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Politics, Governance, and the Law

Who Will Pay Back the Earth? Revaluing Net Energy through the Sustainable Yield of Regional Ecosystems

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The West's dominance of the world order is being tested by China, Russia, and other nations. This standoff over energy and monetary hegemony has critical implications because neither bloc has a regenerative plan for resource management of the planet. Since the population demand for global resources began to exceed its supply in 1971, world economic growth has surpassed the availability of natural resources. Society's increasing need for energy calls into question the legitimacy of sovereign governments in accounting for their ecological deficits. A new measure for the energy-value of resources through their sustainable yield is necessary to adjust the financial imbalances in energy, production, and trade while meeting basic human needs within the limits of Earth's natural systems. The calculation of maximum sustainable yield could transform the neoclassical economic system of value-added into a process of value-renewed exchange by using the metabolic measure of carrying capacity. Biophysical economics may then become the basis for energy, monetary, and security agreements among sovereign nations to devolve the stewardship for restoring net energy-value to people within their bioregional areas. A planetary compact, focusing on the ratio between sustainable yield and human need, would encourage new partnerships between businesses, governments, and the public, granting to citizens the rights and responsibilities to organize the self-sufficiency and sustainability of their own regional habitats.

ENERGY AND WEALTH: THE LEGACY OF MATERIAL PROGRESS

Stories have been shaping human culture from the dawn of time. Behind most of the metaphors and models that our ancestors developed through their interactions with the natural world was energy—the elemental force that generates transformations within matter and sets all things into motion. Human beings were impelled to generate enough energy to feed themselves, survive, adapt to the environment, and propel their genes into the future. This forward movement involved extracting more energy from the environment than the energy that a person used to extract it. The impulse to obtain surplus energy by finding new energy reserves also led humans to believe that Earth's resources were endless. Families and communities could expand beyond their local habitats by removing energy from distant places as long as they produced enough energy to make more energy. The power of energy, often expressed through custom, superstition, religion, nature, governance, or economy, was behind every activity on the planet. Our business now in examining this "energy quest myth" is to understand how effectively *Homo sapiens* has ventured down that long evolutionary trail. Where are we today? What has become of material progress?

Since its emergence on Earth, the human race, like all species, has engaged in a dynamic struggle between the needs of its people and the limits of its environment. As their populations grew slowly, not reaching one billion until the eighteenth century, our ancestors assumed that the natural forces that conditioned their lives were rationally unfathomable, socially arbitrary, yet physically negotiable on a practical level. Human societies and cultures used their acquired skills and common sense to adapt to natural laws for self-betterment. Through their shared knowledge, people learned to use and apply energy resources through common tasks, ethical applications, and functional uses. Cooperation for natural energy in its various forms has occurred within families and communities throughout recorded history, but was seldom practiced in large social hierarchies. In most societies, the net energy that was transferred from ordinary people to their governing leaders and elites resulted in wealth consolidation, top-heavy ad-

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ministrative structures, and, ultimately, major social breakdown (Tainter 2004, 193–216; Diamond 2011, 77–308). With the rapid increase of world population in the twentieth century, the governance of energy sources has become more critical.

Today a new struggle for energy dominance has emerged, and the creation stories of the East and West—that all habitats, even hostile environments, are theirs to conquer and exploit for energy—have become uniquely planetary for the first time (Chakrabarty 2021, 1–20). As ancient ideologies square off now in the form of a renewed China (with centralized state capitalism) and America (a Romanesque plutocracy), their actions are shrouding humanity's own understanding of itself and its purpose in sustaining life. Many people now question the myth of infinite resources and the exponential growth it has generated. At risk of global warming, diminishing resources, and societal collapse, the world's leading nations are applying divisive measures in human security, population mobility, and energy management. Because their idealized models for measuring abundance and wealth are vastly outdated, neither the Global East nor the Global West are facing up to the challenge of ecological overshoot with a regenerative vision for planetary life.

