Growth through contraction: Conceiving an eco-economy

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Introducing the human predicament

We are cursed to live in interesting times. The human enterprise is in a precarious state of "ecological overshoot" propelled by excessive economic activity and growing populations. Eco-overshoot (hereafter, "EO") exists when the human demand for renewable (self-producing) resources exceeds ecosystems' regenerative capacities and waste discharges from people and their economies exceed ecosystems' assimilative/recycling capacities. This is the archetypal definition of biophysical unsustainability.

"Overshoot Day" for 2021 occurs on 29 July. This is the date by which humanity's collective bio-resource consumption and waste production[1] will have "exhausted nature's budget for the year" (GFN, 2021). From July 29 on, we will be maintaining ourselves and our cumulative manufactured capital assets, and growing "the economy" by further eroding remaining stocks of so-called natural capital (fish stocks, forests, arable soils, biodiversity, ground water, etc.) and over-filling nature's failing waste sinks. Think "climate change", society's current environmental obsession: industrial society currently emits annually about 37 billion tonnes of carbon dioxide – the principal anthropogenic driver of climate change – of which about half is accumulating in the atmospheric (NOAA, 2021a). In 2021, carbon dioxide will average over 416 parts per million (ppm), up 48% from the preindustrial concentration of 280 ppm (and still growing at almost 3 ppm/yr) (NOAA, 2021b).

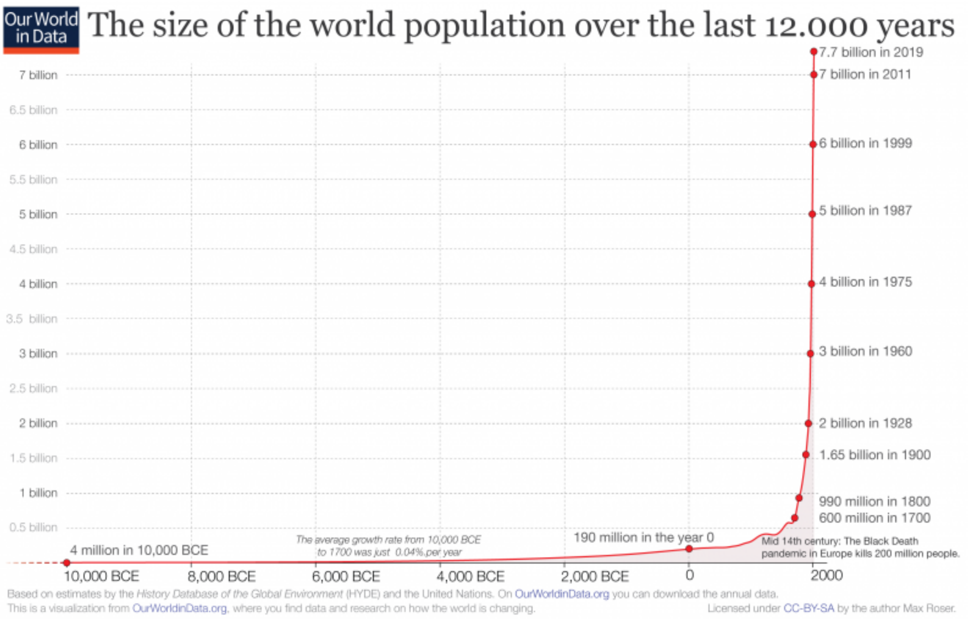
EO is a recent phenomenon. Anatomically modern *H. sapiens* have been around for over 300,000 years (Callaway, 2017) but took nearly the whole of that period to reach a population of just one billion in the early 19th century. Then in only 200 years, < *1/1500th as much time*, human numbers ballooned by a factor of seven and will top 7.9 billion in 2021 (Figure 1). At the same time, real gross world product increased >100-fold and per capita incomes (consumption) increased by a factor of 13 (25 in rich countries) (Roser, 2013). Of course, Earth didn't get any larger.

We can extract two important lessons directly from the sudden, exponential expansion of the human enterprise. First, the entire phenomenon was made possible by fossil fuels. Gross world product and fossil energy consumption (along with carbon emissions) have increased in lock-step; a similar relationship holds within individual industrial nations with readily explicable variations (e.g., Chima and Freed, 2005). Obviously other products of the scientific revolution – e.g., improving public health – contributed to the boom, but fossil fuels (FFs) were essential. FFs power the global industrial machine; they were (and remain) the principal means by which humans acquired access to all the food and other material resources needed to expand the human enterprise at virtually full biological potential. In population ecology terms, rapidly evolving technology and abundant cheap energy eliminated many of the "negative feedbacks" (e.g., disease, food and other resource shortages, etc.) that historically held our populations in check. Human numbers and virtually all material flows associated with *H. sapiens*

[1] Particularly carbon dioxide, the greatest waste by weight of industrial economies.

responded with exponential exuberance in what some authors have termed the “great acceleration” (Steffen, Crutzen and McNeill, 2007).

Figure 1. The super-exponential expansion of the human enterprise enabled by the scientific revolution really took off with the extensive use of fossil fuels in the 19th century



Source of graph: *Our World in Data* at https://ourworldindata.org/world-population-growth.

Second, of perhaps 15,000 generations of humans, only the most recent 10 or so have experienced sufficient population/economic growth (and technological change) in their lifetimes to notice. For 99.9% of human evolutionary history, human numbers everywhere fluctuated in the vicinity of local carrying capacities as the latter varied with shifting climate and other ecological variables (including bouts of plague which in the 14th century wiped out a third to half of the Eurasian population in just a few years). In short, while the present generation and other recent cohorts of *H. sapiens* take continuous growth to be the norm – most economists get nervous if growth falls much below a “healthy” 2-3%/year which means GDP doubles every 23 to 35 years – *the past few decades of explosive growth comprise the single most anomalous period in human history*.

Concern for EO *per se* has yet to penetrate economic and developmental policy circles; few politicians have even heard of it. Nevertheless, EO arguably constitutes a crisis of unprecedented proportions. EO is *the* meta-problem: issues like climate change; plunging biodiversity; tropical deforestation; acidifying oceans; expanding deserts; soil/landscape degradation; air, water and land pollution; resource scarcity and completion; etc., (even the CoViD-19 pandemic), while serious in themselves, are all are mere *symptoms* of this greater malaise.

