What Earth Supplies and What We Need: Carrying Capacity as a Guide for Regional and Planetary Governance and Sustainability

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Learning our Way Forward

The world order is changing before our eyes (Allan 2018, 29-74, 263-284). During the postwar era, nations specialized in measuring Gross Domestic Product, a standard adopted by neoliberalism and globalization to bolster production, trade and finance in the world's wealthier areas (Monbiot and Hutchison 2024, 16-68; Stråth 2023, 272-295). Now, as governments navigate the blistering impact of climate warming, resource overuse, overpopulation, erosion of democracies and civil unrest, the GDP has become, not just a dubious measure of economic value, but a driving force behind the world's ecological decay and multilateral rupturing (Bonneuil and Fressoz 2017, 99-287; Davies 2019, 298-311). Induced by a military-industrial-tech culture that is energized and subsidized through oil power, smart machinery and monopoly patents/copyrights, our civilization has blundered into a selfish race for material surplus with no redeeming purpose (Bishop and Ross 2021, 1-23; Syll 2023, 52-137).

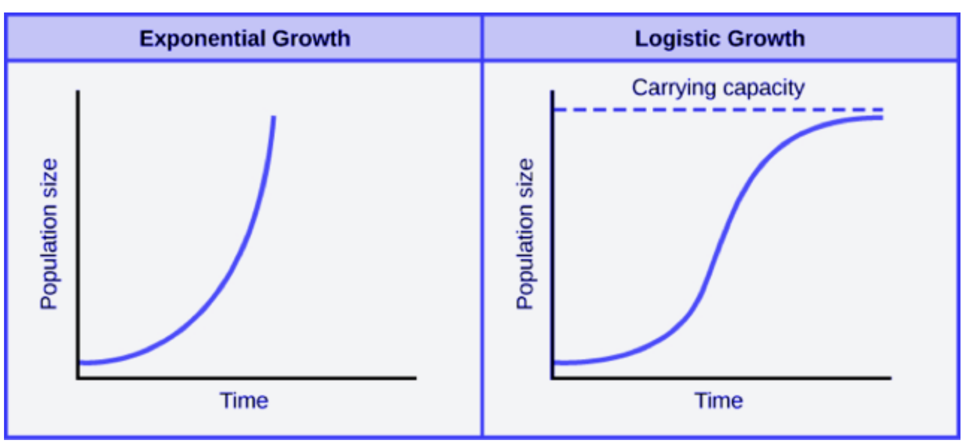
Future diplomacy will require avoiding world war while mutually agreeing to live within the limits of resource capacity for the health and resilience of the planet (Röckstrom et al

2023). Rather than measure a potential market that may be supported through imports and exports, nations must begin to evaluate the wealth of the habitat that is necessary to survive and grow their populations (Cato 2013, 145-163; Hall and Klitgaard 2018, 487-502; Lovelock 2000). Could today's polycrisis be a catalyst for calculating the maximum population that our planet and regions can support through basic resources like food, water and energy (Quilligan 2017)?

Comparing Ecology and Population in Modern History

Pierre-François Verhulst discovered the *sigmoid curve* in 1838, indicating a dynamic connection between the limited resources of an environmental area and its rate of population increase. Verhulst's formula provided mathematical evidence of a metabolic ratio in the *logistic (arithmetic) growth* between the reserves of material or energy resources within a habitat and the physiological needs of a species within that habitat. This is distinguished from *exponential (geometric) growth*, in which no such metabolic information is implied or derived.

Exponential and Logistic Growth



From Handbook of Regression Modeling in People Analytics, by Keith McNulty.

Verhulst's S-curve demonstrates that growth begins when a population is small and resources are abundant. As it increases more rapidly, the population rate becomes exponential. When the competition for resources intensifies and there are less resources, territory or mates available for the population to increase, the growth rate slows. Eventually, if nature is allowed to take its course, the population levels off as resources become more limited and growth decreases to zero, indicating a stable population size at its maximum capacity. If a population exceeds this threshold, however, it will result in resource scarcity, environmental degradation, reduced space and territory, infectious diseases, imbalances in the population of species and social collapse (Odum 2007, 380-393; Tainter 2004, 91-126).