"Be fruitful, multiply and subdue the Earth," the book of Genesis proclaimed. Yet overpopulation, greater complexity, and carbon emissions were never part of our origin stories. There were no instructional chapters to teach people how net energy could be organized or allocated to last indefinitely. In neglecting to quantify its needs for food, water, wood, biomass, minerals, and animal and human labor for most of human history, our race has been slowly withdrawing more energy resources from the environment than it could replace (Graeber 2011, 43–71, 223–50).[1] In 1971 world demand for the energy flows of natural resources exceeded their supplies for the first time, indicating that the entire planet had entered into a condition of ecological deficit. Five decades later, societies are using up topsoil, arable land, surface water, and fossil fuels 70 percent faster than the biosphere can replenish them (Global Footprint Network, n.d.). If international power politics continues to operate as it has for the past five centuries, the world may be swept up in a hegemonic war for energy resources unlike any before.

This article proposes that the replenishment of net energy gain to meet human needs through the maximum sustainable yield of resources is the fundamental story of economics. The following section surveys how the framework of *core and periphery* has led societies to create an intricate system of resource and financial dependency through which raw materials and energy are transformed into useful products and services. Later we explain how net energy became a key component in the monetary hegemony of sovereign nations; how this is impacting geopolitics at present; how the sciences of physics, chemistry, and biology have indirectly shaped modern political economy; and why policymakers, the free market, the scientific community, and the public must learn to restore value to nature through self-organizing and self-sustaining regional systems.

CORE AND PERIPHERY: ENERGY IN THE HOLOCENE AGE

Our starting point is the use of energy resources after the Neolithic Revolution. Although the rise in average agricultural production since 10,000 BCE did not increase the individual nutritional needs of humans, it did increase world population by small steps during this period (J. E. Cohen 1995, 25–31). The same is true for energy sources, a few of which (coal, oil, gas) began to grow exponentially only recently through the rapid rate of economic growth (see table 1).

Tainter (2004) and others emphasize the decisive impact of the center-periphery model for net energy in the rise and fall of civilizations.[2] This pattern began twelve thousand years ago with the Holocene Age, when Earth's glaciers receded and food, wood, and animals became the vital sources of energy and value. Throughout this long span to the present, as populations grew, they developed settlements, towns, city-states, and nations in gradual stages, using energy to create social and economic infrastructure in those core areas. Slow and steady increases in energy extraction and human need resulted in unequal exchanges of material resources and labor energy from the rural periphery to the more urbanized core (see figure 1). The control of energy stocks and flows by the rulers of the core led to a division of labor, social hierarchy, and institutional and technical complexity in the more advanced societies, while draining energy from the periphery through its minerals, biomass, and animal and human labor (Tainter 2004, 91–126).

Yet the economic success of the core's growth phases, which had initially led to higher energy depletion in the countryside, boomeranged back upon the core through diminishing economic returns and the dispersal of waste and pollution. Through agricultural exchange, for example, nutrients like nitrogen and phosphorus that had been removed from the soil in a rural periphery accumulated now as waste in the urban core. With slowing benefits from the energy flows of its ecological periphery, the economic and governance systems of the core began to decline. More and more energy was captured just to maintain this complex infrastructure—including administration of the periphery, security and transportation costs, and constant importation of food—until there was little net energy available for eco-

1 Although water and minerals are not forms of natural energy, we include them in this list because of their capacity to catalyze energy.

2 The concept of core and periphery, applied by Immanuel Wallerstein (1930–2019) to broad geopolitical trends since the sixteenth century, can also be recognized throughout history on smaller scales.

Table 1. Varieties of Energy Sources in the Holocene Age

Stock	Inflows	In today's units	Outflows	In today's units	Time frame
Food	Soil yield	Kilograms	Consumption	Kilograms/yr	10,000 BCE -
Food	Soil yield	Kilocalories	Consumption	Kilocalories/yr	10,000 BCE -
Surface water	Precipitation, rivers	Liters	Consumption, evapotranspiration	Liters/yr	10,000 BCE -
Groundwater	Rain recharge	Liters	Extraction	Liters/yr	10.000 BCE -
Wood	Tree growth, logging	Board meters	Usage, decay	Board meters/yr	10,000 BCE -
Biomass	Plant growth	Kilograms	Biomass conversion	Kilograms/yr	10.000 BCE -
Human labor	Wages, employment	Head	Work	Hours/yr	10,000 BCE -
Animal labor	Forage, training	Head	Work	Hours/yr	10,000 BCE -
Minerals	Dead vegetation	Kilograms	Biomass conversion	Kilograms/yr	5000 BCE -
Coal	Dead vegetation	Kilograms	Combustion	Kilograms/yr	1500 CE -
Whale oil	Whale blubber	Kilograms	Combustion, lubrication	Kilograms/yr	1750-1900 CE
Oil and gas	Extraction	Barrels	Combustion, lubrication	Barrels/yr	1860 CE -
Solar power	Solar radiation	Joules	Photovoltaic electricity	Joules/yr	1980 CE -