Consider that the present relationship between modern techno-industrial (hereafter, “MTI”) society and the living ecosphere is analogous (almost homologous) to the relationship of a malignant parasite to its host. A parasite is an organism that lives on a host organism and gains its own vitality at the expense of the vitality of its host. In ecologists' jargon, humans are naturally "macro-consumers", organisms that necessarily live by consuming other macro-scopic organisms. However, when in EO, the maintenance and growth of the human enterprise is achieved in part, through the over-consumption of plant and animal biomass and the degradation of the ecosphere. Here is malignancy. Plants, non-human animals, and countless species of bacteria and fungi living in community, effectively constitute the living tissues of the ecosphere (some would say "Gaia"); the symptoms of EO – biodiversity loss, fisheries collapses, eroding soils, shrinking forests, pollution, etc., and the loss of associated life-support functions – are ample evidence of tissue destruction and failing eco-vitality. Like any other ill-adapted parasite, MTI culture is systematically – even enthusiastically – consuming the biophysical basis of its own existence. There is clearly something fundamentally dysfunctional about the world's dominant socio-economic system.

The remainder of this chapter unfolds in two parts. The following section describes how humanity, that self-proclaimed most intelligent of species, got into this potentially terminal predicament. I argue that EO is not a technical problem amenable to technological fixes but rather a meta-problem with deep roots in both biology and culture. The final section outlines key elements of one form of bio-cultural adaptation. We must re-conceive the economy and society as cultural components of a regenerative human ecological niche, one that contributes to the functional integrity of supportive ecosystems. Is there any other way to rescue human civilization from itself and restore vitality to the ecosphere?

How we got here from there

> "Tool-wielding monkeys push local shellfish to edge of extinction" (Woodward, 2017).

In one respect, humans came into EO honestly – population outbreaks are a common temporary phenomenon in among wild species "enjoying" unusually abundant resources. Indeed, human EO is the predictable outcome of contemporary cultural nurture combined with ancient human nature.

Some people, uncomfortable acknowledging their animal selves, may dispute the genetic component. However, the fact is that we humans *are* animals, large energy-demanding mammals to be precise. And, like all extant species, *H. sapiens* has evolved over time. Like it or not, we owe much to our evolutionary heritage and are still subject to the forces of natural selection. It should be no surprise, therefore, that we share various adaptive characteristics, including fundamental behavioral predispositions, with other living creatures.

H. sapiens: unsustainable by nature

Two such evolved predispositions are particularly relevant to EO. Unless or until constrained by negative feedback, populations of *H. sapiens* will tend to: 1) expand to occupy all accessible habitats and; 2) use all available resources. Excelling at these traits would obviously be adaptive and help ensure the survival of any species in the competitive struggle for existence. Indeed, this fact highlights one important factor that distinguishes humans from the rest of the pack: in the case of *H. sapiens* – and much to our competitive advantage – "accessible" and "available" are constantly being upgraded by technology.

There is no shortage of empirical evidence to support these assertions. Consider that with the possible exception of various rodents that ride our coattails, humans have expanded to occupy the most extensive geographic range of any vertebrate organism. Not only do we occupy all habitable land-masses and ecosystems on Earth, but we are capable of existing in some of the ostensibly least hospitable habitats on this planet and contemplate establishing colonies on such dead rocks as the moon and Mars. Does anyone imagine that if a new resource-rich continent were to be discovered that we would leave it in pristine condition in acknowledgement that we have messed up everywhere else?

On the resource-use side, many of the symptoms of EO from fisheries collapses to landscape degradation are the direct result of systematic over-exploitation facilitated by ever-improving fossil-powered technology. Factory-freezer trawlers scour the ocean floor destroying whole benthic and sea-bed ecosystems while 18-tonne 600 horse-power combines harvest food-grains from over-fertilized fields and behemothic earth-movers rearrange the face of the planet in scrounging for ever-diminishing deposits of essential mineral resources. *H. sapiens* may not be the only tool-using primate that tends to deplete essential resources (Luncz et al., 2017) but we are undeniably better at it than any other species. Fowler & Hobbs (2003) demonstrated that in terms of energy use (and carbon-dioxide emissions), biomass consumption, and several additional ecologically significant indicators, human demands on their supportive ecosystems dwarf those of similar species by ten to a hundredfold. Competitive superiority has clearly served our species well but the consequences for other species have been devastating (see Box 1).

BOX 1
***H. sapiens*: champions of competitive displacement**

Humans comprise a mere 0.01 % of total Earthly biomass but the relentless expansion of human populations has eliminated 83% of wild animal and 50 % of natural plant biomass. From a fraction of one percent ten millennia ago, humans now constitute 36 %, and our domestic livestock another 60%, of an expanded mammalian biomass compared to <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, with rapidly developing technologies that plunge deeper and can "see" individual fish, commercial fishing deplete 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 (Gremillet 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). Arthropods (e.g., insects) and even gastropods (e.g., snails and clams) are also in precipitous decline (Hallmann et al., 2017, Neubauer et al., 2021).

These data show that *H. sapiens* has become, directly or indirectly, the dominant macro-consumer in all major terrestrial and accessible marine ecosystems on the planet and certainly the major polluter. Meanwhile international organizations and mainstream economists posit from ecologically empty monetary analysis and mineral flows that the economy is "dematerializing" or "decoupling" from nature (e.g., UNEP 2011, Scheel et al., 2020). The fact is that our species is actually the most voraciously successful predatory and herbivorous vertebrate ever to walk the Earth. The resultant 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).