During the 19th and 20th centuries, the formula for logistic growth was used in shipping, engineering, livestock and wildlife management, and population science. Seventy years ago, Howard Odum proposed calling the upper limit or asymptote of the logistic curve, *carrying capacity* (Odum 1953). Since then, this definition has fostered differences of opinion between physicists who believe that the upper limit bears no consequential relationship between the environment and the human population, and ecologists and biologists who claim that it bridges the domains of resource growth and population needs within a constrained system of finite resources (Sayre 2008, 120-134). This dichotomy within the sciences is frequently emphasized by critics of carrying capacity who fear that *maximum population size* may be rationalized as a political tool for reducing human populations through birth control, resource competition or genocide

(Malthus and Stimson 2018). Yet a broader view of logistic growth suggests that resource overshoot is a result of overconsumption, which may enable a population to moderate or guide a fairer, more stable policy for material consumption without depleting or degrading its environment (Daly and Farley 2004, 413-476).

A viable critique of carrying capacity is that it does not fully capture the various nuances of human-and-environment interrelationships (Lewis and Maslin 2018, 269-294). Yet this is not so much an error of the logistic function itself as it is the imprecise data and variances that are often applied to it. In any case, some inexactness in detail does not disprove the anabolic/catabolic relationship between the resources in a habitat and the needs of its population for those resources: instead it reveals the complex research on metabolism that is already in process[1] (Davies 2019, 104-129). Practitioners of the logistic curve in carrying capacity are constantly refining their techniques and sources as more accurate interconnections between the domains of natural resources and species population are discovered and examined. This is particularly true of the data gleaned through real-time remote sensing, GIS and AI technologies, the Kleiber Law and recent advancements in the field of stoichiometric testing and education (Karveia et al 2007, 1866-1869; Liu et al 2021, 1-6).

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[1] As in the difference between people who see a glass of water as half-empty or half-full, there may be a more unifying perspective to this dilemma. The paradox of logistic growth is resolved by considering the asymptote of the logistic curve, not as a statistical *correlation* of balance between constructs in a physical dimension, but as a *ratio* between the asymmetrical energy stocks of physical resources (eg. food, minerals or fossil fuels) and the energy flows within biological species (eg. human beings). This ratio indicates that when units of measure from the domains of physics and biology are compared, they express a *metabolic rate* of interaction between the linear yield of ecosystem resources and the exponential growth of populations.

Some Basics in the Measurement of Carrying Capacity

Here are some general guidelines for conducting research and training in carrying capacity. The biophysical objectives of the project must be clearly stated, along with any assumptions that are made about the data. The narrative must offer a consistent quantitative viewpoint applied to the resource area and its population. Preparation for a study may be labor-intensive because some data sources are not readily accessible from public archives. Selecting the data for *sustainable yield* per resource requires growth rates specific to that resource area which may be difficult to measure. Data on the individual use or consumption of a resource must not substitute for physiological data on personal *resource needs*. The variables in a study may be configured as snapshots or time series[2], depending on the purpose of the research and the data available. While many types of qualifications may be applied to the variables for greater precision, the essential measure for carrying capacity or K (*kapazitätsgrenze*) is:

$$K = LA / (RN/SY)$$

where:
K = Carrying capacity of a given habitat
LA = Area of **land available** for production of the resource (per hectares)
RN = Average annual amount of **resource needs** (in liters or kilocalories per hectare per person per year)
SY = Annual **sustainable yield** of the resource (in liters or kilocalories per hectare per year)

What focuses the energy in this static picture is the identity between the area of physical hectares for RN in the

[2] Advanced differential applications in population biology include rates of population growth over time, as in K = { rN (1-N) } / (dN/dt).

numerator, and the area of biological hectares for SY in the denominator. Trainees in the field of carrying capacity, recognizing that these two land areas 'cancel each other out' for ease of computation, often miss the real point: the ratio of diverse physical and biological data in the same area has metabolic significance through the logistic curve, which cannot be expressed in exponential terms (Odum 2007, 102-216). This is the crucial breakthrough of the logistic function. Since every habitat — from the planetary biosphere to the regional biome and local ecosystem — is bounded through its own logistic growth, metabolic ratios of carrying capacity may be developed for resource governance at the planetary scale as well as in bioregional and local eco-districts.

