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Economics for the future – Beyond the superorganism

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ABSTRACT

Our environment and economy are at a crossroads. This paper attempts a cohesive narrative on how human evolved behavior, money, energy, economy and the environment fit together. Humans strive for the same emotional state of our successful ancestors. In a resource rich environment, we coordinate in groups, corporations and nations, to maximize financial surplus, tethered to energy, tethered to carbon. At global scales, the emergent result of this combination is a mindless, energy hungry, CO2 emitting Superorganism. Under this dynamic we are now behaviorally 'growth constrained' and will use any means possible to avoid facing this reality. The farther we kick the can, the larger the disconnect between our financial and physical reality becomes. The moment of this recalibration will be a watershed time for our culture, but could also be the birth of a new 'systems economics'. and resultant different ways of living. The next 30 years are the time to apply all we've learned during the past 30 years. We've arrived at a species level conversation.

"Ecological Economics addresses the relationships between ecosystems and economic systems in the broadest sense." – **Robert Costanza**, (the first sentence in the first article in the first issue of Ecological Economics)

"The real problem of humanity is the following: we have paleolithic emotions; medieval institutions; and god-like technology."– **E.O. Wilson**

"We live in a world where there is more and more information, and less and less meaning." –**Jean Baudrillard**

"Not everything that is faced can be changed, but nothing can be changed until it is faced." – **James Baldwin**

1. Overview

Despite decades of warnings, agreements, and activism, human energy consumption, emissions, and atmospheric CO2 concentrations all hit new records in 2018 (Quéré et al., 2018). If the global economy continues to grow at about 3.0% per year, we will consume as much energy and materials in the next ~30 years as we did cumulatively in the past 10,000. Is such a scenario inevitable? Is such a scenario possible?

Simultaneously, we get daily reminders the global economy isn't working as it used to (Stokes, 2017) such as rising wealth and income inequality, heavy reliance on debt and government guarantees, populist political movements, increasing apathy, tension and violence, and ecological decay. To avoid facing the consequences of our biophysical reality, we're now obtaining growth in increasingly unsustainable ways. The developed world is using finance to enable the extraction of things we couldn't otherwise afford to extract to produce things we otherwise couldn't afford to consume.

With this backdrop, what sort of future economic systems are now feasible? What choreography would allow them to come about? In the fullness of the Anthropocene, what does a hard look at the *relationships between ecosystems and economic systems in the broadest sense* suggest about our collective future? Ecological economics was ahead of its time in recognizing the fundamental importance of nature's services and the biophysical underpinnings of human economies. Can it now assemble a blueprint for a '*reconstruction*' to guide a way forward?

Before articulating prescriptions, we first need a comprehensive diagnosis of the patient. In 2019, we are beyond a piecemeal listing of what's wrong. A coherent description of the global economy requires a **systems** view: describing the parts, the processes, how the parts and processes interact, and what these interactions imply about future possibilities. This paper provides a brief overview of the relationships between human behavior, the economy and Earth's environment. It articulates how a social species self-organizing around surplus has metabolically morphed into a single, mindless, energy-hungry "Superorganism." Lastly, it provides an assessment of our constraints and opportunities, and suggests how a more sapient economic system might develop.

2. Introduction

For most of the past 300,000 years, humans lived in sustainable, egalitarian, roaming bands where climate instability and low CO2 levels made success in agriculture unlikely (Richerson et al., 2001). Around 11,000 years ago the climate began to warm, eventually plateauing at warmer levels than the previous 100,000 years (Fig. 1). This stability allowed agriculture to develop in at least seven separate locations around the world. For the first time, groups of humans began to

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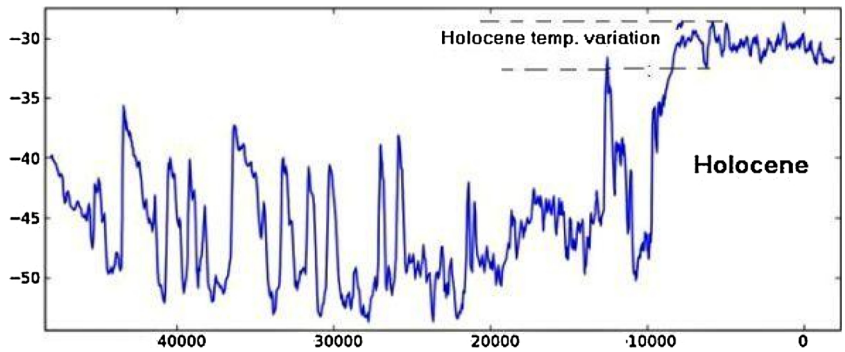

Fig. 1. 50,000 year History of Temperature of Greenland ice surface (C°) (Hansen, 2013).

organize around physical surplus - production exceeding the group's immediate caloric needs. Since some of the population no longer had to devote their time to hunting and gathering, this surplus allowed the development of new jobs, hierarchies, and complexity (Gowdy and Krall, 2013). This novel dynamic led to widespread agriculture and large-scale state societies over the next few thousand years (Gowdy and Krall, 2014).

In the 19th century, this process was accelerated by the large-scale discovery of fossil carbon and the invention of technologies to use it as fuel. Fossil carbon provided humans with an extremely dense (but finite) source of energy extractable at a rate of their choosing, unlike the highly diffuse and fixed flow of sunlight of prior eras.

This energy bounty enabled the 20th century to be a unique period in human history: 1) more (and cheaper) resources led to sharp productivity increases and unprecedented economic growth, 2) a debt based financial system cut free from physical tethers allowed expansive credit and related consumption to accelerate, 3) all of which fueled resource surpluses enabling diverse and richer societies.

The 21st century is diverging from that trajectory: 1) energy and resources are again becoming constraining factors on economic and societal development, 2) physical expansion predicated on credit is becoming riskier and will eventually reach a limit, 3) societies are becoming polarized and losing trust in governments, media, and science and, 4) ecosystems are being degraded as they absorb large quantities of energy and material waste from human systems.

Where do we go from here?

3. Human behavior

Humans are unique, but in the same ways tree frogs or hippos are unique. We are still mammals, specifically primates. Our physical characteristics (sclera in eyes, small mouth, lack of canines etc.) are the products of our formative social past in small bands (Bullet et al., 2011; Kobayashi and Kohshima, 2008). However, our brains and behaviors too are products of what worked in our past. We don't consciously go through life maximizing biological fitness, but instead act as '*adaptation executors*' seeking to replicate the daily emotional states of our successful ancestors (Barkow et al., 1992). Humans have an impressive ability to process information, cooperate, and discover things, which is what brought us to the state of organization and wealth we experience today. But our stone-age minds are responding to modern technology, resource abundance and large, fluid, social groups in emergent ways. These behaviors - summarized below - underpin many of our current planetary and cultural predicaments (Whybrow, 2013).

3.1. Status and relative comparison

Humans are a social species. Each of us is in competition for status and resources. As biological organisms we care about *relative* status. Historically, status was linked to providing resources for the clan, leadership, respect, storytelling, ethics, sharing, and community (Gowdy, 1998; von Rueden and Jaeggi, 2016). But in the modern culture we compete for status with resource intensive goods (cars, homes, vacations, gadgets), using money as an intermediary driver (Erk et al., 2002). Although most of the poorest 20% in advanced economies live materially richer lives than the middle class in the 1900′s, one's income *rank*, as opposed to the absolute income, is what predicts life satisfaction (Boyce et al., 2010). For those who don't 'win', a lack of perceived status leads to depression, drinking, stockpiling of guns and other adverse behaviors (Katikireddi et al., 2017; Mencken and Froese, 2019). *Once basic needs are satisfied, we are primed to respond to the comparison of "better* vs.*worse" more than we do to "a little"* vs. *"a lot."*

3.2. Supernormal stimuli and addiction

In our ancestral environment, the mesolimbic dopamine pathways were linked to motivation, action and (calorific) reward. Modern technology and abundance can hijack this same reward circuitry. The brain of a stock trader making a winning trade lights up in an fMRI the same way a chimpanzee's (and presumably our distant ancestors') does when finding a nut or berry. But when trading stocks, playing video games or building shopping centers, there is no instinctual 'full' signal in modern brains - so we become addicted to the '*unexpected reward*' of the next encounter, episode, or email, at an ever increasing pace (Hagens, 2011; Schultz et al., 1997). Our brains require flows (feelings) that we satisfy today mostly using non-renewable stocks. *In modern resource rich culture, the 'wanting' becomes a stronger emotion than the 'having'.*

3.3. Cognitive biases

We didn't evolve to have a veridical view of our world (Mark et al., 2010). We think in words and images disconnected from physical reality. This imagined reality commonly seems more real than science, logic and common sense. Beliefs that arise from this virtual interface become religion, nationalism, or quixotic goals such as terraforming Mars (Harari, 2018). For most of history, we maintained groups by sharing social myths like these. Failure to believe those myths led to ostracism and death. Beliefs usually precede the reasons we use to explain them, and thus are far more powerful than facts (Gazzaniga, 2012).

Psychologists have identified hundreds of cognitive biases whereby common human behaviors depart from economic rationality. These include: motivated reasoning, groupthink, authority bias, bystander effect, etc. Rationality is from a newer part of our brain that is still dominated by the more primitive, intuitive, and emotional brain structures of the limbic system. Modern economics assumes the rational brain is in charge, but it's not. Combined with our tribal, in-group nature, it's understandable that fake news works, and that people resist uncomfortable notions involving limits to growth, energy descent, and climate change. Evolution selects for fitness, not truth (Hoffman, 2019).

We typically only value truth if it rewards us in the short term. *Rationality is the exception, not the rule.*

3.4. Time bias (steep discount rates)

For good evolutionary reasons (short life spans, risk of food expropriation, unstable environment, etc.) we disproportionately care about the present more than the future, measured by economists via a 'discount rate'(Hagens and Kunz, 2010). The steeper the discount rate, the more the person is 'addicted to the present.' (Laibson et al., 2007). Drug users and drinkers, risk takers, people with low I.Q. scores, people who have heavy cognitive workloads, and men (vs. women) tend to more steeply discount events or issues in the future (Chabris et al., 2010).