The social construction of "reality"

Innate behaviors are by no means the only factor responsible for EO; maladaptive cultural norms play at least an equivalent role. But there's an interesting twist – we humans uniquely "socially construct" our lived realities. More accurately, humans socially construct *conceptual frameworks* through which we interpret reality. Everything from simple ideas to whole cognitive frameworks (tribal myths, religious doctrines, economic models, political ideologies, academic paradigms, cultural narratives, scientific theories) are products of the human mind, birthed in language – including mathematics – massaged through social discourse, and finally accepted as truth or "received wisdom" by *agreement* among members of the social group who have created the construct.[2]

There are several important corollaries: first, the conceptual frames through which we perceive reality determine the quality and characteristics of the reality we perceive; second, we are compelled to live "out of" our constructed realities as if they were real; third, if people do not understand this process – and most do not – then they will live out their lives taking their experience of reality to be the only possible right and true reality. They will be utterly unaware that many of their most important behaviors and choices are determined, largely unconsciously, by myths, models and narratives that our culture has essentially made up. The problem is that many of these constructs are little more than shared illusions, i.e., gross errors about, rather than insights into, the nature of reality.

When social constructs are fundamentally flawed

> "We cannot regulate our interaction with any aspect of reality that our model of reality does not include" (Beer, 1981).

Any construct pertaining to the natural world (e.g., an economic or resource management model) is more likely to succeed the closer it "maps" to any facet of biophysical reality it purports to represent. This principle has been formally stated as "Ashby's Law of Requisite Variety" (Ashby, 1957, 1958) often called "The First law of Cybernetics." In simple terms, the "variety" (i.e., internal complexity, number of possible states) of a control system must be at least as great as the variety of the system it is designed to control. More generally, a system has requisite variety only if its number of adaptive responses is a least equivalent to the number of challenging conditions it may encounter in its environment.

In the present context, the converse statement may be more relevant: Ashby recognized that if the variety/complexity of a particular environment exceeds the capacity of its regulatory system the *environment will dominate and ultimately destroy that system*. Consider that MTI culture – increasingly the entire global community – is in thrall of a (socially constructed) neoliberal economic paradigm based on an *exceedingly bad map of reality*. EO is perhaps the major negative consequence, one certainly capable of destroying the human system.

At its core, the modern world's entrenched economic narrative is simplistically mechanistic and reductionist. This was intentional. The work of neo-classical economists reflected "the late 19th Century faith in progress and the benevolence of its consequences" (Barber 1967, p.

[2] There is another layer of nature-nurture here. The content of our social constructs is culturally determined but social construction itself is an innate species-specific idiosyncrasy.

164). The founders of neoclassical economics*, impressed with the successes of the physical sciences (particularly Newtonian analytic mechanics) sought to create an analogue in economic theory.* Stanley *Jevons, one of those founders,* characterized his theory of political economy not as "a branch of the science of a statesman or legislator, [but as] the *mechanics of utility* and *self-interest* [*Jevons's* emphasis]*"* (Schrader, 2015, p. 135).

Neoclassical writers assumed that individual actors have rationally defensible preferences and that they seek to maximize benefits to themselves (utility) in market exchanges. They asked how markets might best function as an effective mechanism for social organization. This narrowed neoclassicists' analytic focus from larger questions (e.g., economic justice, distributional equity) to understanding how market mechanics influenced the choices and behaviors of major economic actors, from individuals to industries. In this context, they elevated the theory of prices pertaining to both inputs and outputs as essential to understanding how market forces might optimize the allocation of society's resources to the most socially beneficial uses. In this way, "micro-economics – i.e., the study of the [efficient] behavior of households firms and industries – was brought to the centre of the stage" (Barber 1967, p. 165). These concepts remain central to MTI society's understanding of human economic behavior and related aspects of reality.

Indeed, neoclassical framing embodied several implicit and explicit assumptions of particular relevance to contemporary EO. For example:

1. the economy is separate from and can essentially function independently of the biophysical "environment";
2. analytic models are mostly linear, deterministic, and single equilibrium-oriented;
3. important relationships exhibit smooth change and reversibility;
4. factors of production (finance capital, natural capital, manufactured capital,, human capital) are near-perfect substitutes. I.e., human ingenuity – technology – can make up for any potentially limiting natural resource;[3]
5. damage to ecosystems or human communities (i.e., intangible factors not reflected in market prices) become mere "externalities;"
6. ethical and moral considerations that cannot be resolved in the marketplace are political considerations irrelevant to economic analysis.

It is a small step from acceptance of these assumptions to conviction that economic growth can continue indefinitely, unimpeded by "the environment" and propelled by boundless technological progress. By the mid-20th century, growth and accumulation – the material essence of modern capitalism – had become a major preoccupation of governments and the perceived solution to society's ills, especially persistent poverty. Rather than *tame* humanity's ancient survival instincts, seeing the world through the conceptual frame of neoclassical economics served to *reinforce* natural propensities to expand.

And it didn't end there. To this basic framework, the rise of neoliberal thinking in the post WW-II period added support for globalization, free trade, lower taxes, deregulation and minimalist government generally. This served to super-charge the growth model and capital's grip on the

[3] This assumption is particularly relevant. As Nobel Laureate Robert Solow has observed: "If it is very easy to substitute other factors for natural resources, then... The world can, in effect, get along without natural resources..." (Solow, 1974, 11). It follows that "Exhaustible resources do not pose a fundamental problem" (Dasgupta and Heal, 1979, 205).

economic process. Globalization ensured corporations' low-cost access to the world's remaining pockets of resources and to its cheapest sources of labor. Profits rose. Competition, reduced taxes and friendly regulatory regimes further increased profits and salaries/wages, even as they helped lower prices. With more and more money chasing ever-cheaper goods and services, and a buying public spurred on by a burgeoning advertising sector, the human enterprise experienced an unprecedented seven decades of rapid material growth, albeit punctuated periodically by minor recessions and other setbacks. The United States' single longest economic expansion in history – 126 months – was broken only by the onset of the CoViD-19 pandemic in early 2020.

But there remains a fundamental problem. Neoliberal economic models are crude abstractions that omit crucial aspects of reality. Far from exhibiting "requisite variety", the world's dominant economic paradigm contains no useful information about the structure or function of the biophysical systems – or even the social systems – with which the economy interacts in the real world. It defies logic that MTI societies have come to rely so much on the surreal simplicity of market mechanics to "regulate our interaction" with an ecosphere of truly unfathomable complexity. EO is evidence that the complexity of the ecosphere and society vastly exceeds the capacity of our political/economic regulatory system to assert control. Wealth accumulates and the ecosphere is in disarray yet poverty persists and income gaps are widening. The world is beginning to acknowledge that continuous growth is delusional (e.g., Dhara and Singh, 2021). The remaining question is whether the human enterprise can adapt before "the environment" assumes dominance and destroys it.