nomic growth (Tainter 2004, 118–23). The destruction of ecosystems through overconsumption by the core, persistent underdevelopment of the periphery, and an overall decline and collapse of energy supplies sorely weakened the management of the core area (Diamond 2011, 509–24; Graeber 2011, 211–21). This was the pattern of development in all energy-driven societies of the past twelve millennia, as evidenced in the Mesopotamian, Egyptian, Hittite, Roman, Chou, Indus Valley, and Mayan civilizations and numerous others (Tainter 2004, 43–90); Diamond 2011, 77–308).

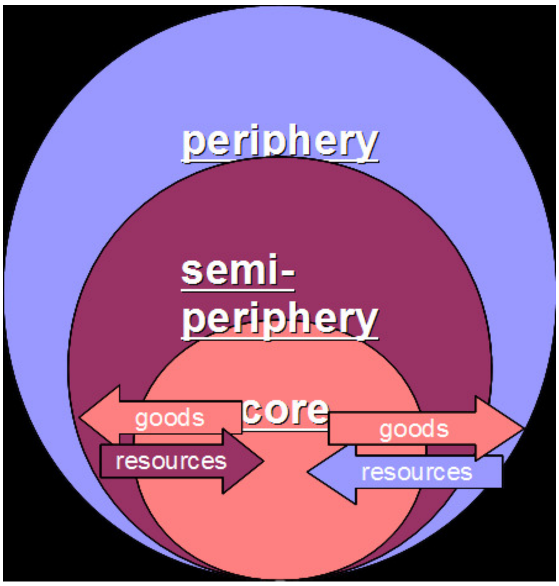

Figure 1. World system sphere. Courtesy of Wikipedia Media.

Things changed dramatically during the Age of Exploration and Globalization (1500–2000). We pick up the story where European nations were becoming an imperial core and the rest of the world its colonial periphery. With the availability of new resources and slave labor in the sixteenth and seventeenth centuries, resulting from territorial conquest, mercantile trading, and the growing use of new forms of energy, economic growth began to increase exponentially and support the value of money (A. Hall 2011, 59–110). In the seventeenth century, high-priced coal and whale oil led to easier commercial production with less energy and physical labor, as well as greater consumption than previously, which led to lower costs for producers, sellers, and buyers. In England from 1500 to 2000, for example, the amount of money spent on producing energy to empower the rest of the economy decreased from 40 percent to 5 percent (C. A. S. Hall and Klitgaard 2018, 86). The trend of higher energy efficiency leading to greater economic growth became more pronounced through the accumulation of net energy and the development of monetary hegemony in core areas (Goldstein 1988, 296–313). Higher currency values in Europe became the norm following a wide-ranging conflict over unequal transfers of net energy, involving issues of religion, trade, and warfare, which ended with the Treaty of Westphalia in 1648. This agreement by over one hundred European states established peace through border protection and domestic noninterference for the first time (Bobbitt 2003, 502–19; Anghie 2005). It also paved the way for national banking in the eighteenth and nineteenth centuries, which incentivized borrowing for investments in production, finance, and military activity, all of which secured the monetary value of energy. The enormous boost from resource energy production in the colonial periphery also stabilized currency values in the core nations of imperial Europe.

Yet heavily strained by the escalating energy-related costs, each sovereign core eventually struggled to maintain monetary control over the contenders in the neighboring states that challenged its authority. In five different periods, a new nation established itself as monetary hegemon by overpowering the existing core nation: 1494–1517, Portugal versus Spain; 1579–1609, Netherlands versus France; 1688–1713, England versus France; 1792–1815, England versus Germany; and 1914–1945, the United States versus Germany (Goldstein 1988, 281–347). Once the challenger prevailed over the incumbent ruler, it consolidated its own power and legitimacy over the trade and financial practices of the defeated hegemon, beginning a new cycle of monetary politics that applied the victor's own version of the core-periphery model to the new social order.