Unfortunately, most of our modern challenges are *'in the future'*. Recognition that the future exists and that we are part of it springs from a relatively new brain structure, the neocortex. It has no direct connection to deep-brain motivational centers that communicate urgency. When asked to plan a snack for *next* week between chocolate or fruit, people chose fruit 75% of the time. When choosing a snack for *today*, 70% select chocolate. When choosing a movie to watch next week 63% choose an educational documentary but when choosing a film for *tonight* 66% pick a comedy or sci-fi (Read et al., 1999). We have great intentions for the future, until the future becomes today. Our neocortex can imagine them, but we are emotionally blind to long-term issues like climate change or energy depletion. *Emotionally, the future isn't real.*

3.5. Cooperation and group behavior

Group behavior has shaped us as much as individual behavior (Wilson and Wilson, 2008). Humans are strongly 'groupish' (Haidt, 2013), and before agriculture were aggressively egalitarian (Pennisi, 2014; Boehm, 1993). Those historic tribes that could act as a cohesive unit facing a common threat outcompeted tribes without such social cohesion. Because of this, today we easily and quickly form ingroups and outgroups and behave favorably and antagonistically towards them respectively. We are also primed to cooperate with our in-group whether that is a small business, large corporation, or even a nation-state - to obtain monetary (or in earlier times, physical) surplus. *Me over Us, Us over Them.*

3.6. Cultural evolution, Ultrasociality and the Superorganism

"*What took place in the early 1500s was truly exceptional, something that had never happened before and never will again. Two cultural experiments, running in isolation for 15,000 years or more, at last came face to face. Amazingly, after all that time, each could recognize the other's institutions. When Cortés landed in Mexico he found roads, canals, cities, palaces, schools, law courts, markets, irrigation works, kings, priests, temples, peasants, artisans, armies, astronomers, merchants, sports, theatre, art, music, and books. High civilization, differing in detail but alike in essentials, had evolved independently on both sides of the earth.*" **Ronald Wright**, A Short History of Progress (2004, pp50-51)

"*Ultrasociality refers to the most social of animal organizations, with full time division of labor, specialists who gather no food but are fed by others, effective sharing of information about sources of food and danger, self-sacrificial effort in collective defense.*" (Campbell, 1974; Gowdy and Krall, 2013).

Humans are among a small handful of species that are extremely social. Phenotypically we are primates, but behaviorally we're more akin to the social insects (Haidt, 2013). Our ultrasociality allows us to function at much larger scales than as individuals. At the largest scales, cultural evolution occurs far more rapidly than genetic evolution (Richerson and Boyd, 2005). Via the cultural evolution that began with agriculture, humans have evolved into a globally interconnected civilization, 'outcompeting' other human economic models along the way to becoming a defacto 'superorganism' (Hölldobler and Wilson, 2008). A superorganism can be defined as "*a collection of agents which can act in concert to produce phenomena governed by the collective*"(Kelly, 1994). Via cooperation (and coordination), fitness transfers from lower levels to higher levels of organization (Michod and Nedelcu, 2003). The needs of this higher-level entity (today for humans; the global economy) mold the behavior, organization and functions of lower-level entities (individual human behavior) (Kesebir, 2011). Human behavior is thus constrained and modified by 'downward causation' from the higher level of organization present in society (Campbell, 1974).

All the 'irrationalities' previously outlined have kept our species flourishing for 300,000 years. What has changed is not 'us' but rather the economic organization of our societies in tandem with technology, scale and impact. Since the Neolithic, human society has organized around growth of surplus, initially measured physically e.g. grain, now measured by digital claims on physical surplus, (or money) (Gowdy and Krall, 2014). Positive human attributes like cooperation have been co-opted to become coordination towards surplus production. Increasingly, the "purpose" of a modern human in the ultrasocial global economy is to contribute to surplus for the market (e.g. the economic value of a human life based on discounted lifetime income, the marginal productivity theory of labor value, etc.) (Gowdy 2019, in press).

3.7. Human behavior – summary

Our behavioral repertoire is wide, yet informed, and constrained by our neurological heritage and the higher level of organization exhibited by our economic system. We are born with heritable modules prepared to react to context in predictable ways. "*Who we are*" as a species is highly relevant to issues of ecological overshoot, sustainability and our related cultural responses.

4. Energy

Ecological economics acknowledges that real economies are completely dependent on energy. However, orthodox economic theory remains blind to this reality. As a result, so do our institutions and our citizenry. The disconnect has massive implications for our future. This is so critical it deserves reiteration.

4.1. Energy in nature

Energy is and always will be the currency of life. The effectiveness of energy capture is central to biological systems. Any movement, activity or event in nature requires energy. Organisms utilize foraging strategies that optimize energy intake vs. energy expenditure adjusted for time and risk (Krebs and Davies, 1997). In this way, biological organisms too, are investors. A larger energy surplus gives an organism a competitive advantage for growth, reproduction, defense, competition, maintenance and repair (Lotka, 1922). As such it is the 'net energy' after energy costs have been subtracted that is the enabler and driver of natural – and human – systems (Hall, 2016).

4.2. Energy and power

Biological systems maximize power. Metabolism is the *rate* at which organisms acquire, transform, and expend energy and materials (Brown et al., 2004; Schröter, 2009). "Power" is energy accessed/utilized per unit-time. Organisms and ecosystems naturally structure themselves to maximize power via accessing energy gradients. An oak tree doesn't grow one leaf (maximum efficiency) or e.g. 100 thousand leaves (maximum gross energy), but an intermediate amount of leaves placed to maximize the surface area of the tree to the sun for photosynthesis (Schneider and Kay, 1994). Systems which maximize useful power generally outcompete those which do not (Odum, 1995).

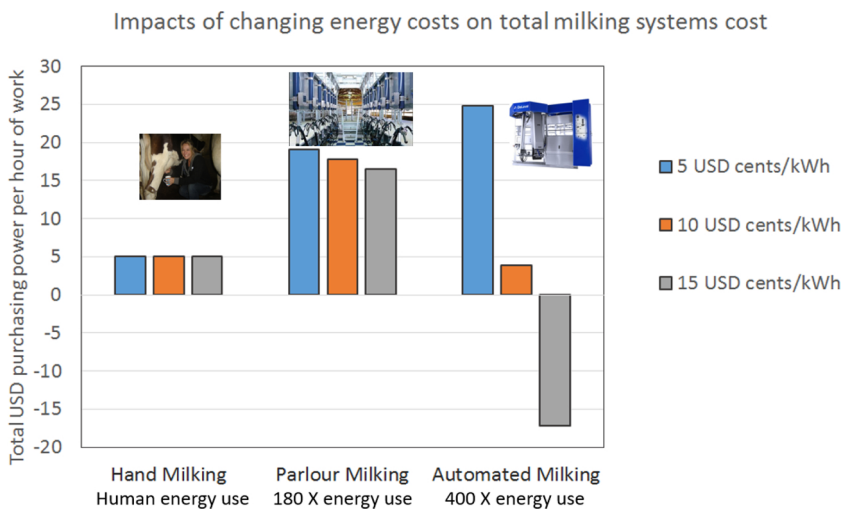

Fig. 2. Impact of technology + cheap/expensive energy on wages/profits.

4.3. Energy benefits

Major transitions in human societies over the past 10,000 years were linked to the benefits from different energy types and availability (Day et al., 2018). Industrialization changed the historic human relationship of energy capture from using the daily flows of nature to using technology fueled by large amounts of cheap fossil energy.

One barrel of crude oil can perform about 1700 kW h of work. A human laborer can perform about 0.6 kW h in one workday (IIER, 2011). Simple arithmetic reveals it takes over 11 years of human labor to do the same work potential in a barrel of oil. Even if humans are 2.5x more efficient at converting energy to work, the energy in one barrel of oil substitutes approximately 4.5 years of physical human labor.

This energy/labor relationship was the foundation of the industrial revolution. Most technological processes requires hundreds to thousands of calories of fossil energy to replace each human calorie previously used to do the same tasks manually. Consider milking a cow using three methods (see Fig. 2): manual (human labor energy only), semi-automated electric milking machines (1100 kW h per cow per year), and fully automated milking (3000 kW h per cow-year). The manual milker, working alone, requires 120 h of human labor per year per cow; semi-automated machines require 27 h of labor; and full automation, 12 h. We'll estimate that the human milker generates economic value of $5 an hour working alone. Using electric milkers at $0.05 per kWh, output rises significantly *and*—because cheap electricity substitutes for so many human hours of labor—the revenue increases to $19 per hour with semi-automated milkers and to $25 per hour with the fully automated technologies. (Note: this large economic benefit could go to the owner of the dairy farm, the employees, or to consumers in the form of cheaper milk – or any combination) (Hagens, 2015). This same principle extrapolates to most modern industrial processes: we save human labor and time by adding large amounts of cheap fossil labor (Cleveland et al., 1984; IIER, 2011).

Although modern industrial output is energy inefficient it is extremely cost efficient because fossil energy is much cheaper than human energy. This is the "fossil subsidy", that makes modern profits, wages and standards of living considerably higher compared to previous civilizations based on diffuse renewable flows. The average human in 2015 produced 14 times more GDP than a person in 1800 – and the average American 49 times more (Lindgren, 2011)! Modern Americans -via their energy subsidy - now have the physical metabolism of 30+ ton primates (Brown and Group, 2013; Patzek, 2011).

However, these windfalls come with a downside. Industrial profitability is vulnerable to energy price increases. As indicated in orange and grey bars in Fig. 2, a doubling or trebling of energy costs makes previously high-profit industries with large energy input requirements unprofitable (e.g. airlines, cement manufacture, aluminum smelting etc.). Additionally, the reduction in profits from energy price increases cannot be offset entirely by efficiency improvements because the business model itself was predicated on large amounts of cheap energy. These "reduced benefits" due to energy price increases are a worldwide phenomenon (EIA, 2013; Kingsley-Jones, 2013).