Now what? Getting real about ecological overshoot

EO exists when total energy and material flows through the economy exceed the productive and assimilative capacities of the ecosphere. The only way global society can address EO and regain effective "control" is through absolute reductions in energy and material throughput. Since total throughput is the sum of individual consumer demands, EO implies that Earth cannot sustain even current average per capita consumption. Thus EO is not merely a technical issue; it is a bio-cultural phenomenon that must be addressed through significantly dematerialized lifestyles combined with greater equity and significantly reduced populations. How significant? By one conservative estimate, the human ecological footprint (EF), the area of bioproductive land and water ecosystems required to support the human enterprise sustainably, is about 20.9 billion ha compared to total available biocapacity of 12.1 billion ha (GFN, 2021b) – we have overshot global carrying capacity by ~73% (the difference is made up through natural capital depletion and gross pollution). In short, achieving sustainability would require reducing human demands on the ecosphere by *at least* 42%.[4]

Any planned contraction would not be "across the board." For sustainability with justice, moral and ethical considerations demand that wealthy consumers, those mainly responsible for EO, bear the brunt of material cutbacks. As early as 1993, analysts recognized that "Industrialised world reductions in material throughput, energy use, and environmental degradation of over 90% will be required by 2040 to meet the needs of a growing world population *fairly* within the planet's ecological means" (BCSD, 1993, p. 10, italics added).

[4] EF estimates are actually conservative for several reasons. In particular, while the method can estimate the area of ecosystems "appropriated" by humans (the human EF) and compare this with available productive land and water area (biocapacity), it cannot account for of erosion, other forms of depletion or lost productivity through pollution.

Some will object that such seemingly extreme intentional "adjustments" to consumer lifestyles are simply not in the cards. Perhaps so, but we may have no choice. First, (over)expansion by the human enterprise was catalyzed by the unprecedented abundance of food and other resources made possible by fossil fuels (FF). Continued resource abundance will be necessary to maintain growth or even current average consumption levels. This may not be possible because of increasing mineral resource scarcity (Clugston, 2012; Michaux, 2021), land degradation, failing water supplies (NASA, 2015; UNDRR, 2021); growing energy uncertainty and the sheer scale of ongoing ecosystems destruction (Bradshaw et al., 2021).

Second, the IPCCs' demonstration that we need virtually 100% decarbonization by 2050 to avoid greater than 1.5ºC mean global warming and the possibility of catastrophic climate change, has spurred the global community to attempt a transition from fossil fuels to so-called green renewable energy sources (RE). Many sources claim that such transition is not only technically feasible but can be achieved with a minimum of disruption while stimulating investment and high-quality employment in virtually every jurisdiction (e.g., Jacobson et al., 2018; Ram et al., 2018).[5] Citizens are being urged to believe that "…every region on Earth can replace fossil fuels with renewable energy to keep warming below 1.5ºC and provide reliable energy access to all" (FFES, 2021).[6] However, despite promotional hype about wind turbines and solar PV (where most RE investment is going), and now hydrogen, and despite significant progress in electricity generation in some favored locations, there are myriad theoretical and practical reasons why *modern REs cannot quantitatively substitute for fossil fuels* (e.g., Berman, 2021; Jensen et al., 2021; Alexander and Floyd, 2018; Clack et al., 2017; Bossel, 2006). Several extended life-cycle studies suggest that the energy returned on energy invested (ERoEI) in wind and solar is insufficient to power modern society (e.g., de Castro and Capellán-Pérez, 2020). Worse, Ferroni and Hopkirk (2016, 2017) demonstrate that in mid-latitudes, solar PV is actually a net energy sink – its manufacture, installation and maintenance consume more energy than the system produces. In a commentary on the now considerable series of dubious technological "fairy tales" for reaching net zero carbon emissions by 2050, three climate scientists agree with the present analysis that "The only way to keep humanity safe is the immediate and sustained radical cuts to greenhouse gas emissions in a socially just way" (Dyke et al., 2021).

All of which means that the RE-will-save-us strategy is a dead end. Absent a more comprehensive "exit plan," humanity will soon confront a chaotic combination of significantly

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[5] Note that such analyses and solutions are entirely self-referencing. Acceptable solutions to eco-crisis (wind and solar generation, electric vehicles, hydrogen technologies, as yet unproved carbon capture and storage technologies, etc.) involve massive capital investment, job creation and other economic stimuli, i.e., anything that will ensure business-as-usual-by-alternative-means. As Spash (2016) has argued, the problem becomes the solution!

[6] Many analysts ignore the sheer scale of the required transition. The IPCC emissions reduction schedule requires reductions of ~7% year assuming we began in 2021. In the absence of carbon capture and storage, this would mean substituting for 7% of fossil fuel use. Consider that in 2019 fossil fuels contributed 492.34 Ej (136,761.11 Twh) to global primary energy production (84%). Seven percent of this is 34.46 Ej or 9573.3 Twh. If we assume a conversion ratio of 2.47:1 for wind and solar (W&S) energy (i.e., 1 unit of wind/solar energy = 2.47 units of fossil energy when converted to electricity), we would need 3875.8 Twh of new W&S electricity in just the first year. However, the total amount of W&S electricity generated in 2019 was 2153.7 Twh (equivalent to <4% of supply). In short, to meet the IPCC Paris target (-7% emissions per year) we need to build 1.80 (3875.8/2153.7) times the entire multi-decade cumulative global stock of wind and solar installations in the first year alone. Repeat the process in subsequent years. This is impossible. In any event, building out RE infrastructure at this pace would itself blow emissions limits; and even if it could be done (coupled with 100% carbon capture) the world would still have an overshoot crisis (Energy data from BP Statistical Review of World Energy 2020).