Today's Entropic Economy of Weights and Measures

Most citizens in sovereign nations are taught that the market economy is a self-organizing unity. To prove this, a number of economists in the past century have attempted to develop correlations between inflation and unemployment based on a theoretical balance between supply and demand.[3] This idea originated in classical economics, which held that the free market is like a law of nature that tends toward equilibrium (Davies 2019, 130-144; Smith 2008). Hence, in the pricing of natural resources, modern nations endorse the free market's exponential system of resource growth by presuming a

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[3] This includes the monetary theories developed from the 1920s-1970s by neoclassical economists Irving Fisher, Bill Phillips, Paul Samuelson, Robert Solow, Milton Friedman, Lucas Papademos and Franco Modigliani. All of them attempted to portray an inverse correlation between the inflation rate and unemployment rate. In practice, the proposed interactions have not been validated, particularly since the 1970s. Yet the formula is still being used by many central banks in setting interest rates. The problem is that these calculations do not measure the energy already underlying the economic value chain, mistaking downward swings in the supply of thermodynamic stocks of resources for *inflation*, while confusing upward swings in the demand for biophysical flows to meet population needs with *unemployment*.

dynamic parity between supply and demand, which implies an underlying equivalency between nature and society (Fullbrook 2019, 15-91). This is why national policies for environmental and human resources are now based on exponential growth through market demand and monetary debt, rather than the logistic curve between available resources and population needs (Davies 2019, 268-297; Mauldin and Tepper 2011, 109-292; Quilligan 2010, 115-152).

It's easy to see how this happened. Except for coastlines, lakes and rivers, nation-states were formed without regard for ecosystem boundaries (Hanski 1999). Even a bioregion may be divided geographically among many nation-states, or exist as a portion of a single nation. Because most nations (except island-states) are *not* naturally-bound districts with a logistic identity between areas of energy-infused resources and areas of population needs for this energy, governments have evolved their own system of value equivalence (Fullbrook 2019, 37-85; Lindeman 1942, 399-417; Reid and Taylor 2010, 19-50). Hence, nation-states, like their market economies, do not use the logistic function that relates an ecosystem to its population because these entities are based entirely on political, not ecological, boundaries (Carr 2004, 21-69; Lewis 2018, 149-224). This also allows governments and businesses to ignore the distribution of wealth from nature, and focus instead on the redistribution of wealth within their own societies to oligarchs, CEOs and shareholders.

Rather than calculate the energy value of a resource before it is extracted from nature, neoclassical economics relies on the mass and length of products to determine their retail prices (prior to a customer's marginal preferences for the items) (Fullbrook 2019). The supply chain costs for resource extraction, production, transportation and distribution are thus expressed as a market exchange value based on the weights and measures of these goods (Chapin et al 2009). Yet the thermodynamic value of energy is misrepresented: economic 'supply' excludes the ecological quality and limits of resources, and 'demand' excludes the needs of all living organisms that have no actual money to spend (Fullbrook and Morgan 2019, 72-196). That is why today's economies account for the value of commodities through the energy-draining technosphere, but neglect the embodied energy issuing from the biosphere (Stiegler and Ross 2021,18-62).

This entropic misallocation is now reaching crisis proportions because human beings have learned to take more from the planet than it can reproduce, hoarding supplies without replenishing or redistributing them for the benefit of others, while leaving us all disengaged from energy, nature and our own selves (Alombert 2024; Victor 2008, 47-98). At the same time, the field of biophysical economics is demonstrating how the precepts of supply and demand misconstrue the asymmetrical quality of the thermodynamic funds and flows of energy that emanate through an ecosystem to satisfy the needs of a population, and do not constitute a natural or metabolic equivalence of any type (Hall and Klitgaard 2018, 6-65; Saito 2017, 64-137).

A Cure or Poison for the Planet's Metabolism?