4.4. Energy scale

In 2018, the global economy ran on a constant 17 trillion watts of energy - enough to power over 170 billion 100-watt light bulbs continuously. Over 80% of this energy, shown in Fig. 3, was the 110 billion barrels of oil equivalents of fossil hydrocarbons that power (and is embodied in) our machines, transportation and infrastructure. At 4.5 years per barrel, this equates to the labor equivalent of more than 500 billion human workers (compared to ~4 billion actual human workers). The economic story of the 20th century was one of adding ancient solar productivity from underground to the agricultural productivity of the land. These fossil 'armies' are the foundation of the modern global economy and work tirelessly in thousands of industrial processes and transportation vectors. We didn't pay for the creation of these armies of workers, only their liberation. Transitioning away from them, either via taxation or depletion, will *necessarily* mean less 'benefits.'

4.5. Energy substitutability

Modern economic theory considers all inputs fungible and substitutable. If the price of one input gets too high, the market will develop an alternative. However, energy does not cooperate with this theory because different sources of energy exhibit critical differences in quality, density, storability, surplus, transportability, environmental impact, and other factors. For instance, there are hundreds of medium and high heat industrial processes (for textiles, chemicals, cement, steel etc.) using fossil fuels that have no current (or even under development) alternative using low- carbon technology (Khanna et al., 2017). Energy can only be substituted by a similar form/quality energy.

4.6. Energy primacy

Energy is so fundamental, that its availability sets the physical limits to our social scale. All life, commerce, work, or creation of order is enabled and limited by available net energy (Hall and Klitgaard, 2011). As GDP increases globally, energy needs to increase in lockstep. Until the 1970s, energy and GDP were nearly perfectly correlated; a 5% increase in GDP required a 5% rise in energy consumption (Cleveland

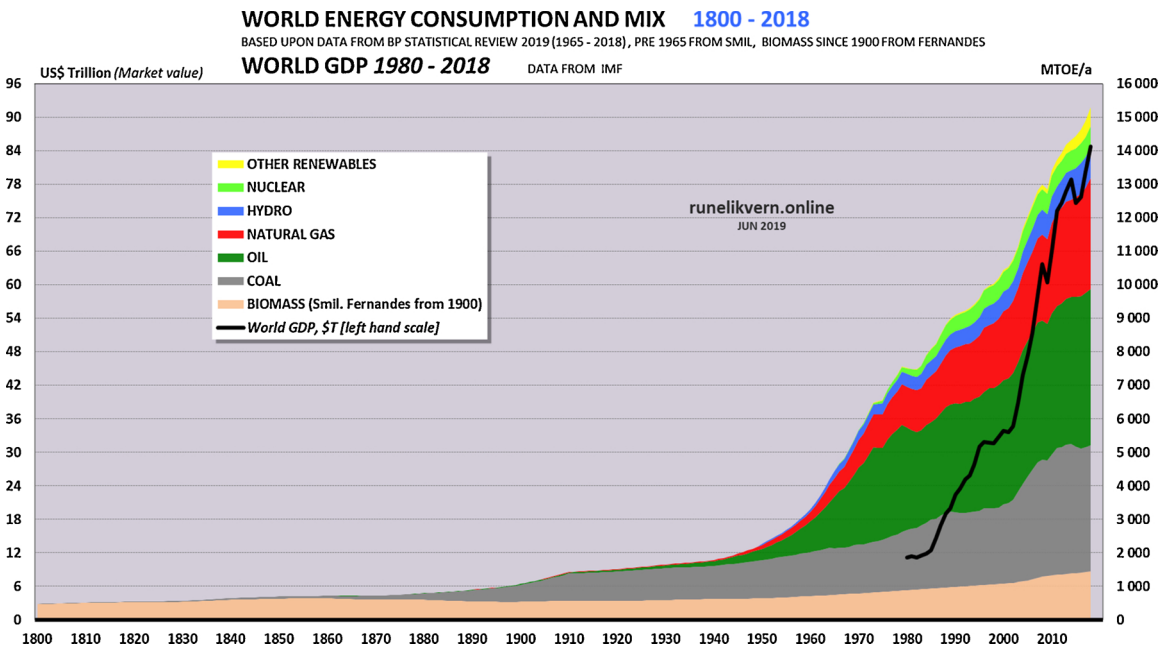

Fig. 3. Global energy mix 1800–2018 (Source: BP, 2019, Likvern 2019).

et al., 1984). This was followed by a short-term energy/GDP decoupling due to efficiency advancements resulting from the oil & natural gas price shocks in the United States. This further led to a switching from oil use in power plants to nuclear and natural gas. By the mid-1980s debt and globalization were used to increase access to energy needed to keep GDP growing. Much fanfare is made about long term declines in energy intensity. For instance, from 1965 to 2012 the number of MegaJoules used per $ of global GDP declined from 11 to 8, ostensibly signifying a decoupling. However, averaged annually, over these years, the correlation between energy and GDP remained a tightly linked 99.4% (Energy & Stuff, 2019).

But as a result of these trends, energy intensity improved faster than the historical rate during the last two decades of the 20th century. Heterodox theories linking productivity to energy (Gilliland, 1975) were cast aside in favor of other less limiting descriptions of human economic prosperity. From 2000–2012, the annual rate of relative decoupling dropped back down to 0.3% per year (Energy & Stuff, 2019). Since then, data is inconsistent due to many changes to GDP accounting methods, but the general principle remains: for additional economic activity, we need more energy.

Today, energy is still treated as merely another input into our economic system – $10 of gasoline is considered to have the same contribution to human output as $10 of Pokemon cards. This is in spite of the fact that: a) energy is needed to create and transform all material inputs and b) energy can only be substituted by other energy.

Mainstream economic theory attributes all economic productivity to labor and capital, and therefore assumes the economic importance of energy equals its cost share (Solow, 1994). However, biophysical analysis of all production inputs shows that the economic importance of energy is substantially larger than energy's share in total factor cost, with the opposite being true for labor. This means that energy has a significantly greater role in our wealth and productivity than its nominal cost share signal. In the case of Japan and Germany over 60% of economic productivity is explained by energy input (Kümmel and Lindenberger, 2014). The relationship would be considerably stronger if tested at the global level (Ayres et al., 2013), because globalization allowed us to shift energy and resource use away from advanced economies (Bank of America Merrill Lynch, 2019). Alternative methods highlight that primary energy consumption is tied to accumulated global wealth via an energy constant of 9.7 ± 0.3 mW per 1990 US dollar (Garrett, 2012). Rather than being an insignificant factor in productivity *energy is the major factor*.

Prior to the industrial age, all relevant economic theorists (including Adam Smith, David Ricardo and others) used land and land productivity to describe the human ecosystem (Warr, 2011). As the global economy expanded with increasing subsidy from fossil energy, land productivity and physical input constraints were considered unnecessary and eventually removed entirely from economic theory. By the time of the first energy crisis in the 1970s, macroeconomic descriptions had been reduced to labor and capital via the Cobb-Douglas function and Solow Residual, where they (mostly) remain today (Keen et al., 2019; Santos et al., 2018). We had created an infinite growth model on a finite planet.

Economists view capital, labor and human creativity as primary and energy secondary or absent. The opposite is, in fact, true. We are energy blind.[1]

4.7. Energy and technology

Most modern technological advances are not stand-alone but powered by either liquid fuel or electricity. Biophysically, there are two general types of technology. Type 1 technology finds ways to use energy more efficiently (power plant improvements, better vehicle fuel efficiency) or invents new energy sources (solar or geothermal). Type 2 technology consists of devices that replace manual human labor (chainsaws, cars) or new ways for humans to use energy (Facebook, Candycrush).

Currently Type 2 dominates technology inventions and increases total global demand for energy (De Decker, 2018). Technology like the 'cloud' is not really "virtual". Computers and cellphones (including servers and networks), consume over 15% of the world's electricity, and this will increase with the advent of 5 G (Andrae and Edler, 2015).

Technology is an expression of the available energy we can exploit (Brockway, 2013). What we call "technological progress" at any time is

[1] Note: some biophysical researchers extend energy's role in the production function too far -to a complete 'energy theory of value'. Though capital and labor are both variables *dependent* on energy, they are each essential in their own right. If you don't have enough capital (i.e. factories), you can burn as much oil and coal as you want, but will lack the output. If you don't have the skilled labor to do the job, you will have poor resource productivity.

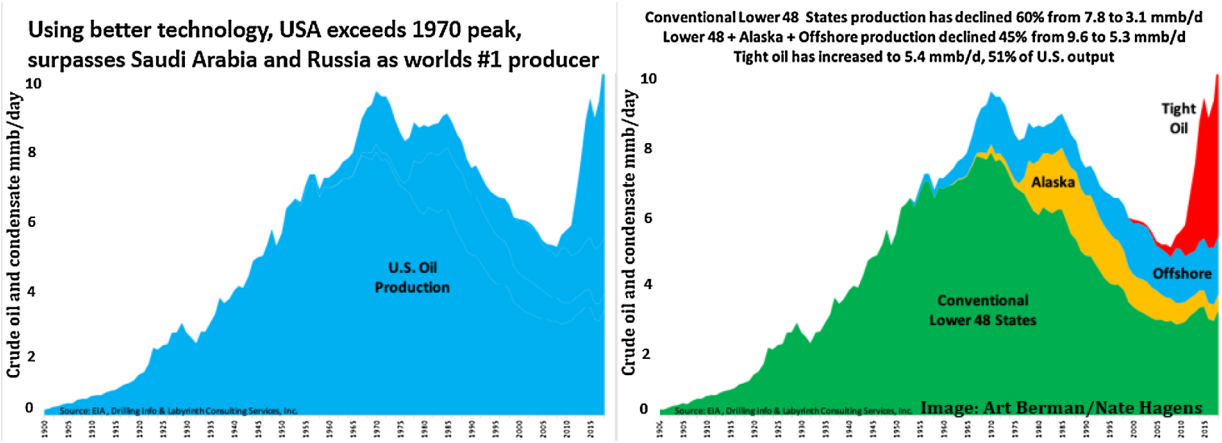

Fig. 4. U.S.A. Oil Production.1900–2018.

mostly the development of the capital base to support an ever-greater throughput of available energy at a later time. With growing GDP as a global goal, extra energy allows for more inventions that in turn make our economy more complex. Furthermore, higher social/technological complexity itself requires higher energy consumption– resulting in the *energy complexity spiral* (Tainter and Patzek, 2012).