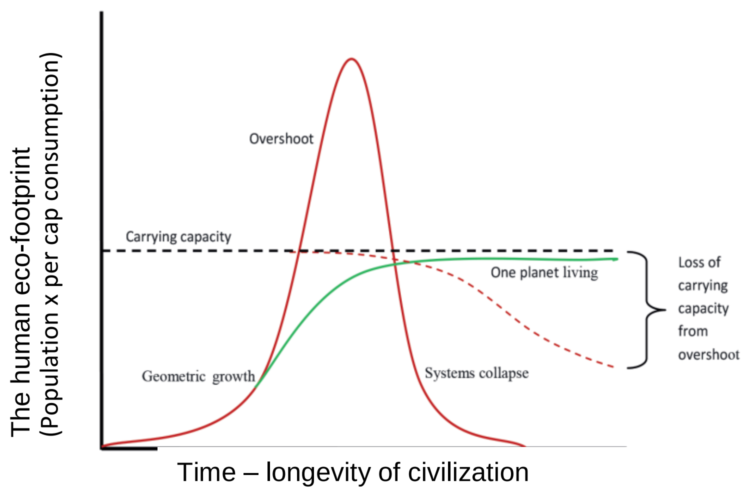
reduced energy supplies, economic contraction, food and other resource shortages, increasing civil unrest, and geopolitical conflict, i.e., the collapse of civilized order. Of course, should MTI society decide simply to "party on" while economic fossil energy supplies last – which seems increasingly to be the default position of governments – we will face more disastrous climate impacts and economic contraction accompanied by widespread famine, mass migration, domestic turmoil, international chaos and systems collapse. Either way, it is past time for the world community to acknowledge and *authentically internalize* reality – plan for a cooperative, dignified contraction of our eco-footprint or face the prospect that the ecosphere unleashed will indeed come to "dominate and destroy" the human system.

What goes up will come down

If this seems over-the-top consider that, as matters stand, the ballooning human enterprise resembles the boom or "plague" phase of a one-off population boom-bust cycle (Rees 2020). Boom-bust cycles are common in nature during periods of unusual resource abundance – think fossil fuel – or when some species population is introduced to a new, resource-rich but previously unexploited habitat (see Scheffer, 1951 for a classic example). Booms invariably generate busts.

Figure 2 illustrates the dilemma and shows what must occur for civilization to have a reasonable chance of surviving more or less intact. The solid red curve traces humanity's present overshoot trajectory – note the similarity of the first half of this curve to the plot of real-world population growth in Figure 1. Sometime in the mid- to late 20th century, the human eco-footprint blew past Earth's long-term human carrying capacity (CC) (the dotted horizontal black line). Beyond this point, the depletion of renewable natural capital) has resulted in an accelerating erosion of future carrying capacity (dotted red line).

Figure 2. Global humanity's one-off boom-bust cycle



A more sophisticated species, aware of its dependence on ecosystems and tuned to changing ecological conditions might have socially-engineered a sigmoid slowing of exponential growth. Its eco-footprint would have converged asymptotically toward, and fluctuated moderately thereafter, in the vicinity of mean global CC (solid green line). This is the essence of one-planet living – the balancing of population and material well-being within the regenerative and assimilative capacities of Nature (Moore and Rees, 2013).

This option is no longer fully available. The best we can do to avoid full systems collapse – the common fate of many earlier complex societies (Tainter, 1988) – is to manage the contraction of the human enterprise so that it detours on the way down to run more or less parallel to the dotted red line. The subsequent scale of the population and economy will be considerably less than the optimal "one planet living" (green) curve because of greatly depleted natural capital. EO causes a loss of CC that will take decades to recover.

Framing adaptation: the biophysical dimensions

Since the growth-based neoliberal capitalist economy is failing in biophysical terms, a first step toward a viable alternative must be to revisit the ecologically-relevant assumptions of the prevailing paradigm.

First, we must abandon thoughts of human exceptionalism. Far from being independent of nature, all human societies and economies are open, fully contained dependent subsystems of the materially-closed ecosphere (Daly, 1999; 1991). Like other species, humans are subject to the laws of physics, chemistry and biology, the most important of which are the first and second laws of thermodynamics and the law of conservation of mass.

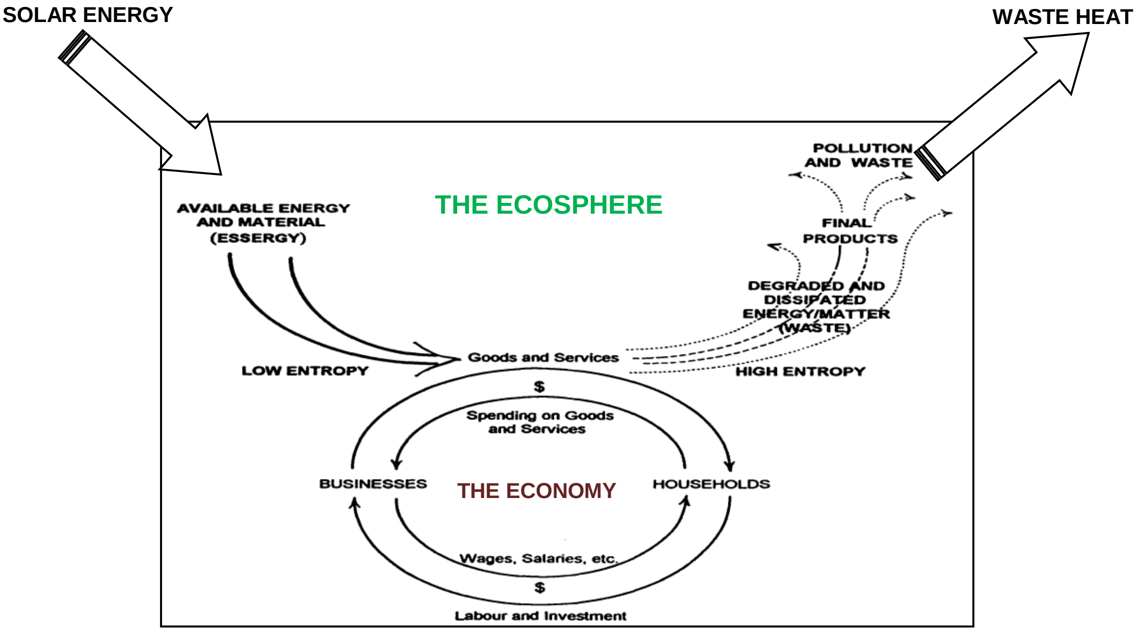
The second law – the entropy law – recognizes that all real processes, including all economic processes, are "dissipative", i.e., production and consumption *permanently* (irreversibly) dissipate all of the energy and a significant proportion of the material involved. Moreover, the laws of energy conservation (first law of thermodynamics) and mass conservation together dictate that 100% of the energy and material assimilated by the economy – including once useful products – eventually return to the "environment" as useless degraded waste (pollution).[7] There are no exemptions. Both the ecosphere and the human subsystem are self-producing dissipative structures. However, while the ecosphere "feeds" on high-grade solar energy through photosynthesis and ejects low grade waste heat into space, the economy both feeds on the ecosphere and treats it as a waste dump (hence our parasite analogy). Beyond a certain scale, the economy can only increase the entropic disordering of the ecosphere. The more important flows in the economy, therefore, are not economists' circular flows of abstract money value but rather the irreversible one-way flows of energy and matter (Figure 3).[8]