During the eighteenth through the twentieth centuries, these power struggles were also evidenced in the recurring colonist revolutions and demands for reparations and climate justice, involving devalued labor, resources, and terms of trade (Chakrabarty 2021, 95–106; B. J. Cohen 2000, 47–67; A. Hall 2011, 527–654). After World War II, when higher market prices for food calories and nutrients, water, wood, biomass, minerals, human and animal labor, and fossil fuels began to dominate the international system of trade and finance, imbalances in the net energy-value between geographic locations created widespread disparities across the developing world (Stavrianos 1981, 623–755). As traditional agriculture was displaced by industrial agriculture based on cheap and seemingly endless sources of petroleum, the former colonial territories developed a nascent understanding of the ecological footprint involved in energy balances and deficits. In the 1970s the issues of agriculture, natural resource supplies, social poverty, aid, labor, trade, finance, monetary policy, and ecological degradation were contested globally. With the publication of *North-South: A Program for Survival* in 1980, a detailed solution was proposed (Brandt 1980).

But this new pact, in which the wealthier Northern Hemisphere would supply more aid, technology, and financing, while the less developed nations of the South would sell their labor, raw materials, and mass-produced goods, was only the latest expression of the core-periphery dichotomy where energy flows are misaligned and misappropriated (Allen, Tainter, and Hoekstra 2003, 33–43). Altogether, the effects of exchange-value during the modern fossil fuel period—including the degradation of the environment through waste and pollution, declines in the purchasing capacity of the middle classes and poor, severe and successive debt crises, destabilization of governments, and the spread of conflict among the wealthier states—were strikingly similar to those of earlier civilizations (Turchin 2023, 161–89). The Global North and Global South were still following the same biogeographical practices of exchange:

- Energy transfers of ecological reserves of biomass and energy from peripheral regions to the hegemonic core, rapidly boosting resource consumption
- Consolidation of wealth and rebuilding within the core, enabling purchases of energy from the peripheral areas without measuring the net value of this energy
- Higher resource demand and overconsumption in the core exceeding the available energy, resulting in the disintegration of economic and social infrastructure in both areas

A major factor in today's planetary dysfunction has its source in the myths of an infinite biosphere, value-added accounting, and chronic misvaluations of net energy between the world's core and periphery regions (B. J. Cohen 2008, 36–55; Daly and Townsend 1993, 70–73; Graeber 2011, 166–206). These myths continually interpret nature's thermodynamic laws as a competition for the unlimited accumulation of energy wealth, requiring societies to rely on the feedback mechanisms of profit, compound interest, debt, and GDP rather than the signals of energy yield from natural systems and the physiological needs of populations. In all instances, the wealth transfer to the social core expresses the increase in financial value accrued through the exchange of energy, while the wealth deficit in the social periphery is the mounting debt generated by higher energy-value in the core exchanged for less energy-value (Eichengreen 2008, 210–32). Similar monetary dynamics are now playing out in geopolitics, with a significant twist. China's emergence since the 1990s as an industrial and technological powerhouse in the Global East periphery / Global South semiperiphery has elevated it to contend for the role of monetary hegemon on a planet whose population, for the first time in history, is surviving on diminishing energy resources.

ROOTS OF TODAY'S ENERGY CRISIS: GLOBAL EAST / GLOBAL WEST

When Russia invaded Ukraine in February 2022, the United States imposed economic sanctions on Russia, putting its political weight behind the North Atlantic Treaty Organization and Europe to defend Ukraine. By freezing $300 billion of the Russian Central Bank's foreign exchange reserves, Washington and Brussels shut Russian banks and companies out of the West's financial technological networks. Without access to dollars and euros, Russia asked China and friendly nations in the Global East and Global South to use their own payments infrastructures and financial institutions to circumvent their reliance on the dollar. In response, more than one hundred countries, representing 87 percent of the world's population, refused to follow the West's ban on Russian trade. This stunning lack of confidence in the transatlantic alliance and its hegemonic influence over the international monetary system was a pivotal moment in the rules-based regime of globalization (Hirsch 2022). Eighty years of postwar order and five decades of oil-backed currency had reached a crucial turning point, committing the Global East to form an independent monetary system with the Global South, effectively ending the Global

West's monopoly on the global flow of financial capital and net energy gain.[3]

With a core-periphery clash squarely in focus, Chinese president Xi Jinping and Russian president Vladimir Putin announced in June 2022 that their nations were developing their own global reserve currency. It would rely on an index of national currencies outside the international trade settlement system and share financial structures for regional trade with partners across the Global East / Global South. Forty-six nations, including India and Brazil, joined this new currency union to generate their own unit of money and sphere of influence. In December 2022 a Chinese–Saudi Arabian summit discussed creating an alternative to the US dollar based on either a petro-yuan currency or a basket of currencies including gold, OPEC and Russian oil reserves, or other minerals (Prashad 2022). This meeting was followed by a political truce brokered in Beijing between Iran and Saudi Arabia (the US guarantor of the petrodollar).