4.8. Energy Depletion

Using photosynthesis as a trickle charge, hundreds of millions of years of living biomass were stored as hydrocarbons in Earth's battery. We are drawing down this carbon battery 10-million times faster than it was charged (Schramski et al., 2015). Estimates of remaining oil and natural gas vary widely (Mohr et al., 2015), but the cheap high quality oil, at scale, has largely been found and exploited (Fustier et al., 2016; Masnadi and Brandt, 2017).

The left side of Fig. 4 conveys a misleading, but common interpretation of current U.S. oil production. Due to technology advancements, U.S.A has become the world's top oil producer. One is left with the false impression that technology has triumphed depletion making oil abundant and therefore not a risk to future growth. However, reality is more accurately depicted in the right panel, where, collectively, non-shale oil sources are shown to be in permanent decline. The up-tic in total production is a consequence of tight oil (in red), recently scaling to 52% of all production. Tight oil is in the source rock where all other oil originated. Tight oil is economically and ecologically costly and quickly depleted (by as much as 90% in the first 3 years). A typical new well requires complex equipment, 1200 truckloads of water, 100 train carloads of sand and $8-10 million in drilling and completion cost (Robinson, 2014). This explains why the US Drilling Oil and Gas Wells Producer Price Index increased 350% from 2005 to 2014 (U.S. Bureau of Labor Statistics, 2018).

During this time, the market price of oil, has not kept up with its extraction cost. Since Q3, 2014, capital expenditures on shale plays have exceeded cash flow 19 quarters in a row (Rassenfoss, 2019). Because of the steep decline rates of existing fields (shale and conventional), the International Energy Agency asserts that with no new drilling, world oil production would be cut in half by 2025 and to only 15% of today's output by 2040 ("WEO 2018," 2018). Of course, we *will* invest in new oil fields – but doing so will require a higher oil price, which would lead to lower economic growth (see Fig. 2, grey columns).

Energy's cost share of our economy, after five centuries of decline, reached a low in 1999 and has been increasing since (King, 2015). When obtaining energy requires more energy, materials and money, the economy suffers because discretionary wealth is redirected or drained away (Capellán-Pérez et al., 2019). Earth's geological battery of energy dense carbon is not unlimited, and we've already found and used the cheapest and easiest. Relative to 2008, debates about oil scarcity, and 'peak oil' have morphed into 'peak demand' and electrification of transportation as solutions. However, the net energy of remaining reserves, their affordability, and society's ability to allocate capital to recover them remain central questions (Brockway et al., 2019).

4.9. Energetic remoteness

Barriers of energy, time, materials and complexity separate us from the things we want and need. Our natural subsidy of concentrated ores is declining along with the natural subsidy of fossil hydrocarbons. We don't face 'the end' of oil, copper and water, but we do face increasing effort and cost to extract these resources from lower grade ores. This will have a corresponding effect on benefits to societies.

Energy enters the global economy via exploration, extraction, transformation of natural resources, and transportation. Energy is thus embedded in every industrial process, mineral and material in our economies. Raw materials — such as copper, phosphorous, or aluminum — are easier to extract and refine when they are concentrated. As energy becomes more expensive, and we deplete the concentrated, easy resources, many commodities become more "remote" for our use because they become more expensive to find and extract.

Copper is a key industrial commodity for scaling renewable-based technologies such as electric vehicles (García-Olivares and Ballabrera-Poy, 2015). Fig. 5 shows the annual copper production relative to 2001 (in blue) for the country of Chile. The total energy used to process copper ore and overburden is shown in red. Lower quality ore grades require increased energy (and water), leading to less copper expected to be available in the coming decade (Copper Commission of Chile, 2018) at the same time demand for copper is increasing.

This same 'energetic remoteness' applies to many key resources, including water, lithium, and food. We use around two calories of fossil fuel to grow one food calorie in our modern agricultural system – but we use 8–12 additional fossil calories to process, package, deliver, store and cook modern food (Bradford, 2019). In the natural world, this is unsustainable. Organisms that require more energy to find food than the food contains, will die. We only get away with this because our institutions and policies treat the energy subsidy from fossil hydrocarbons as interest, not principal. Everything we do will become more expensive if we cannot reduce energy consumption of industrial processes faster than prices grow.

4.10. Energy and money

Society runs on energy and materials, but most people think it runs on money. Indeed, money is the only part of our economies not subject to laws of thermodynamics because it is created as debt subject to

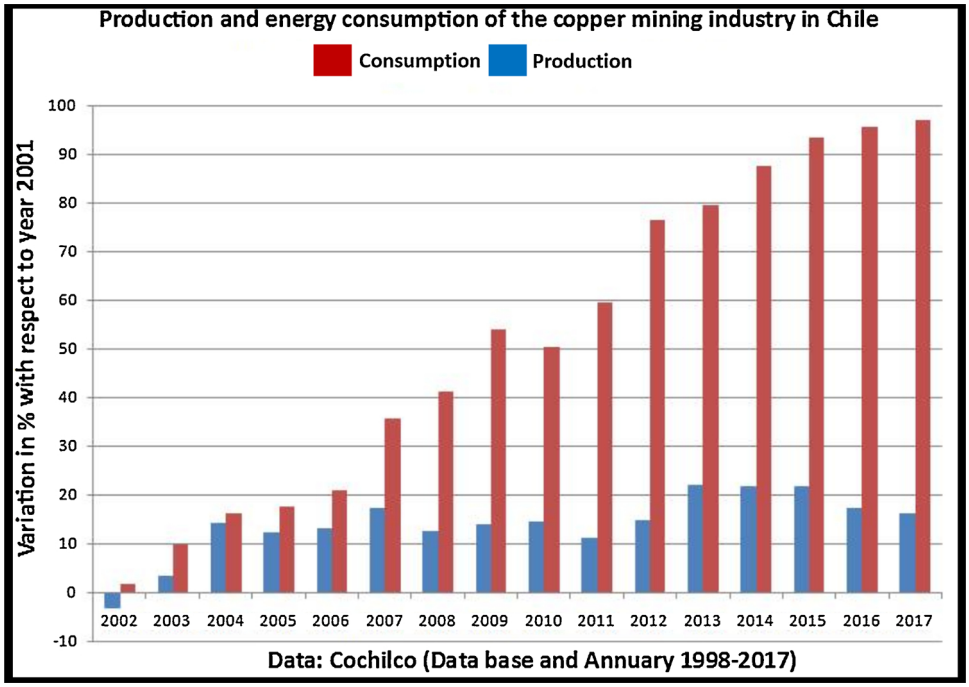

Fig. 5. Energy consumption and copper production (Copper Commission of Chile, 2018).

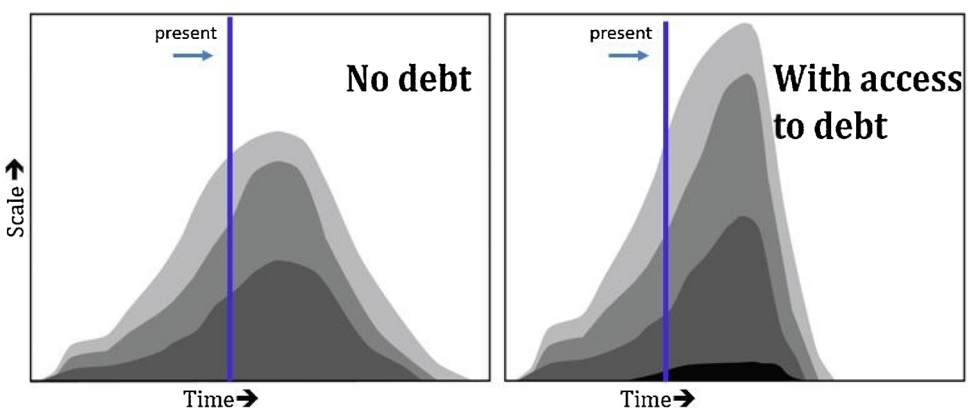

Fig. 6. Hypothetical oil field production with and without using debt.

mathematical laws of compound interest (Soddy, 1933). Commercial banks are not intermediaries that lend out existing capital (Jakab and Kumhof, 2015), but rather create money by loaning it into existence (McLeay and Radia, 2014). Contrary to what is taught in economics textbooks, money is not lent out from existing wealth– it is created (Werner, 2014; Ament, 2019). This new money eventually gets spent on a good or service which will contain embodied energy. *Money is a claim on energy yet its creation is not tethered to energy availability or cost.*

4.11. Energy and debt

Since money is a claim on energy[2], then debt is a claim on *future* energy. Business schools teach that debt is neutral to the capital structure, an 'intertemporal transfer of consumption *preference*.' Thus, GDP generated with debt, or with cash, are considered equivalent. In an economy of perpetual growth opportunities, this might be appropriate. However, in every single year since 1965, both the USA and World have grown debt more than GDP. This makes debt more accurately an 'intertemporal transfer of *consumption*'.

Debt is a social construct with physical consequences. Fig. 6 illustrates how debt pulls resources forward in time. In this hypothetical oil field, the differing shaded areas represent different cost tranches of an oil resource.[3] Obtaining access to cheap financing allows a company to expand drilling into marginally commercial areas as long as new creditors believe in future prospects. This debt funding allows the oil company to 'create a bigger straw', to extract new higher-cost oil (dark black on right panel) and raise total field production (Hughes, 2019). However, this results in steeper future declines because the temporary increase cannot be sustained: the next tranche available for

[2] Money is a claim on energy, materials and many other things. But every single good and service which generates GDP requires some energy conversion, hence the simplification: '*money is a claim on energy*'.

[3] By definition we can't compare a real field drilled using debt financing relative to the same one using no debt. But an oil production profile depends on the rate of capital input. E.g. In 2019 the Bakken now requires about 750 $7.5-million-dollar wells to offset the 40.6% first year field decline to keep production flat at current levels = $5.625 billion per year (just for drilling and completion). The higher production grows the more wells have to be drilled just to offset decline (Hughes, 2019). It is extremely unlikely this could be done without debt, and its related risks.