Second, societies, their economies and particularly the ecosystems *within which they are embedded* are complex adaptive systems. This means that their behavior under stress is often non-linear, characterized by lags, thresholds and other discontinuities; it may be chaotically unpredictable if pressed beyond certain thresholds. Such "catastrophic behavior" by the host ecosphere might well be fatal to human society. Biophysical systems have multiple equilibrium states which are unknowable before the fact. If pressed beyond some heretofore invisible "tipping point" – a major concern of climate scientists and systems ecologists – the earth system may collapse irreversibly into a new stable state hostile to

[7] Nicholas Georgescu-Roegan (1971) and later his student, Herman Daly (1991), were the first to argue the relevance of thermodynamic laws to economics but have been ignored by mainstream analysts.
[8] This seems to invalidate recycling and, in part, it does. Energy cannot be recycled; material recycling always falls short of 100% and requires the use/dissipation of *additional* energy and materials.

civilization (Steffen et al., 2018). Obviously, any economic sub-system must conform to the operational dynamics of the ecosphere if it is to survive. The operational dynamics of the ecosphere exemplify a dynamic steady-state (Daly, 1991).

Figure 3. The potentially parasitic economy



The economy, represented by the textbook stand-alone "circular flow of exchange value" (bottom part of diagram), is actually an open, fully-contained, growing sub-system of the materially closed non-growing ecosphere (rectangle). The ecosphere self-produces by dissipating sunlight but the economy dissipates the ecosphere.

Third, there are limits to factor substitution. Herman Daly has championed the fact that manufactured capital and natural capital are generally complements not substitutes – more fish boats or fishers do not compensate for the collapse of the fish stock (e.g., Daly, 1991, Ch.13; Daly, 1994). Indeed, some form of natural capital is a *prerequisite* for all forms of manufactured capital. Moreover, because self-producing "natural capital" maintains the life-support functions of the ecosphere, the risks associated with its depletion are unacceptable, and there may be no possibility for technological substitution "*conserving what there is* could be a sound risk-averse strategy" (Pearce et al., 1990, p. 7, emphasis added).

Fourth, it is implicit from the above that the notion of "externalities" – ecological and social costs of production not reflected in market prices – is a pernicious holdover from linear, reductionist thinking. There is no separate "environment" and no true "externalities." Faulty accounting has helped propel humanity into EO; the climate and many ecosystems are approaching tipping points unremarked by economic analyses. If we could now impose a full social-cost accounting framework, we would no doubt find that the heretofore externalized costs of growth at the margin already exceed the marginal economic benefits, i.e., we have exceeded optimal economic scale. It seems that eco-overshoot also entails economic or civilizational overshoot.

As long as this is true, further growth is uneconomic growth that makes humanity poorer rather than richer (Daly, 1999). Thus, if intelligence and logic are to be major determinants of future economic policy, a primary objective should be to manage the economy with "steady-state" material throughput in the vicinity of optimal scale. Note that if so-called externalities could suddenly be included in market prices, many frivolous and even perceived "essential" items would be beyond the reach of perhaps a majority of consumers. Consumption – or at least material throughput – would plummet; producers and consumers would have to adapt to biophysical reality (to the ultimate benefit of people, communities and the ecosphere).

The economy as adaptive (eco)niche

Ecologists who study the material and social relationships of non-human species say they are mapping those species' ecological niches. An organism's "niche" describes its food, habitat and related resource demands and the role that the species plays in maintaining the function and structure of its ecosystem. Well-adapted niches are non-disruptive; they define the relevant species "economic" relationships within, while contributing to the structural integrity of, relevant ecosystems.

MTI cultures understand the economy to comprise that set of activities central to the production, allocation, distribution and consumption of goods and services. Certainly material flows and relationships are a good starting point to define the human ecological niche – such relationships exist in all societies – but we should keep in mind that indigenous cultures have no concept of a separate entity called "the economy."

Indeed, problems begin when people formalize the economy in ways that abstract it from community and ecosystems and give it an identity of its own. Contemporary capital-serving neoliberal economies have gone rogue; they are now the independent variable in the equation of human societies everywhere. Ordinary people and their supportive ecosystems are now dependent variables expected to bend to every efficiency-based demand of the economy that might be required for continuous growth, growth that mostly serves the already wealthy as inequality increases. Eco-social crisis is inevitable. If humans are to reintegrate with nature and themselves in community, mere reform is not enough. We need to reconstruct the global and local economies, literally from the ground up, as adaptive eco-niches.

The once and future economy

The aggregate symptoms of EO leave little doubt that the continuity of civilization requires that the world community socially construct a new way of being on Earth that transcends MTI sensibilities. We need a personal-to-civilizational metamorphosis from contemporary growth-obsessed juvenility to adult maturity. We must create a world in which people can enjoy emotionally satisfying, materially sufficient lives in community without wrecking the planet.

The most adaptive form of this new civilization might be a network of cooperation-based eco-regional economies supporting many fewer people thriving more equitably within the regenerative capacity of their local ecosystems. The more spiritual among us might argue that a true eco-economy can emerge only through an *ascension of consciousness* whereby people recognize and honor the inextricable interconnectivity of all forms of life. Others will agree that confronting EO demands at least a conscious transformational paradigm shift, i.e., the abandonment of the foundational beliefs, values and assumptions of neoliberal capitalism and their replacement with a framework that better reflects biophysical reality. Either option may seem impossibly daunting, but if humanity does not attempt a preemptive correction to EO, an overstressed ecosphere will impose its own solution.

