a economically viable combination of fossil fuels and renewables sufficient to double energy production, we still have a problem. The use of so much energy to expand and raise the human enterprise even further-from-equilibrium, would guarantee both disastrous climate change and accelerate the parasitic hollowing-out of the ecosphere. Bottom line: human enterprise will almost certainly be forced to contract by energy/food/etc. shortages or foundering life-support systems.

3. Discussion – where is the 'economics' in the ultimate human saga?

The forgoing narrative obviously describes humanity' *ecological* predicament but it is no less a description of *economic* reality. On an elementary level, each of the concepts explored above provides a key to understanding: a) the full implications of humanity's extraction and use of energy and material resources including direct and unaccounted costs; b) the limited utility of attempts to price so-called natural capital; c) the eventual inevitability of simultaneous depletion (physical scarcity) and pollution (entropic disorder) on a global scale; d) the fundamental conflict between continuous material growth and maintaining ecological integrity; e) why inequality cannot be resolved through economic growth alone and; f) the limited scope for enhanced 'factor productivity' and factor substitution which constitute mainstream's major means to sustainability. On this last point: SOHO thermodynamics underscores that, while some dematerialization may occur, it is not even theoretically possible to 'decouple' the economy from the ecosphere (see also Ward et al., 2016); empirical data provide "…no evidence of decoupling of rising standards of living and consumption-based carbon emissions—which means that the future has to be different from the past, because 'business-as-usual' economics will lead us to 'Hothouse Earth'" (Schröder and Storm, 2018, p. 22).

The most profound and disturbing insight from all this is that, left unchecked, highly evolved and perfectly normal eco-behavioral predispositions, as manifested in humanity's fossil-energy powered economic exploitation of the natural world, have the potential to collapse the human enterprise. Some say societal collapse is inevitable (Bendell, 2018). These issues should be at the core of economic thinking for sustainability. In practice, however, daily reports on the state of the economy or global markets (which may actually follow news about the latest pollution disaster, heat wave or super-storm) never ask when

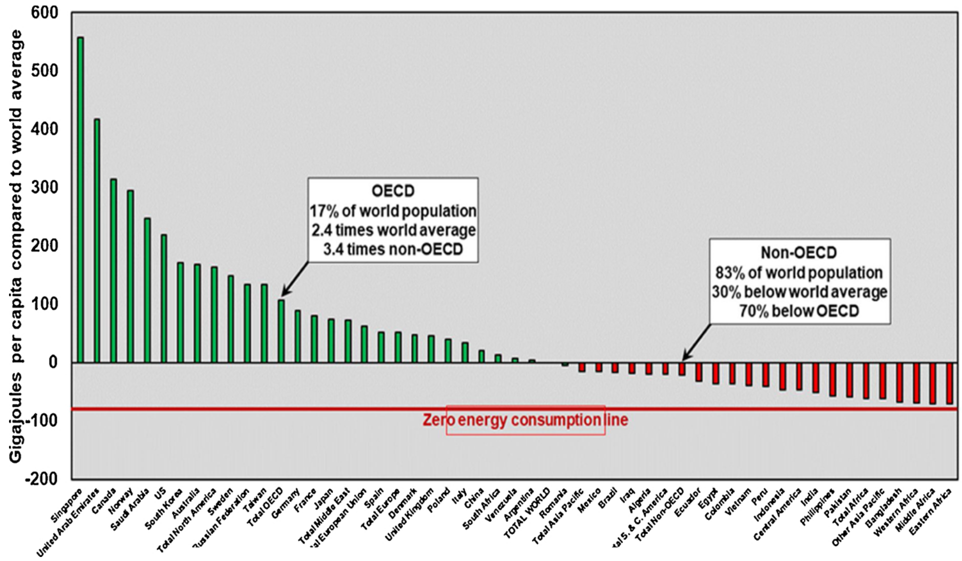

Fig. 2. Per capita primary energy consumption in 2018 relative to world average.

'enough is enough', just how 'far-from-equilibrium' can we safely go, or what life-style changes are necessary to avoid catastrophe. On the contrary, the mainstream fantasy—'green-grow the economy so the next generation has the wealth and technology to mitigate the consequences—remains compelling enough to merit the 2018 Nobel Prize in economics (Hickel, 2018). This obsession with growth cannot end well.