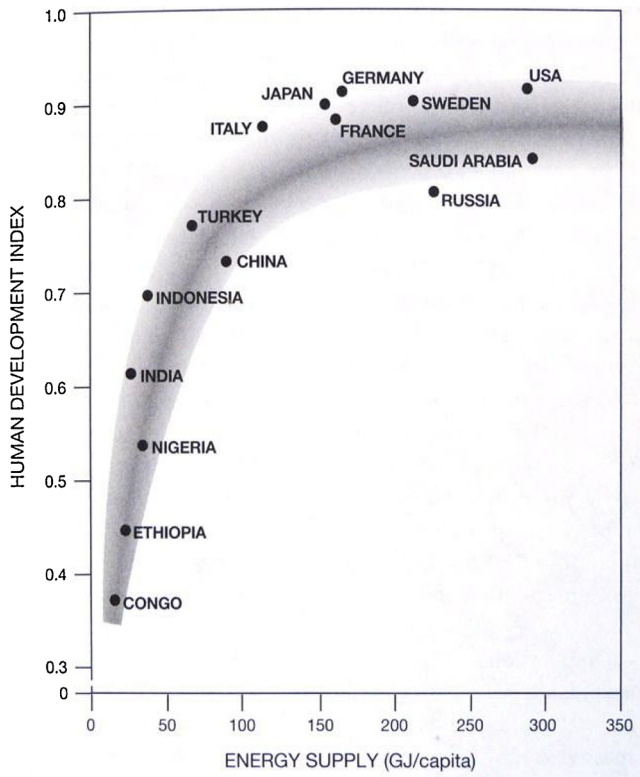

Fig. 7. Energy Use per capita vs Human Development.

development yields poorer well and financial performance often accompanied by higher decline rates and lower quality oil. Unconventional oil and gas typifies this phenomenon (Kelly, 2019).

Fig. 6 illustrates not only how oil production responds to debt infusions, but the consumption of entire economies. Low entropy (high concentration, high quality) resources underpin our productivity. Thus debt can be seen as a tool humans use to access an energy gradient, and the resulting goods and services. Debt has been referred to as 'fake energy' (Weyler, 2011). More accurately, debt moves real energy and consumption from the future, to the present, unsustainably. But it is fake in the sense that to pay back the debt, we have to also pay back the energy. One could say this amount (and related consumption) is "borrowed" energy.

4.12. Energy and well-being

Despite the pervasive belief that more money and energy makes us happier, evidence suggests this is mostly not true. After basic needs are met, additional energy use yields a slower growth of the Human Development Index (Smil, 2017). Although Americans use 20 times more energy per capita than Filipinos, the percentage of 'very happy' citizens remains equal (Hagens, 2007) (Fig. 7).

Other biophysical (and psychological) indicators may track human well-being more closely than GDP and energy use (Lambert et al., 2014; Roy et al., 2012). If we have social support structures, many physical inconveniences can be overcome (Venniro et al., 2018). After basic needs are met, the best things in life are free.

4.13. "Externalities' and energy

Society may remain energy blind, but we are rapidly becoming aware of the negative consequences of the global human enterprise (Weyler, 2018). Negative impacts for humans include: topsoil loss, endocrine disrupting chemicals (Fischer, 2019), declining sperm counts (Levine et al., 2017), mounting inequality, water shortages (Schewe et al., 2014), declining median incomes (in the developed world) (Hannon, 2019), populism, depression (Hidaka, 2012) worry about the future, and geopolitical risks. Negative impacts to the natural world include: CO2 risks to climate (C. Oppenheimer et al., 2017) to ecosystems (Saunders, 2005), ocean acidification, coral loss and other ocean impacts (Caesar et al., 2018; Schmidtko et al., 2017; Ward, 2008; Yeo, 1998), deforestation, insect decline (Hallmann et al., 2017; Sánchez-Bayo and Wyckhuys, 2019), bird decline (Allinson, 2018), extinction of primates (Estrada et al., 2017) decline of (wild) mammal populations (Bar-on et al., 2018), plastics in oceans (Eriksen et al., 2014; Koelmans et al., 2014), microplastics and airborne phthalates (Jamieson et al., n.d.; Lenoir et al., 2016), loss of forests, and general risk of a 6th mass extinction (Ceballos et al., 2015; González et al., 2017). All readers of this journal are aware of the social and ecological impacts of economic activity 'external' to the market pricing system. Most of these are enabled and worsened by cheap energy, but are absolutely internal to a fossil fuel based economy.

4.14. Energy – summary

Soaring GDP in the 20th century was tightly linked to soaring burning of fossil hydrocarbons. Society doesn't yet recognize these links because we conflate the dollar cost of energy extraction (tiny) with the work value (huge). Energy is only substitutable with other similar quality energy. Increasingly, advanced technology is achieved *with* energy, and most technological advances increase future energy requirements. We can (for now) readily print money but we can't print energy to give it value. We can only develop new sources or extract what exists faster or learn to use it more efficiently. We've papered over already visible declines in energy growth rates and resource quality by using credit in breathtaking volumes. Modern economic theory ignores or minimizes most of these points, as do our institutions, policies and plans. In the future, the scale, quality, and cost of energy will dictate what sort of human systems are possible. We remain energy blind.

5. Synthesis

Fig. 8 is a conceptualization of the last few and next few hundred years (not to scale). The green line represents sustainable flow levels available to humanity which reached technological and geographical limits in the 19th century. The red line represents the one-time pulse of non-renewable natural resource inputs to human economies (oil, gas, copper, etc.). The black line represents financial markers (money, credit, etc.) of the underlying primary capital.

In the pre-Industrial era up to Point A, humankind migrated around the planet accessing solar flows using relatively simple technology such

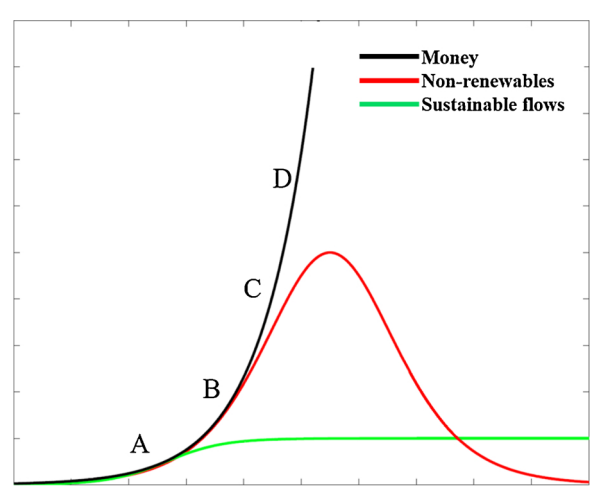

Fig. 8. Humans and Resource Access.

as agriculture, sails, slaves and animal labor. At the dawn of the industrial revolution, Point B, humanity added the condensed stocks of hydrocarbons to previously flow-based human economies. A valid description of the Solow residual (i.e. the economic growth not explained by labor or capital) was absent during this time because the black line and red line were tracking together.

Between B and C we hit an energy crisis in the 1970s, which we 'solved' by both 1) using debt to pull consumption forward in time and 2) globalization and outsourcing to the cheapest areas of production. These changes allowed economic growth to continue until it hit a wall with conventional finance in 2008 (Point C)– at which point central banks and global governments were forced to essentially redesign the entire financial system. This new (ongoing) paradigm involved measures such as too-big-to-fail guarantees, artificially low interest rates (even negative!) (Salmon, 2019), quantitative easing, central bank balance sheet expansion and various GDP-friendly rule changes (Alderman, 2014). The continued increase in global credit allowed: access to costlier tranches of resources, more social programs, cheap financing for renewable energy, and a sustained – if tepid – return to economic growth since 2009. We are now heading towards Point D, where our global monetary representations of reality continue to decouple from the underlying biophysical reality (red curve).

Since 2007 we have grown our global debt 3.5x faster than we've grown our economies bringing global debt/GDP ratio to over 300% (Tiftik et al., 2019). Most institutional experts and pundits are aware of Point D, but because of cultural energy blindness, are generally not aware of this point in relation to the red line, or even that there is a red line. Eventually we will discover that the black line (money and credit) also has limits, which ultimately are tethered to the growth enabled by energy and resource availability and cost.

5.1. Humans → superorganism

We expend energy to produce work because our brains seek emotional states similar to that of our successful ancestors – physical and emotional homeostasis, comfort, status, excitement, relaxation, etc. all modulated by hormones, neurotransmitters and endocrine signals. To a Tibetan monk, this 'state of comfort' might be sitting quietly all day on a wooden bench, but for most humans in modern consumer culture, achieving this emotional state means: eating at a better restaurant, buying a better car, air conditioning or heat, fast internet, faster transportation, etc. For most people these preferences have a strong correlation to devices and processes requiring energy. Our ancestors didn't live with *Instagram*, *Fortnight,* Teslas, sushi or Netflix. Addiction to modern stimuli and comfort tethers to resource consumption (Hagens, 2011; Ladika, 2018).

Additionally, we do not choose to wait or defer consumption and experiences. Rather, we have a strong preference for positive experiences in the present moment (Hagens, 2010). Even the ecologically literate will avoid 'sustainable' practices that accomplish equal goals but require more time (Penn, 2019). Since consumption requires energy, and we (generally) prefer immediate gratification, we can understand how our behaviors are linked to power (energy/time) in the real world (Hagens and Kunz, 2010). This seeking of 'power' by individuals, aggregated at the economy level, also explains the compulsion of debt, which pulls energy and material consumption to the present .

5.2. The Superorganism: blind, hungry and in charge

What began some 11,000 years ago as hunter gatherers cooperating to obtain physical surplus from land, has morphed into a globally connected human culture maximizing financial representations of physical surplus (Gowdy and Krall, 2013). In pursuit of economic growth, modern human culture appears as a self-organized, mindless, energy seeking Superorganism, functioning in similar ways to a brainless amoeba using simple tropisms. But why? How?