The Global West dismissed this new monetary order, focusing on the gigantic hurdles that the East periphery and the South semiperiphery would face in establishing a reliable alternative mechanism for clearing international currency transactions (B. J. Cohen 2008, 257–59). When a parallel to the US dollar system could be launched—or what it might use for reserve assets—is unclear. To replace the American dollar as the global reserve currency, China would have to offer full convertibility of its yuan, end capital controls, and open its financial markets to foreign exchange (Raisinghani 2023). In addition, China's industrial production, retail sales, and property markets had weakened during and after the COVID-19 pandemic, exposing the country to possible deflation for the first time in decades and reducing the likelihood of the yuan's replacing the US dollar (Weber 2020).

Despite the West's strong public reaction to these events, the world had crossed the line of soft strategic competition (Eichengreen 2011, 97–152). China and Russia had issued a hegemonic challenge to overturn the monetary sovereignty of the United States by diversifying the use of the yuan in regional and global trade over the next two decades, which could lead to instability in cross-border capital flows, currencies, and asset prices for the United States and its allies.[4] In apparent retaliation, in May 2024 both America and Europe protested Chinese support for Russia's ongoing war in Ukraine, threatening new financial sanctions on Russia and high tariffs on a variety of Chinese exports, including machine tools, microelectronics, and green technologies. As before in history, an economic proxy war has broken out between an incumbent core that controls the world's monetary system through its link to energy flows and a contending periphery and postcolonial semiperiphery that stand for the self-determination of people burdened by their loss of net energy and the nonconvertibility of their currencies (Goldstein 1988, 348–76). At stake is the ultimate rule of the world's stocks and flows of energy wealth (Papa 2023).

Net energy gain has always been the sine qua non of economics, but the possibility of dedollarization has brought this obscure reality into the open. Today's geopolitical confrontation shines a spotlight on the world's preeminent monetary rivals, the mercantilist industrial engine of the Global East and the oligopolist financial complex of the Global West, which are vying fiercely to secure the asset value of their currency reserves by capturing the systems and sources of the world's net energy (Hudson 2022, 43–44). Once again, the new world currency would be based upon the myth of infinite resources and control of Earth's energy flows, forcing nations, businesses, and investors to choose between the opposing monetary blocs (Helleiner, Kirshner, et al. 2009, 187–215). This sets up a perilous round of energy warfare that will be driven entirely by money and power, not ecological constraints or benefits (B. J. Cohen 2008, 214–15). Both the Western core and the East/South periphery are intent on extracting energy through their state agencies and corporate cartels, then turning this energy production into exchange-value. Thus, the energy-value of money in the victorious core nations will remain greater than the purchasing capacity of their currency, while the energy-value of money will be lower in the defeated periphery nations than the purchasing capacity of their currencies (Malden and Tepper 2011, 283–96). In essence, the biosphere, serving as a "lender of last resort," would continue to subsidize the core states more than the periphery states with no systemic means of compensating for these net energy differences, thereby allowing the core to take more net energy-value from the periphery than the core is actually purchasing (B. J. Cohen 2008, 135–48; Hudson 2022, 129–50).

This imbalance in the flow of thermodynamic value is why the existential threat of monetary and political hegemony to the planet is a grave concern: major economic deterioration is probable now because there are no winners in the zero-sum game of sovereigns. As long as the distracted financial, industrial, and technocratic empires of China, Russia, Europe, and the United States are absorbed in building up arsenals on both ends of Eurasia, international cooperation to reverse land waste, soil and water degradation, and greenhouse gas emissions will be non-

3 The United States delinked the world from the gold standard and its system of fixed exchange rates in 1971, allowing the value of international currencies to float while persuading central banks across the world to place their monetary reserves in US Treasury securities. In 1973 the United States established an energy-monetary connection by persuading Saudi Arabia and OPEC to recycle their oil profits into US Treasuries and linking the dollar to the value of OPEC oil. The United States still holds monetary hegemony through the petrodollars that are invested in its government.