In fairness, neoliberal algorithms do not reference most human ecological behaviors so it is perhaps unsurprising that their consequences are ignored in mainstream discourse. But we do have to ask why the implications of basic human ecology are not framing elements of *ecological* economics.

3.1. The Jekyll and Hyde of human nature

It's not just economists who seem reluctant to face reality. Defense of the *status quo* remains the default position of most other academic disciplines, governments, transnational corporations and international organizations. Global society is mesmerized by the prevailing cultural narrative of perpetual material growth abetted by continuous technological progress. This begs the question, how can such an unlikely 'story'—such a 'choreographed hallucination'—have so much staying power within the best educated of human generations in the face of cascading contrary physical evidence?

Part of the answer lies in yet another domain of human nature. Motivational studies tell us that *H. sapiens* is not primarily a rational species—emotion and instinct play a remarkably large role in directing human affairs. Indeed, circumstances in which high intelligence rule our actions may actually be quite limited and their effect relatively trivial in the grand evolutionary context (see Rees, 2010). In particular, when humans feel their physical safety or social status is under threat, or they are sorely tempted by some forbidden fruit, the Dr Jekyll of reason may not be able to prevail over the Mr Hyde of emotion or instinct. Some argue that free will as normally understood is largely illusion (Harris, 2012; also Overbye, 2007). The obvious problem for sustainability is that "[b]iological drives…can be pernicious to rational decision-making in certain circumstances by creating an overriding bias against objective facts" (Damasio, 1994, p. 192).[9]

The propensities that qualify *H. sapiens* as a dogged K-strategist and master of maximum power are among the 'biological drives' that become 'pernicious' at the biophysical limits to growth. To these we can add natural optimism and an innate tendency to favor the here-and-now and close relatives/friends over distant places, future possibilities and total strangers. Discounting—temporal/spatial/social— clearly militates against determined environmental protection today (and is one ecologically-significant behavioral trait that *has* been incorporated into mainstream economics).

And there is yet another twist to the human psyche that conspires to dilute the heady wine of reason. Cognitive neuroscience tells us that repeated social, cultural, or sensory inputs can acquire a physical presence in our brains, i.e., repeated experiences and cultural norms become engrained as semi-permanent synaptic circuits. Once entrenched, these structures filter subsequent inputs—people select information that matches, and seek out experiences/people that reinforce, their neural 'presets'. Conversely, "when faced with information that does not agree with their pre-formed structures, they deny, discredit, reinterpret, or forget that information" (Wexler, 2006). One variation of this latter tendency, "the white male effect" manifests as defense of cultural identity and the *status quo* (Kahan et al., 2007) and is associated with high levels of climate change denial (McCright and Dunlap, 2011).

When exercised by society's power elites, temporal discounting and self-interest are sufficient to compromise even the most important global environmental agreements. For example, parties to the 2015 Paris climate accord—national governments coached by teams of corporate lobbyists—discussed numerous capital-intensive technological solutions ranging from so-called green energy technologies (e.g., wind and solar) through unproved approaches to carbon capture and storage, and even nuclear fission and fusion, all techno-solutions that would contribute to investment and growth. Reductions in energy/resource use, lifestyle changes, fair income redistribution and population control—i.e., serious threats to the *status quo*, were not on the table.

Arguably, "What is going on is a rebooting of a stagnant capitalist economy, that needs new markets – new growth – in order to save itself. What is being created is a mechanism to unlock approximately 90 trillion dollars for new investments and infrastructure" (Morningstar, 2019). In short, the real commitment of the international community is to technological solutions that will sustain growth and not jeopardize the current social and economic system (Spratt and Dunlop, 2017). Perversely, then, climate disaster policy is designed to serve the capitalist growth economy "…so the latter becomes the solution to (not the

[9] It complicate matters that perfectly rational short-term individual behaviour may well seems 'pernicious' (i.e., irrational) in light of the longer-term collective interests of society.

cause of) the [problem]. Unfortunately, many environmental non-governmental organisations have bought into this illogical reasoning [believing] without justification, that the financialization of Nature will help prevent its destruction" (Spash, 2016, p. 931). (The fact that many NGOs are dependent on the corporate sector for financial support is a corrupting factor.)