In nature, an individual starling follows three simple rules (Reynolds, 1987):

1) *Do what your neighbor does*
2) *Don't get too close*
3) *Fly towards the center*

When tens of thousands of starlings follow these simple rules we see a beautiful, complex murmuration in the sky. This is an emergent result not predictable by the biology and behavior of the individual birds.

In similar ways, the surplus creating "requirements" of the global economic superorganism call forth compatible behaviors like acquisitiveness, greed for possessions, and simplified individual behaviors. Today, *most* modern humans – as individuals – follow something like the following 3 simple rules:

1) *Execute optimal foraging algorithms by coordinating with other humans (families, small businesses, corporations, nations) towards acquiring financial surplus*
2) *Pursue culturally condoned behaviors*
3) *Spend the financial surplus on comfortable, fun things or experiences (as long as culturally acceptable)*

In a global culture maximizing surplus value, human brains are thus linked to energy use via the 'pursuit of comfort' and 'avoidance of pain'. In aggregate, human economies require power just as animals eat food, or oak trees grow leaves (Odum, 2007). The emergent property of 7.7 billion humans going through their daily lives following simple rules like these is a 'Superorganism' with a 17 TW metabolism[4] .

6. Implications

There are several key implications from humanity effectively functioning as a Superorganism.

6.1. Gross domestic product (GDP) → gross world burning (GWB)

Biological scaling laws follow the natural, emergent outgrowth of networks —in the case of animals, a blood circulatory network which transports hemoglobin throughout the 'volume' of the organism. Klieber's Law observes that the energy metabolism of animals is proportional to their mass scaled to the ¾ power (Thommen et al., 2019). The flow of petroleum through modern economies can be likened to the flow of blood in mammals (Marder et al., 2016) with the veins and arteries of the human 'sphere' being the global air, sea and road transportation nodes (Kleinschroth et al., 2019). Virtually all human infrastructure - gas stations, surface area of roads, hospitals etc., scale using similar biological allometry relationships (West, 2017). Connections – veins in bodies, social media, telephones or highways, scale at roughly ½ of the number of nodes squared ($.5n^2$). Each of these nodes requires energy to maintain and new nodes need energy to connect. Modern human society can thus be viewed as a macro-organism, whose energy metabolism increases at the size of the global GDP to the ¾ power (Brown et al., 2011; Patzek, 2011). Larger animals – and larger economies-are more efficient, which is why they don't scale 1 for 1.

Economic growth can only experience '*absolute decoupling*' if we increase GDP while decreasing primary energy consumption. *Relative decoupling* occurs when total primary energy grows but at a smaller rate

[4] It remains to be seen what impact counter-culture movements will have on the Superorganism. So far, those who reject consumption and mindless conventional behavior have had only negligible effect on global energy use and carbon emissions. However, in the context of this paper, counter culture activity is also emergent and may yet prove to help redirect or respond to the Superorganism.

than GDP. Since dual statistics began in 1965, there has been no absolute decoupling globally and negligible relative decoupling (0.5%) (Heun and Brockway, 2019). From 2012–2017 there appeared to be an increase in relative decoupling but this was largely an artifact of a larger portion of GDP going to financial (virtual) assets, implying an even tighter energy/economy link once the financial system recalibrates (Kovacic et al., 2018). Nor has the move to 'service' economies reduced the strong GDP/energy link (Fix, 2019).

Every single good and service in the global (or your own) economy started somewhere with a small fire. We cannot decouple this basic relationship on an absolute basis (Ward et al., 2016), and relative decoupling will be minor as long as GDP growth is our cultural goal. GDP is a poor metric of our well-being and cultural progress. It is however a reasonably good metric of how much energy humans burn: GWB – Gross World *Burning*.

In principle a superorganism could be super intelligent but ours is not. In the 1930s economists chose GDP as a metric to track economic activity, not as an end goal. Yet almost 100 years later, our economies unconsciously, relentlessly, pursue the GDP carrot, often toward frivolous endeavors that promise the greatest financial return in the shortest time. Currently, no one is driving this societal bus, neither billionaires, politicians, nor a secret cabal (White and Hagens, 2019). We are all caught up in the global growth imperative, which is immune from self-criticism. In the same way that ants pursue individual tasks for the growth of the colony, humans have outsourced our individuality to the 'cloud', which is itself devoid of an actual brain. The more people involved in a decision/process, the more our decisions resemble simple bacterial tropisms which unconsciously move towards energy acquisition. At the largest levels, the global economy is moving much like a starling murmuration following simple emergent rules. In the year 2019 C.E. the emergent result of 7.7 + billion hominids living their daily lives is an energy seeking Superorganism, out of control, yet still hungry. This superorganism is not human. It's a thing-in-itself (Ding an sich) with its own survival instincts that override the individual humans that comprise it (White and Hagens, 2019).

6.2. Climate change and ocean risks- the metabolism of the superorganism

Fig. 9 depicts CO_2 concentrations over time with highlighted major efforts to reduce emissions. Despite these efforts, 2018 marked the year with the most energy ever burned, the most CO_2 ever emitted by humans, and the highest atmospheric concentrations in over three million years (Willeit et al., 2019). Because of the direct linkage of human economies to 'fire' and fire to carbon, climate change and ocean acidification are - and will likely remain - directly linked to the metabolism of human economies. A central finding in the AR5 climate assessment was that the single largest driver of emissions globally was growth in income (Victor et al., 2014). The tight power-law relationship described above infers that current levels of economic consumption would not be feasible without fossil carbon and hydrocarbon consumption (Marder et al., 2016). In an economic system dependent on energy to grow, motivating voters to choose to keep carbon in the ground is akin to arguing with a forest fire. *Climate change and its mitigation are thus 'downstream' of the superorganism.*[5]

6.3. Population

Overpopulation is also downstream of this Superorganism's growth dynamic. The global economy and monetary systems are based on and require growth. Growth requires consumption. Consumption requires consumers. Additional consumers requires more babies. In countries with

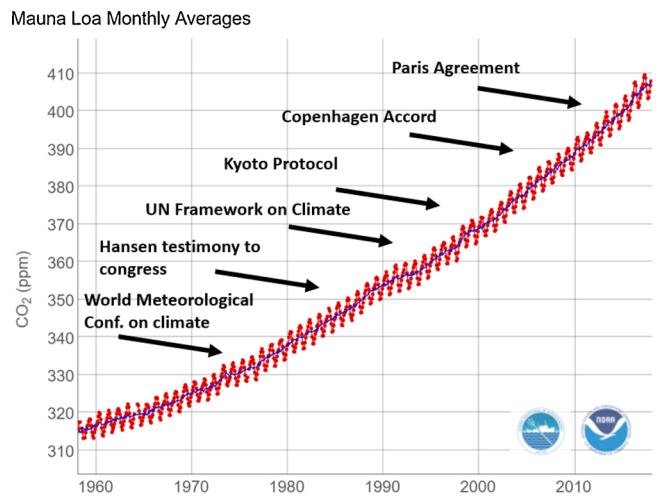

Fig. 9. CO2 concentrations vs human social mileposts.

falling population growth (e.g. Denmark), governments now pay for advertising for couples to go on 'sexy vacations' (McCoy, 2014). Since the current economic system requires growth, we need someone to pay for toys, diapers, teachers, and pensions. A baby strike (unlikely) would eventually crash the financial claims on future energy. Climate and overpopulation are behaviorally downstream of the GDP-seeking emergent property of human cultures. We can 'solve' these issues, but not until the Superorganism a) shrinks b) changes direction or c) is overthrown.

6.4. Renewables

Beyond absolute or relative energy decoupling, there is *carbon decoupling* -e.g. the same level of GDP using less carbon. Environmental media have popularized the narrative we can completely de-carbonize the economy. Proponents point to the fact that since 2003, over 20 countries, including the USA and UK, have reduced GHGs while growing their economies (Aden, 2016). However, this accounting neglects that these economies exported their carbon-intensive manufacturing to cheap labor regions. China's industrial sector alone uses almost as much energy as the entire US economy (National Bureau of Statistics, 2018), and the USA now imports what it used to produce.

Carbon emissions and economic activity *can* be "decoupled" if we increase non-fossil energy production faster than energy consumption growth (essentially: faster than economic growth). But that's not happening globally. Figure 10 shows the increase in consumption from fossil carbon and hydrocarbons and from renewables this century. The only year that fossil fuel consumption dropped (or increased less than renewables) was the global financial crash of 2009. In fact, the increase in global electricity demand in just 2018 was more than the entire historical installed capacity of solarvoltaics (BP, 2019). Fig. 10 reveals that the only genuine solutions to overshoot and carbon emissions will include economic contraction, not growth.

The *Superorganism* grows, and doesn't (voluntarily) shrink. Under this logic we will have to change economic systems before we can meaningfully decarbonize the economy. Even the switch from wood to coal wasn't really a 'transition' only an addition. We are consuming more forest biomass globally today than we were at the dawn of the industrial revolution (BP, 2019). Likewise, renewables are adding energy, not replacing hydrocarbons. If this continues, renewables[6] will continue to scale, but only as part of a larger energy dissipating, CO2

[5] There is an irony here: climate stability birthed human agriculture which birthed the Superorganism which via industrialization and the Carbon Pulse, is now in turn destabilizing the climate

[6] technically 'rebuildables' – an oak trees and geese are renewable (via acorns and eggs), solar arrays, wind turbines etc. are at best 'repeatable', use complex material infrastructure, and are themselves a product of the 500 billion fossil army laborers)