To begin the process, the world community would have to agree that each national government:

- Accept the conceptual limitations of neoliberal economic thinking outlined above;
- Formally recognize the end of material growth and the need to reduce the human ecological footprint;
- Acknowledge that while humanity remains in eco-overshoot, sustainable production/consumption means absolutely less production/consumption;
- Concede the theoretical and practical difficulties/impossibility of an all-green quantitatively equivalent energy transition;
- Recognize that equitable sustainability requires an economic leveling; i.e., fiscal and other regulatory mechanisms to ensure income/wealth/opportunity redistribution between and within countries – greater equality is better for everyone (Wilkinson and Pickett, 2009);
- Participate in a global population strategy to enable a managed, non-terrifying descent to the one to two billion that could live comfortably indefinitely within the biophysical means of nature.

Clearly, for the transition to succeed, the denizens of MTI cultures must consciously abandon and evolve beyond the core paradigms which define their present way of being in the world. We can hardly fully define a whole new culture in this space but can suggest some pertinent characteristics: Contemporary worship of material-growth-through-efficiency must give way to other values that have been sacrificed to market capitalism. The cult of individualism must concede to the need for cooperative collective solutions. A sense of unity with – or at least respect for – nature, recognition of material limits, loyalty to place, greater social equality, community cohesion, regional self-reliance and local economic diversity are all prerequisites for, long-term economic security, social well-being and ecological stability. Above all, the new human eco-niche must be regenerative, i.e., the emerging "consciousness" must ensure that the economy is re-embedded in community and that this (re)union develops as a fully integrated mutualistic component of its sustaining ecosystems. (In many respects, this vision represents a reversal of Karl Polanyi's *Great Transformation*, capitalism's severing of the economy from local community and governance structures in the name of growth, efficiency and profit maximization.)

Dubious of the benefits of relocalization? There is also a push factor. Globalization and unfettered trade – i.e., dependence on distant "elsewheres" for food and many other resources – will no longer be possible in the emerging energy-constrained world.[9] Hence, adaptive eco-economies *must* be more eco-centric local economies. Agriculture and essential light manufacturing – e.g., food processing, textiles, clothing, furniture, tools – will all be relocalized providing ample meaningful employment. There will be a resurgence of personal skills and pride in workmanship. As an immediate additional benefit, when citizens become acutely aware of their dependence on *local* ecosystems they become more actively

[9] This is a good thing. Globalization is a driver of overshoot – globalized "free" trade in the late 20th century greatly accelerated resource (over)exploitation and pollution and facilitated population growth.

concerned about the state of those systems. A sense of conscious participation in one's eco-niche is not possible if the relevant ecosystems are half a planet away.

Implications of eco-economics for settlement and spatial planning

Most people are unaware that the "ecological footprints" of modern cities – the ecologically productive land and water area required to support urbanites' contemporary lifestyles – are typically several hundred times larger than the cities' physical or political areas (Rees, 2012). The products of these distant hinterlands are conveyed to cities by fossil-powered ships, planes and trucks. In the US, for example, more than 80% of towns and cities are provisioned only by trucks; heavy duty diesel-powered Class 8 trucks haul 70% of the nation's freight. Even if 100% electrification were possible, the extreme demands of heavy-duty haulage ensure that "all-electric or hydrogen fuel cells for propulsion is not an option" (USDE, 2011; Friedemann, 2016).

In the absence of abundant cheap energy, it will not be possible to provision large cities and megacities. Many urban populations will have to be dispersed and redistributed. Consistent with the relocalization imperative, the following policies/objectives would reconfigure present settlement patterns into more functionally self-contained human econo-ecosystems. Senior governments should cooperate with regional and local officials to, for example:[10]

- Create national sub-systems of self-reliant bioregions or eco-regions centered on existing smaller cities with boundaries based on ecologically meaningful land-forms and biophysical features (e.g., watersheds, heights of land);
- Size each urban-centred eco-region initially to contain, where possible, a productive ecosystem area equivalent to its population's currently globally dispersed supportive hinterland; i.e., internalize their *de facto* "eco-footprints." (There will be insufficient domestic land/water in many countries forcing recognition of the need for much lower levels of material consumption and a gradual reduction in population.);
- Re-localize government services and decision-making authority, i.e., devolve sufficient governance and taxation powers to the new urban eco-regions to enable effective management of their internal resource- and ecosystems;
- Organize the regional economy and commerce to sustain the population as much as possible on domestic bio-resources and ecosystems, thus reducing reliance on trade. There will still be some trade but:
- Imports should be restricted to true necessities that cannot be produced locally; exports should be limited to bio-resources in true eco-surplus, i.e., harvest rates must be less than regeneration rates to prevent natural capital depletion;
- Facilitate the organization of producer and consumer co-ops – every working person should have a genuine stake in the eco-economy. The ratio of highest paid management to average worker wages should be no greater than 5:1 (the average for Spain's well-known Mondragon cooperatives);

[10] No one really knows how to create the conditions which nurture and support the shifts we need. Cultural evolution means that the many components of society must evolves in parallel lines but not necessarily at the same pace. Nor should the process be identical from place to place; there is no grand set template. Fortunately, the network of eco-regions proposed here provides ample opportunity for small-scale planning experiments – learning exercises – so that the successes/failures of differing initiatives can be widely shared as the overall initiative is gradually scaled up.

- Reintegrate animal husbandry with food-cropping in keeping with sound soils management and to reduce the need for artificial fertilizer with its associated ground- and surface-water pollution;
- Re-design urban waste management to convert settlements from resource-depleting throughput systems into self-sustaining circular-flow ecosystems. E.g., collect, treat and recycle animal and domestic nutrient-containing wastes onto the eco-region's farm-and forest lands whence it came. (Circularity in nutrient flows is structurally and functionally necessary for any ecosystem's continuity.);
- Invest in natural capital restoration; regenerate depleted soils, degraded landscapes, wooded areas and other wildlife habitats to promote biodiversity, enhance regional productivity, increase carbon sink capacity and mitigate climate change. (Human overuse has already dissipated half the world's topsoil but soil still contains several times as much carbon as the atmosphere.);
- Recognize that governance of regional ecosystems and landscapes for the common good will sometimes require stinting customary private property rights. Importantly, citizens who realize that their security depends on maintaining the integrity of local ecosystems have an incentive to support such measures.