Perhaps more disturbing, many ordinary citizens are all too willing to go along for the ride, trusting their leaders, buying into trivial mitigating pursuits as solutions and thus becoming both victims and perpetrators of eco-destruction. Russell and Bolton (2019) explain such social complicity and argue that the world's best hope to avoid collapse may be for an "…unavoidable and ultimately staggering ecological disaster [to strike] soon at the heart of the developed world. [This event] would need to induce a level of terror intense enough to convey to all that our harmful actions really do end in destructive consequences, thus sending the message that we can no longer act with impunity".

4. Conclusions – now what? A future role for ecological economics

De facto human eco-behavior should become the foundation for eco-economic policy in the 21st Century. It is clear for the reasons explored above that the human enterprise already exceeds global carrying capacity and is dangerously into overshoot—68 % in 2016, according to the Global Footprint Network (GFN, 2019). Ecological economists should look biophysical data in the eye and respond accordingly; they must ask and seek to answer difficult questions that may not even occur to the mainstream. For example: 1) What weaknesses inherent in existing 'environmental economics' actually facilitate ecosystem degradation and overshoot? 2) Can the damaged exosphere sustainably support yet another two billion humans plus a doubling of GWP and various forms of energy/material demand, as is expected by mid-century? 3) What eco-economic tools and policies help might maintain a satisfactory quality of life while implementing a planned contraction of planet-depleting economic activities and populations? 4) What circumstances promote people's capacity for cooperation, community-building and short-term sacrifice to achieve mutually beneficial future ends (e.g., survival)? 5) How can eco-econ help identify efficient policies to regenerate key ecosystems and maintain essential life-support functions, including a predictably stable livable climate? (As I write this section, parts of India are suffering unprecedented water shortages combined with record temperatures in the high 40s and low 50 s degrees Celsius. Similarly, France, Spain and much of the rest of Europe are seeing June temperature records tumble—France recorded its all time record temperature on 28 June 2019, as the mercury reached 45.9 °C, a full 1.8 °C above the previous record.)

Of course, the over-arching question is whether society will be willing/able to organize globally to abandon the myth of 'perpetual-growth-with-decoupling' and articulate a compelling new social-construct-for-survival that will override, rather than reinforce, peoples' innate myopia and expansionist tendencies. Is there some combination of fear and hope sufficient to dissolve our culture-wide conspiracy of denial or must we rely on some "staggering ecological disaster" to wake a world of sleep-walkers? Below are some elements of the paradigm shift needed to rescue human civilization from itself in the 21st Century. Consistent with the biophysical evidence and ecol-econ theory, ecological economists should research ways to assist the global community to acknowledge:

- the fallacy of human exceptionalism. *H. sapiens* is a biological species like all others subject to the same natural laws and limitations, particularly the laws of thermodynamics;
- that the human enterprise is an embedded subsystem of the ecosphere and that decoupling from nature is not even theoretically possible.;
- that in the absence of rational controls, humans will use any source of abundant cheap energy to (over)exploit ecosystems and other 'resources';
- that the human enterprise is an aggregate 'dissipative structure' whose maintenance and growth *necessarily* drives the entropic disordering of the ecosphere;
- that there are "fuzzy" biophysical limits to ecosystems exploitation that may not be evident and whose location (tipping points) may shift dangerously with changes in both natural conditions and exploitation rates;
- that human society has exceeded regenerative limits of ecosystems and become parasitic on the ecosphere. An economy that grows and maintains itself by depleting the biophysical basis of its own existence is inherently unsustainable;
- that human population dynamics are consistent with those of other 'K'-strategists and suggest we are in the outbreak (plague) phase of a population cycle;
- that technology has limits. Society maintains itself 'far-from-equilibrium' on depletable fossil fuels and, as yet, there are no adequate substitutes. We therefore face a climate/energy conundrum:
  - if we attempt to maintain the *status quo* on remaining fossil fuels, the world will suffer the dangerous consequences of ± 3 °C mean global warming including disorderly economic contraction (Steffen et al., 2018). On the other hand:
  - if we massively invest in current alternatives, it will not be possible to reduce CO_2 emissions sufficiently to avoid climate change, there will certainly be energy shortages, inadequate investment elsewhere and, again, disorderly economic contraction (e.g., Sers and Victor, 2018);
- that in the absence of a controlled descent, chaotic collapse is probable and the usual outcome for societies whose leaders ignore evidential warning signs or are too corrupt or incompetent to act accordingly (Tainter, 1988);
- that (un)sustainability is a collective problem requiring collective solutions and unprecedented international cooperation;
- that Earth is over-populated even at average material standards. A one-earth life-style for 7.3 billion people requires that humans learn to thrive on the biocapacity represented by 1.7 global average productive hectares per capita (compared to the eight gha/capita require by contemporary North America) (Data from Global Footprint Network);
- that gross income/wealth inequality is a major barrier to sustainability. One-Earth living requires mechanisms for fair income redistribution and otherwise sharing the benefits of economic activity.