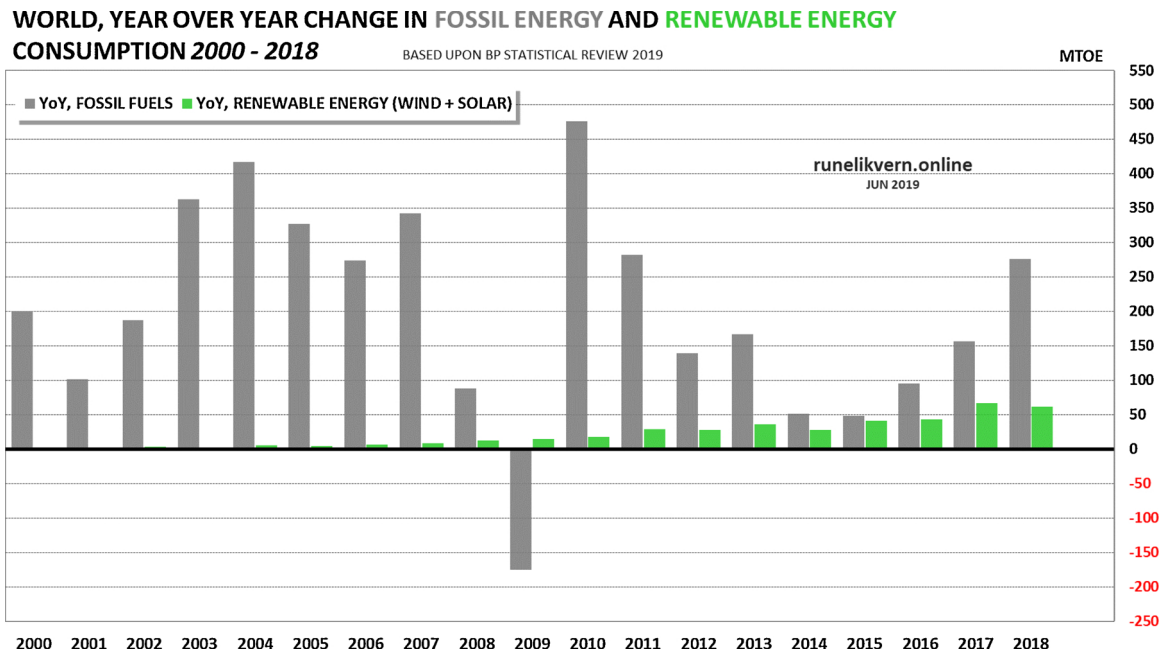

Fig. 10. Fossil energy and renewable energy consumption.

emitting structure (Heinberg and Fridley, 2016; Smil, 2013).

Additionally, between 1970 and 2010, estimated total global extraction of natural resources from Earth (fuels, ores, salts, biomass, etc.) grew 3.2-fold from 22 to 70 billion tons (UNEP International Resource Panel, 2016). During the same time period, the size of the world economy, adjusted for inflation, grew 3.4-fold from $18.9 to $65.6 trillion. For one additional unit of Gross World Product (GWP), we needed close to one additional unit of natural resources. If we remain at 17 TW, whether carbon intensive or carbon neutral, we'll still need ~1 kg of minerals and materials for every $2 of global GDP. Physics suggests that this is not possible, and that our answers will primarily be found through social changes linked with contraction, not technical innovations resulting in long-term growth.

6.5. Credit and financialization

Although we currently witness emotional signals that injustice, wealth inequality, and climate change, are real and urgent issues, there appears to be little awareness of constraints concerning energy and finance. The modern system has used finance to obfuscate the fact that we have consumed beyond our means for at least the past 50 years. *The energy/credit/growth dynamic is the least understood but most important phenomenon driving the current global economic and ecological situation.*

Think of credit as a magic wand, that allows us to spend more than our income with a promise to pay it back in the future. This only works well when our economy is growing and there are enough untapped resources (e.g. 1950) to allow future growth to repay those debts.

Fig. 11 indicates debt (black) vs GDP (green) for the USA. The charts for most other developed nations debt/GDP show similar patterns. Without growing (just) our government debt our economy would have stopped growing over a decade ago. Much of our recent GDP growth has just been spending borrowed money (Coogan, 2019a). Globally, this 'debt productivity' (economic growth relative to debt growth) is now down to about 30-cents on the dollar. Should this ratio reach zero, we'd be adding debt just to keep the economy the same size. We have been growing our obligations faster than we're growing our economies,

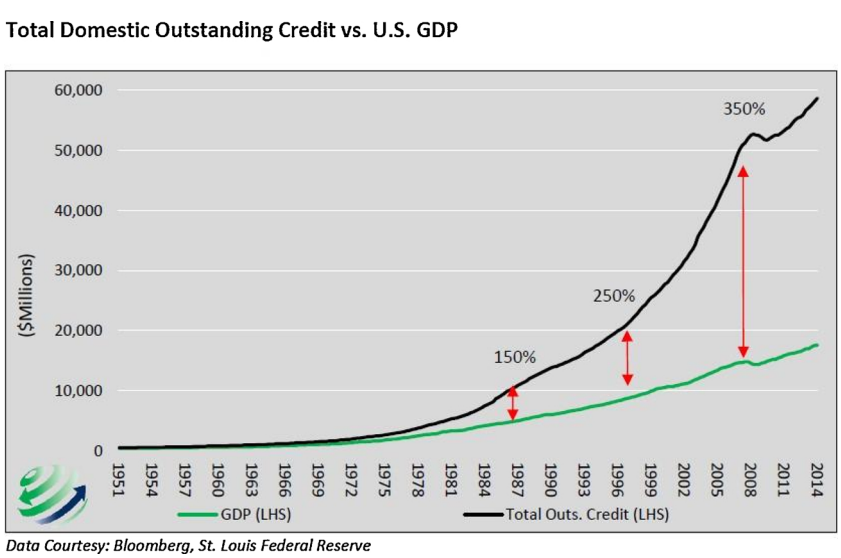

Fig. 11. US GDP vs Debt 1951–2014.

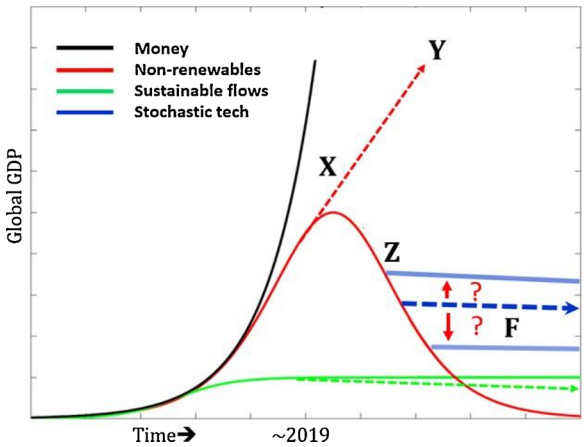

Fig. 12. The Great Simplification (~Point Z).

because we had to. Globally, accessing our magic credit wand is dangerous and unsustainable, yet the Superorganism requires us to attempt it.

For example, the large amounts of credit created by China since the Great Financial Crisis increased demand (and prices) for commodities and energy globally. China's economy is now very large – approximately $13 Trillion – but they've created about $55 trillion in credit to maintain their current consumption. When growth stops – which is inevitable – there are trillions of dollars of unsupportable loans *in China alone* – versus $800 billion in the Global Financial Crisis in 2008/9 (Coogan, 2019b).

In 2018, global credit growth began to slow. Along with slower economic growth there are signs of deflationary impact — because many people can no longer afford basic things (inflation remains — but mostly in healthcare, education, real assets and financial assets) (Irwin, 2014). Global bonds that have negative interest rates (something unimaginable in the past) total $14 trillion and growing. In Scandinavia, a home mortgage may now carry a below-zero interest rate (Coogan, 2019b). This low cost of capital, which has incentivized homeowner loans, is also crippling return rates for savers, and posing significant risks to pension funds, which depend on 7–8% a year annual returns.

We increasingly hear about the risks that climate change has on insurance, and financial futures. The head of the Commodity Futures Trading Commission (CFTC) recently stated: "*It's abundantly clear that climate change poses a financial risk to the stability of the financial system*"(Behnam, 2019).

What the CFTC commissioner didn't say is that *finance* poses a financial risk to the stability of the system. Despite massive credit injections, our productivity per unit of labor since 2011 is at 40 year lows (U.S. Bureau of Labor Statistics, 2018). If you add all the unfunded liabilities on top of government and private debt, the USA currently has obligations of 1200% of GDP (Shin and Brancaccio, 2018). As debt relative to GDP rises, the 'debt productivity' of each additional dollar declines, eventually reaching a limit requiring: write-offs, foreclosures, deflation, and a smaller economy at best, with currency reform and systemic risk at worst.

At its core our culture has a flawed macroeconomic model. We are slowly figuring out the relationship between energy, technology and the economy. It is yet to be seen if there can be such a thing as 'credit decoupling', (growth, but with decreasing global credit), but based on the correlation of the past 50 years and the direct link between money creation, and the spending of it, this seems unlikely. The next big questions revolve around 'what is money', *en route* to 'do we have a goal?' In the meantime, what's relevant is that we cannot solve a credit crisis using more credit (McCulley, 2009). Recall that debt is a lien on energy. If we are ever to honor our current debts, the amount of energy required will be immense. If the energy is not available, at cheap prices, those debts will never be repaid, something that has happened historically with debt again and again (Graeber, 2011).

7. The great simplification

Fig. 12 returns to the big picture. After kicking various cans down the road to continue growth, we are now approaching Point X, using the black line (credit) to increase the rate at which we access fossil energy and non-renewable resources, and hence generate global GDP. All governments and major institutions nominally are planning for growth (towards Point Y). We are using the black line (finance) and the stories that support it to temporarily extend the red line in that direction. Recall how debt pulls resources forward in the oilfield example. An entire economy is no different. We should be planning for an energy level around **F** which would consciously direct our remaining low-entropy energy and materials to build renewable infrastructure and a society based largely on ecosystem flows.[7] However, the Superorganism dynamic of the market can only 'see' and move towards Point Y. It cannot see the risk of Z (a rough landing point if we stopped using credit to drive growth), nor how to make a long term plan for an energy throughput in the neighborhood of Point F.

Under this analysis, a reduction of GDP in advanced economies is now likely: 1) when we can no longer access consumption via adding credit, and 2) with a shift towards lower quality and more costly energy and resources. The 20th century experienced increasing energy quality and decreasing energy prices. The 21st century will be a story of decreasing energy quality and increasing energy cost. In tandem with some fraction of the best remaining fossil energy, we certainly could use intermittent renewable energy in ways that could power a great human civilization – but it would look quite different than the one we currently live in and are planning for. Unfortunately, the Superorganism cannot plan, only slough forward seeking more energy and growth.