Clearly, it would have been advantageous to have begun such a process 50 years ago.

Truly renewable energy

It should by now be obvious that the post-carbon economy must adapt in myriad ways to greatly reduced energy supplies. (In 2019, fossil fuels accounted for 84% of the world's primary energy [BP 2020].) Any remaining fossil fuel budget must be dedicated to essential uses such as food production; less important and frivolous FF technologies should be banned (leaf blowers, recreational ATVs, jet-skis, motorized pleasure craft, private automobiles – including EVs – non-essential air travel, and most military uses come to mind). The eco-economy will be powered by truly renewable benign energy sources such as biomass (especially wood), simple mechanical wind and water power, passive solar, and animal and human labor.

On this last point, citizens of the MTI world forget that industrial energy now does the work that people and animals use to perform. North Americans each have the energy equivalent of hundreds of human slaves in continuous employment to provide them with the goods and services they have come to take for granted. If we ignore nuclear- and hydro-electricity, "99.5% of 'labor' in human economies is done by oil, coal and natural gas" (Hagens and White, 2017). On the draft animal side, the population of working horses and mules in the US peaked at 26 million in about 1915 – when the human population was about 100 million – only to be gradually replaced by fossil-powered farm and industrial equipment (Kilby, 2007). The post-carbon US economy may once again need this many work-horses (and about 50 million acres of dedicated fodder-producing land) *even if the population shrinks back from 331 to 100 million*. By comparison there are only five to 10 million horses in the U.S. today, of which just 15% are working farm or ranch animals (Kilby, 2007). Again, rebuilding the herd should have begun decades ago.

However things unfold, a drop of 50% or more in energy availability need not be catastrophic - there are even several silver linings. Sixty percent of the energy flow through the modern economy is lost to inefficiencies (LLNL, 2020); Americans and Canadians use four and five times more energy per capita than the global average, so there appears to be much room for improvement and adaptation; modern versions of older technologies will be more efficient and certainly more ecologically sophisticated than today's so-called renewables. And finally, human labor on the land will mean more physically active lives in closer contact with each other and supporting ecosystems. This should help to underscore the benefits of co-operation, restore our sense of connection to the natural world and instill a hands-on appreciation of the true human eco-niche. Meanwhile, a waning focus on material growth will allow the emphasis to shift to progress of the mind and spirit and the art of living in community – largely untapped frontiers with unlimited potential. Personal growth and collective well-being know no bounds. Humanity may yet grow to realize our full potential for high intelligence, forward planning and compassion through the necessity of material contraction.

Epilogue

> "Due to the power/interest structures of global capitalism and the juggernaut-like momentum of the global economy, it is most unlikely that any of the [proposed] radical changes to society and the economy… will be adopted in time [to avoid catastrophe]" (Dilworth, 2010).

> "Leaked UN draft report warns of accelerating climate devastation – species extinction, more widespread disease, unliveable heat, ecosystem collapse, cities menaced by rising seas" (Aljazeera, 2021).

The adaptations to EO proposed in the paper run 180 degrees from the capital-intensive growth-oriented "solutions" supported by governments, corporations and international organizations anxious for the economy to come "roaring back" from the CoViD-19 pandemic. As argued above, the mainstream model generating these cancerous solutions is fatally flawed – it is narrowly focused on climate change (a solitary symptom of EO), ignorant of energy realities and emerges from an economic vision that is devoid of biophysical insight. It neither acknowledges EO nor modern humanity's quasi-parasitic relationship with an increasingly turbulent ecosphere. In short, our prevailing econo-governance framework fails the test of requisite variety and puts global society in ecological peril.

By contrast, the present analysis acknowledges EO and advances adaptive approaches to human ecological dysfunction that are wholly consistent with biophysical evidence and trends. The downsizing and re-localization of economic activities and their reintegration with communities and supportive ecosystems disaggregates the human enterprise into manageable spatial and eco-economic units more consistent with Ashby's law; these proposals reflect values that other researchers increasingly accept as essential for the survival of civilization (e.g., Wiedmann et al., 2020); they are also consistent with the view that the required transformation cuts much deeper that those assumed even by the emergent degrowth movement (Trainer, 2021). Assuming that our best science is valid, which approach has the higher probability of success: staying our growth-obsessed trajectory or diverting to an eco-sensitive, socially just downsizing?

Evidence-based logic points to the latter but there is scant evidence that the world community or any individual nation is preparing voluntarily to embark on a deliberate long descent. Rather than taking falling birthrates as a hopeful trend, most governments lament their supposed negative implications for pension schemes, national competitiveness and economic growth. Even today's narrow focus on reversing climate change is doomed to fail. National governments, spurred on by their corporate sponsors have placed their bets on faulty or non-existent capital-intensive technologies to reduce carbon emissions. Meanwhile, they avoid taking the really hard decisions needed to wean society from fossil fuels while pumping hundreds of billions annually into direct and indirect FF subsidies. True to humanity's innate tendency for temporal discounting, it seems that the world community's default position is to stick with fossil fuels. Governments and monied elites would much rather tempt the uncertain risk of potentially catastrophic climate change some time in the future than the certain risk of social upheaval, economic disruption and threats to their privileged status that would accompany rapid (unplanned) contraction today. Most ordinary people – for now – seem content to go along for the ride.

But the tide may be turning. The seemingly impossible socioeconomic reset proposed in this paper may yet be within reach. Increasing numbers of thoughtful citizens, activist organizations, and NGOs are taking to the streets. They recognize that the most effective stimulus for rapid social progress has always been popular resistance—peaceful protests, civil disobedience and even revolution—often in that order. As the human eco-predicament worsens, there is (shrinking) room for hope that along this spectrum there will yet be a popular awakening, one sufficient to catalyze the greater transformation needed to conserve prospects for global civilization while there is yet time.

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