Consistent with these biophysical and social realities, the global community should:

- accept that rational short-term economic behavior at the individual or small group level has become maladaptive at the long-term global level;
- formally acknowledge the absurdity of perpetual material growth and accumulation (the hallmarks of capitalism) on a finite planet;
- 'choreograph' (i.e., socially construct) an extended eco-economic 'story' compatible with the steady-state operating principles of the ecosphere;
- shift the primary emphases of economic planning from quantitative growth and efficiency toward qualitative development and equity—at present, the US and many of its OECD allies are growing but de-developing;
- begin the public cultural, social and economic discussions and formal planning necessary to reduce fossil energy and material consumption consistent with GFN (2019) estimates of overshoot (~70 %) and IPCC mandated emissions reductions (100 % decarbonization by 2050).
- develop economically efficient and effective instruments to ration fossil fuels and allocate the remaining global carbon budget to

essential uses (e.g., food production and intercity transportation) until adequate green energy supplies are available;

- commit to devising and implementing policies consistent with a 'one Earth' civilization. The overall goal should be an ecologically stable, economically secure steady-state society (Daly, 1991) whose citizens live more or less equitably within the biophysical means of nature. Victor (2019) shows that achieving a steady-state is possible;
- conceive and implement a global fertility strategy to reduce the human population to the two billion (±) people that might be able to live in material comfort on this already much-damaged single planet Earth.

No doubt the political and economic mainstream—and many ordinary citizens—will see these principles and actions as impossibly radical. Again, however, they are consistent with basic theory and empirical evidence. On its current trajectory, the present system *will* crash; the corrective throughput reductions suggested above are in line with those of various other technical analyses (Bringezu, 2015; IPCC, 2018; IGES, 2019). Governments and corporate interests who reject this framework therefore have a moral obligation to explain why adherence to growth-through-technology does not risk fatal catastrophe. Time is short: "Effective planetary stewardship must be achieved quickly, as the momentum of the Anthropocene threatens to tip the complex Earth System out of the cyclic glacial-interglacial pattern during which Homo sapiens has evolved and developed" (Steffen et al., 2011).

It remains only to ask: what is the probability that in the present "post-truth" era the leaders of the increasingly fractious world community will be able to come to this or any other shared diagnosis and prescription for what ails the world? Humans are certainly prone to short-sighted self-delusion but are also capable of high intelligence, reason, introspection, compassion and even collective action toward a common goal. Herein, at least, lies possibility (though little latitude for error). These almost uniquely human qualities will have to triumph over primitive instinct, heated emotion and once-successful (but now maladaptive) cultural norms in shaping our collective response to anthropogenic global change. Belligerent intransigence may well destroy prospects for civilization and even deny *H. sapiens* the possibility for further ascent of the evolutionary ladder.

Tragic irony indeed if the Anthropocene is cut short by humanity's self-annihilation.

Declaration of Competing Interest

The author declares that he is free of any conflict of interest in researching, writing and submitting this paper.

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