4 The subtext is the $9 trillion foreign debt of the United States, which is, in effect, a lien on US oil supplies by global investors. Since the United States is deeply dependent on cheap oil for the production of goods and real wealth, a default on its foreign debt would drive energy costs higher in the United States, making less money available to pay off the principal on this debt.

productive. While the contending states struggle to obtain net energy to maintain their economies at previous levels of economic growth, Earth's shrinking habitats, species extinction, and biodiversity loss will worsen, further undermining the ecosystems that create biomass and allow human beings to meet basic needs and reproduce their species (Wallace-Wells 2019). Add to this the imminent danger of thermonuclear war, and the Holocene extinction and Anthropocene epoch are fait accompli.[5]

Neoclassical economics is neither a physical nor a biological science. This raises some curious questions. Most of the energy on Earth (excluding tidal, geothermal, and nuclear sources) is the movement or work that is generated through photons from the sun, reaching plants directly through photosynthesis, and indirectly through seeds, animals, minerals, and fossil fuels. So why is sunlight not being put to better use, and what good is it to produce more oil when it takes more energy to produce the oil than is present in the oil produced? How is environmental renewal possible when the planet's core and periphery nations are both streaming value-added economic signals through their thermodynamic chains and pipelines from energy sources to the needs of species? Until these contradictions are addressed, the half-hearted commitment by the Global East and West to phase out fossil fuels cannot possibly offset their own shrinking energy reserves with the widening energy deficits of the planet.

Contributing to the net-energy conflict between East and West is a deep epistemological confusion in the science of thermodynamics over the meaning of energy, power, motion, heat, and life. Many physicists, chemists, and biologists are in disagreement on several aspects of energy transformations that fall at the intersection of their disciplines (Coveney, Boon, and Succi 2016). This is confounding political and economic decision-making because the social sciences, including political science and economics, are heavily influenced by the natural sciences. Before world leaders can make progress in equitable energy distribution, they have to examine the true costs of their thermodynamic applications and policies in society. As noted in the sections below, the misinterpretations of science in public policy have standardized the net transfers of energy from the poorer to the wealthier areas of the world, generating excessive levels of social inequality and deteriorating Earth's biosphere and biodiversity.

POLITICAL ECONOMY OF THERMODYNAMICS: BENEFITS AND DEFICITS

The laws of thermodynamics, introduced fairly recently in history, created new possibilities for the utilization of energy. During the past two centuries, applications of the first and second laws of thermodynamics have increased social complexity, improved living standards, and increased social and environmental control, creating extraordinary benefits for civilization. These advances include technological efficiency, agricultural productivity, human longevity, mass literacy, the rise of democracies, and countless other gains. Yet most people are more aware of the practical impact of thermodynamics in their lives than its empirical significance in science. Since the sciences of thermodynamics conduct their research out of public view, our everyday assumptions about the relationship between energy and economics are sparse. Just as the dynamics of energy were a mystery to our ancestors, the links between energy and profits, interest rates, deficits, and debt are equally unclear. For these reasons, we survey the political economy of thermodynamics.

A variety of researchers postulated the first law of the conservation of energy. This group includes Galileo (1564–1642), Christian Huygens (1629–1695), Gottfried Leibniz (1646–1716), Isaac Newton (1643–1727), Rudolf Clausius (1822–1888), and William Rankin (1820–1872). All contributed to the principle that the *total amount of energy and matter in the universe remains constant*. This means that energy and matter may be converted from one form to another, but are never used up (Georgescu-Roegen 1971, 280). The law of conservation of energy became a primary influence during the first Industrial Revolution (1680–1740), when the idea of transforming energy into matter was applied in the creation of iron and material products for mass distribution. The machinery in factories was activated by coal combustion and steam pressure. This led to breakthrough innovations in chemistry, manufacturing, mining, metallurgy, transport, and agriculture, as inventors and industrialists learned to turn this productive power into large volumes of popular goods. Their hard, energy-driven work became highly profitable.