8. Social traps

Many challenges we face appear as classic social traps, whereby short-term social pressures guide individual behavior in opposition to the best long-run interest of the individual and society (Costanza, 1987). Cognitively, the implications presented in this paper are understandable to most people fluent in the issues, but behaviorally remain almost the perfect storm for the human brain to ignore or deny. The issues are: complex, abstract, in the future, threatening to politicians and business owners, difficult to answer, largely ignored by leaders, and depressing to think about. Typically, a description of our biophysical reality is met with denial or nihilism.

Both denial and nihilism help the mind remove dissonance and thus emotionally absolve a person from working to make (uncomfortable) changes that might improve our chances. This and other social traps appear to mitigate against meaningful action. Our super sociality results in valuing conformity over science, and valuing fairness of process over quality of results. We attempt to use social sorting mechanisms (popularity/status) to solve complex problems. Perhaps the biggest social trap of all is that we don't actually need all this energy and material stuff to be happy or healthy. Nevertheless, led by the emergent drive of the Superorganism, we let pecuniary metrics, social comparisons, and novel technology, drag us into unnecessary and wasteful consumption.

9. Discussion

"The major problems in the world are the result of the difference between how nature works and the way people think." **Gregory Bateson**

[7] The dashed green line indicates future carrying capacity of sustainable flows is less than it used to be, and declining by the year due to human pollution and impact on natural systems

"When a system is far from equilibrium, small islands of coherence have the capacity to shift the entire system" **Ilya Prigogine**

9.1. What next? Predictions for the superorganism

We can't precisely predict the future, but we can increasingly be confident of what won't happen. Given the biological and social underpinnings of growth and *kicking the can* described above, we can hypothesize what scenarios are unlikely:

- *Growing the global economy while simultaneously solving climate change (reducing CO2) or avoiding a 6th mass extinction.*
- *Growing the economy while replacing hydrocarbons with low carbon energy.*
- *Voting en masse to keep remaining carbon compounds in the ground.*
- *Leaders embracing or preparing for an end of growth before it happens.*

To avoid paying the societal debt bill we've amassed over past decades, we tend to keep kicking the can forward, with more financial guarantees, stories, and rule changes – all in increasingly less sustainable ways. With the backdrop of the Superorganism we might make some predictions:

- *As more people recognize that energy underpins our futures, we'll witness more schemes focusing on gross energy as opposed to its net contribution to society. Many technologies will be promoted that are viable, but not relevant, affordable or scalable.*
- *We will continue to create money and credit expecting their abundance to overcome physical world problems, until they too reach limits (no creditworthy lenders, interest too high of % of growth, fiscal cliffs, etc.).*
- *To avoid social instability, we will remediate wealth inequality via programs like Universal Basic Income (If such 'wealth transfers' are direct, they will stabilize society but access more carbon as they are transfers of bank digits to direct calls on resources and energy. (Good for low income humans, bad for dolphins).(These transfers can be indirect e.g. ecological restoration, local public infrastructure etc.)*
- *Around the world, as economic prospects deteriorate, people will foster group cohesion by blaming their problems on outgroups, and tend to vote for leaders who promise better economic futures, or things to be more like the past, (linked to more economic growth, linked to energy, linked to carbon). Trump, Bolsonaro, Matteo, LePen, Morrison, etc. are but recent examples. (Conservative names listed, but most liberal types also promise "better economic futures.").*
- *As USA and Brazil attest, one of the few remaining economic cans to kick is de-regulation and removal of environmental protection. As the economy gets worse, environmental initiatives (e.g. climate mitigation) will become less popular – not because people disbelieve or care less but because they'll have less financial and emotional bandwidth to advocate for them.*
- *As a globally tethered economic system, we will likely do anything we can to kick the can further down the road. We are caught in a spiral of growth, limits to growth, response to limits, more growth, more limits, more response.*

9.2. Cultural evolution and the superorganism

We are members of a social species collaborating at various scales to execute optimal foraging algorithms in a novel, resource-rich environment. This results in a persistent, collective pursuit of economic growth. This growth imperative is now accentuated by:

a) Creating currency not tethered to physical resources
b) not creating the 'interest' due when money is created and
c) increasingly using methods of finance to solve problems created by finance.

Humankind, as a species, circa 2020 C.E., is ecologically functioning as a mindless, energy dissipating structure. We could overcome this, but will we? Events in coming decades will open up frozen cultural opportunities, but will occur stepwise. It is unlikely we'll solve our environmental problems via new rules and pricing structures, while keeping the risks of credit, limits to growth, social cohesion, and populism walled off. It is likely we will have to solve social and financial problems first, before we can integrate longer time-horizon issues relating to ecosystems and more benign cultural aspirations.

Humans have unwittingly been ensnared in the Carbon Trap – whereby, to maintain our lifestyles and existence, we have to continue burning the ancient carbon that is inexorably destroying the natural world. No one is to blame for this trap but we are all complicit. We need to retire our ~500 billion strong fossil armies, but if we really did this, it will transform our way of life in ways we are likely to resist.

The Superorganism framing of *Homo sapiens* appears unflattering, yet it offers both clarity and hope. Understanding that humans in large numbers predictably self-organize by following simple energy scaling tropisms gives us a chance to visualize and prepare for what is likely to happen (financial recalibration, less energy and material throughput, more local economies, less carbon, etc.) This awareness empowers individuals and small groups to pursue creative paths of future mitigation and planning outside of – or in parallel with – the aggregate human Superorganism.

Finally, just as we discovered that we live in a heliocentric world, and that we evolved, we now begin to see that we are part of a biologically emergent Superorganism which is de-facto eating the planet. *If we figure that out, what new pathways might it open up?* Our biology is not going to change – but our culture and our economic system could. How will we use the coming financial/energy recalibration to move towards a slower, wiser, less damaging system? What sorts of responses would be beneficial? *What sort of new stories do we need?*

There is a recent trend in environmental media asserting climate change is the primary systemic risk faced by civilization. One of the points of this paper is to suggest that climate change is one symptom of a much larger dysfunction. Multiple interrelated risks all point to an impending, imposed reduction in energy/material throughput in coming decades. There are 2 primary implications of this:

1) *Societies need to physically and psychologically prepare for circumstances with less credit, complexity, energy/material throughput, and will need social support structures for those falling off the treadmill,* and

2) *We need a science-linked blueprint describing how a new economic system based on biophysical reality might emerge from this Great Simplification* –e.g. taxes on non-renewables (not only carbon but other rapidly depleting resources), a reduction in the role of casino finance, caps and floors on income, etc., all informed by the species-level view. This is the small chink in the armor of the Superorganism. It is here that we should aim the arrow of heterodox economic ideas and the research agenda for Ecological (Systems) Economics for the next 30 years.

The concept of societal 'collapse' has now made its way into the mainstream media (Kemp, 2019). The word 'collapse' imbues a finality. It also sounds binary – yes or no. Our situation is much more nuanced, geographically dispersed, and actionable. By kicking so many cans to keep growing, we now face a *bend* or *break* scenario. We face a complex challenge to avoid the 'break' by bending. This bending will comprise a 'recoupling' with nature and with each other, while using fewer non-renewable resources. Physically this is possible. For example, a 30% GDP drop in the USA would bring that nation back to a 1990's level of per capita GDP and a 50% drop in GDP would bring the USA back to a 1973 level.

The real challenge will begin when growth ends. Eventually, we likely face a global depression and other challenging departures from our recent trajectory. Those who understand and care about these things, who have social support, a modicum of resources, and psychological health, <u>*have to step up.*</u> This is not a time to minimize our individual impact, which only makes us a smaller part of 1/8-billionth of

the Superorganism. Those who understand need to be effective at larger scales. We need to maximize our impact during this liminal space for *Homo sapiens*. The answers now are at least as much social as they are technical.

10. Conclusion

> *"There is science now to construct the story of the journey we have made on this Earth, the story that connects us with all beings. Right now we need to remember that story — to harvest it and taste it. For we are in a hard time. And it is knowledge of the bigger story that is going to carry us through."* **Joanna Macy**

A bunch of mildly clever, highly social apes broke into a cookie jar of fossil energy and have been throwing a party for the past 150 years. The conditions at the party are incompatible with the biophysical realities of the planet. The party is about over and when morning comes, radical changes to our way of living will be imposed. Some of the apes must sober up (before morning) and create a plan that the rest of the party-goers will agree to. But mildly clever, highly social apes neither easily nor voluntarily make radical changes to their ways of living. And so coffee and stimulants (credit, etc.) will be consumed during another lavish breakfast, but with the shades drawn. It's morning already.

It is likely that, in the not-too-distant future, the size, complexity, and (literal) `burn rate' of our civilization will be much reduced by forces other than human volition. This paper suggests that we will not plan for this outcome – but we could react to it with airbags, social cohesion, an ethos and prepared blueprints based on intelligent (and wise) foresight.

What aspects of our current world can and should be preserved? What can we do to make the path ahead less painful? How can we nurture ecosystems and species, as well as the great body of human culture and knowledge, so that they can, as far as possible, survive the bottlenecks of the 21 st century? What really, could we aspire to become as a species? Can we use science to guide us from mildly clever to moderately wise? Can we tap into our wiring for group cooperation to align ourselves with a purpose beyond turning trillions of barrels of fossils into microliters of dopamine? What sort of economics will help us ask, research and inform these questions?

Thirty years ago, ecological economics pioneered a systems approach to economics, but unfortunately became dominated by a narrow, micro-focus on ecosystem services, monetary valuation and conventional economics (Plumecocq, 2014). Whatever we'll call it, we are desperately in need of a set of guideposts and principles that include not only ecology but also biology, psychology, physics and emergent behaviors. This discipline will focus at least as much on *'what we'll have to do'* as on *'what we should do'*. And it will apply the evolving knowledge of experts with a view to the maps and charts made by generalists. Ecological economics was shaped as a next step from earlier classical ideologies so as to consider the inclusion of sources and sinks. Over the next 30 years, ecological economics must be both torchbearer for a systems economics and midwife to a smaller flame.

Declaration of Competing Interest

There are no conflicts of interest with any of the content/materials in this paper.

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