Jacques Derrida observed that an idea is enlivened through collective dialogue, but when written down its meaning is deadened through individuation. This is also true when reporting on the energy-value of Earth's resources for a population. For example, biophysical measures may offer a *remedy* by detailing how the metabolism between resource energy and population needs has been used by a community in developing social resilience (eg., food production created in community gardens). Yet physical measures with a similar objective may produce the *toxin* of entropy through the pursuit of individual energy efficiency (eg., the automotive exhaust created by driving to the supermarket for food)[4] (Stiegler 2011, 14-44). This is why, given our current addiction to exponential growth, humanity has no clear path for protecting its ecological assets from extinction, decreases in soil fertility, desertification, deforestation, fishery declines, pollution or the increasing competition for scarce resources among nations (Smith 2016, 25-123). To gather reliable data on the fund-flow metabolism of the planet, we need another way of calibrating the overshoot or undershoot of resources for its populations (Hall and Klitgaard 2018, 299-455) than the market system of measurement.

Nature is teaching us how. The ratio between ecology and its organisms can be determined when the logistic areas for energy resource availability and population needs coincide precisely, which is mainly a function of dedicated data collection. Thus, instead of calculating or allocating resources through the arbitrary boundaries of nation-states, the most

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[4] Derrida derived this notion from Plato, who said that that the process of putting something into writing has both positive and negative effects, comparing this with pharmaceutical drugs that could either be a cure or a poison. For example, *biophysical counting* indicates that world population is rising by 83 million per year but human beings are consuming Earth's resources at 1.7 times the sustainable rate, far exceeding the planet's ability to replenish them (Earth Overshoot Day). This reporting provides society with vital figures for use in developing policy. Yet our *physical accounting* of GDP, prices, exchange rates and interest rates, plays no role in determining how many people the Earth can support because the data that is gathered and disseminated does not express the living wealth of the environment, thereby contributing to the planet's ongoing extraction and degradation of resources (Davies 2019, 269-286).

practical units for organizing economic life are local, regional and planetary, where resource capacity is defined by the geographical qualities and limits of ecological energy systems and the biological needs of the communities within those areas (Krausmann et al 2018, 131-140). Already, some businesses have begun measuring the fund-flow value of food, wood, biomass, animal and human labor, minerals and fossil fuels in quotients of energy such as *joules*, rather than their trade or exchange value in national currencies (Cato 2013, 164-181). This is crucial because the sufficiency and deficiency coefficients of ecosystems are far more accurate indicators of resource value than the calculations of weights and measures used for the commodities in market economies (Georgescu-Roegen 1971; Odum 2007, 252-280).

Meeting this Moment by Revaluing the Earth

The world's polycrisis is extremely complex but also straightforward. Revaluing the Earth means reevaluating ourselves and our reason for being. This planet owes us nothing, yet we owe our lives to it (Illich 1977, 93-143; MacAskill 2022, 9-163). Through civilization's prodigious development of fossil fuels, industry and technology in recent centuries, humans have been over-borrowing massively from the elements of nature to forge and acquire products (Saito 2017, 25-61; Victor 2008, 72-98). Now it's time to restore our entropic credit with the biosphere through broad discussions for an economy of *supply and need,* based on how the size of a population modifies its ability to provide enough energy to sustain itself (Evanoff 2011, 130-164; Fullbrook and Morgan 2019, 288-564; Victor 2008, 191-224). This public dialogue will engage the mutual agency and trust of many kinds of groups — planetary, transnational and bioregional councils, researchers in the humanities and social and natural sciences, businesses, communities and local activists — to apply new indicators and incentives for energy and environmental planning, conservation and distribution at scale (Cabrera 2004, 71-104; Elo et al 2014, 189-230).

Could these data-driven negotiations result in a social contract among nations to live within the sustainable yield of their habitats' renewable resources, while staying within the limits of their nonrenewable resources (Quilligan 2024)? Perhaps. (MacAskill 2022, 191-252). Sooner or later, sovereign nations must confer technological and political power to planetary institutions beyond their political borders, while devolving economic power to the bioregional and local communities within their state boundaries (Blake and Gilman 2024, 41-162). This kind of *collective self-organization for sustainability* — affording us healthier ecosystems, burgeoning biodiversity and civic unity through human dignity and well-being — is entirely possible (Han 2020; Pratt 2022, 234-275; West 2017, 411-426). What it requires is tracking the fund-flow metabolism between nature and human beings and redistributing Earth's physical resources to meet the biological needs of its population (Fullbrook and Morgan 2021, 384-422; Max-Neef 1992). That is the challenge now.

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