Business practitioners of the first law typically extol the freedom of individuals to make a living by creating goods that are useful for the rest of society. This logic, following inductive reasoning from the part to the whole, concludes that energy use must be expanded for the sake of material development and growth. Instead of directing the energy of human labor to the service of meeting people's basic needs, however, the energy-value of resources is subsumed by the exchange-value of finance—the amount of money that individual demand will generate from the sale of products or through an investment in their production and distribution. Fundamentally, the greater the energy-powered production, the greater the financial return on investment (ROI). This is the basic application of the first law in economics. ROI incentivizes society to *add* value at every stage

5 Geologists, anthropologists, and historians have proposed that an Anthropocene extinction era began in the mid-twentieth century, ending the Holocene Age (Chakrabarty 2021, 166–72). Geologists maintain that this change took place when human activity, waste, and pollution began leaving permanent deposits or indelible records in nature, such as plutonium isotopes from nuclear explosions; nitrogen from fertilizers; plastic particles within water, soil, and rocks; and toxic ash from power plants (Zhong 2022).

Table 2. Thermonomic Measures of Energy

Thermodynamics	Economic Application	Abbreviation	Measure of Value Today	Sample Unit of Measurement
1st Law	Return on Investment	ROI	Gross Domestic Product	\$5 €5 ¥5 \$2 €2 ¥2 40% 40% 40%

ROI = (net profit ÷ initial investment) X 100%

of the energy-value chain—from the stocks of extraction and production to the flows of transport, retailing, and consumption. Often called cost-benefit accounting, the widespread use of energy-produced ROI has culminated in the free market economy and has become international in scope (see table 2).

Since the 1970s ROI has influenced many businesses to orient their investments, technology, and institutional change toward sustainable practices. By converting dense industrial production into lighter ecological solutions, companies frame sustainable development as a naturally adapting balance between the supply of nonrenewable resources and the demand for renewable resources. While this has led businesses to experiment with a wide variety of methodologies and metrics, there is a lack of reliability, comparability, and transparency in much of the data on green energy solutions. A major reason for these disparities is that ROI rarely accounts for the true costs of the thermodynamic pressure, heat waste, and labor involved in the manufacturing of green energy technologies or the production of green energy. Another reason is that financial value in the cost-benefit model of ROI is often calculated without internalizing the deficits and risks that arise from resource depletion, ecological overshoot, and social inequality. Thus, when companies are rewarded for their efficiency gains, higher asset prices, and lower capital expenses, it is generally because their bookkeeping has neglected the substantial costs of producing more energy to create new energy. This is why innovative technology and increased efficiency result in greater energy consumption and overproduction, rather than lowering their environmental impact per person (Jevons 1866).

The economic breakthroughs of the first law have led many in business to assume that increasing the production of energy through fossil fuels will result in a greater amount of solar energy (Thomson 2023). But this is a misinterpretation of the first law that energy can neither be created nor destroyed. Matter and energy may be transformed into one another, but this pressure-induced change in physical form does not mean that matter or energy can *reproduce* themselves through a major net energy gain. Numerous proposals to turn the ancient biomass of dead plants and animals into affordable solar energy incorrectly surmise that these limited fossil fuels can be extracted and burned at a minimal cost to create solar power through the positive profit ratios of ROI. But a prime reason why producers struggle to create surplus energy from the energy needed to generate green technology is their persistent undervaluations of energy sources, energy extraction, and net energy gain (Jansen 2023).

Despite many important advances in the field since the 1970s, the amount of energy required to transform fossil fuels into alternative energy is still greater today than the amount of energy that is produced (Holechek et al. 2022).[6] This has resulted in large energy imbalances, increasing ecological overshoot and delays in plans for developing renewable forms of energy (Union of Concerned Scientists, n.d.). Many entrepreneurs and investors remain confident that solutions will be found to lower the costs of producing renewable energy through nonrenewable energy. But the advocates of first law applications have yet to show how societies will make this crucial transition to a solar economy through ROI measures without compensating for the net loss of energy. In the meantime, there is mounting daily evidence of the overconsumption and social inequality that result from focusing on a narrow interpretation of the law of conservation of energy and matter (Syal 2022).

The second law of thermodynamics, formulated by Sadi Carnot (1796–1832), James Joule (1818–1889), Rudolf Clausius (1822–1888), William Thomson (1824–1907), Ludwig Boltzmann (1844–1906), and Constantin Caratheodory (1873–1950), maintains that *all systems seek to be in equilibrium*. From this perspective, expending energy and matter is different than the conversion of these forms into equivalent states (Prigogine 1980, 5–12). The first law maintains that the *quantity* of energy and matter does not change during the pressure-driven transformation from one to the other; yet the second law demonstrates that the *quality* of energy and matter is significantly altered in this process through changes in temperature. When heat passes from hotter to colder objects, energy dissipates as it flows from a densely structured, warmer condition toward a less-ordered, cooler condition. So, as coal is burned up to produce steam power, the energy that is expended through temperature loss cannot be recovered and thus cannot be explained by the first law. The ignition of high temperatures in mass production was in wide use in the second Industrial Revolution (1870–1914). The heat that was depleted through

6 A study by Holechek et al. (2022) showed that "in order to attain zero fossil fuel use by 2050, the annual rate of increase in renewable energy production will have to expand 6-fold if energy demand is held constant at the 2020 level and 8-fold if energy demand increases 50% due to increased population and per capita consumption."

the energy-matter conversions of various types of industrial products—in baking ceramics, forming metals, refining crude oil, developing chemicals, drying crops, and processing food—exemplified the energy diffusion and disorder postulated in the principle of entropy. Through the increase and decrease of heat required in the process of economic production, low-entropy energy and matter are ultimately consumed and dispersed as high-energy waste and pollution (C. A. S. Hall and Klitgaard 2018, 71).

In the seventeenth century, Thomas Hobbes (1588–1679) commented on the harsh effects and unceasing disparities of human existence. In justifying the need for centralized government, he observed that the quality of life of a person in the state of nature is "solitary, poor, nasty, brutish, and short," unwittingly identifying the symptoms of entropy in nature and society (Hobbes 1651, pt. 1, ch. 13; Chakrabarty 2021, 217). Beginning in the late eighteenth century, when pollution, resource depletion, and human alienation began to increase through industrialization, some liberal governments proposed that the satisfaction of people's basic needs and the alleviation of personal fear, illness, and disease should become part of governments' guarantee of security, welfare, and justice for their citizens (Daly and Townsend 1993, 55–67).[7] Largely because classical and neoclassical economics could not account for the dissipation of entropy in any form, the idea of maintaining a healthy balance of net energy while compensating for the social and natural imbalances resulting from entropic heat waste became a strong influence in several nineteenth- and twentieth-century governments. These include the United States, England, France, Germany, and Norway.

Proponents of this second law application in economics during the Progressive and world war eras sought to address the debilitating effects of unequal energy exchange, overconsumption, class society, inequality, and ecological destruction (Rifkin 2014, 117–206). Rather than rely on clergy or kings to provide for people's earthly security as in prior eras, the second law of thermodynamics encouraged sovereign governments to foster complex inventions and policies for the public good, as well as social safety nets to protect people from the consequences of entropy. Many innovative products were chartered, developed, or subsidized by modern governments to relieve personal work and stress, provide convenience and entertainment, and foster human communication, understanding, and social betterment. Such inventions include the telegraph, electric motor, light bulb, radio, television, automobile, airplane, satellite, transistor, integrated circuit, computer, and information technology.

During the latter half of the twentieth century, many policymakers sought to counteract the effects of CO_2 pollution and waste from climate change and its impact on social poverty, seeking to relieve the grim aftermath of entropy through public education, health care, economic and social opportunities, pensions, environmental protections, transportation infrastructure, and subsidies for energy businesses. But increasing the quality of life through governmental restrictions on the stocks and flows of energy—from its extraction, production, transport, sale, and distribution to its consumption, waste, and pollution—has had mixed results (Daly and Farley 2011, 51–57; Schiller 1980). Governmental policy measures for keeping entropy low, based on deductive reasoning from the whole to the part, conclude that collective heat waste must be minimized for the sake of personal material well-being. The problem is that governments have no systemic way of measuring many types of energy waste as empirical units on a broad scale. Thus, the second law of thermodynamics, which establishes that the entropy of matter and energy will increase through time, has yet to be administered through steady-state homogeneity or social welfare to address its heat effects, including CO_2 emissions in the atmosphere, pesticides in the soil, microplastics in the oceans, and temperature stress in living beings (Speth 2008, 107–25).

In recent decades, the measures of e*nergy return on energy investment* (EROEI) and *net energy gain* (NEG) were developed.[8] EROEI differs significantly from NEG. EROEI is the usable energy obtained from a source divided by the energy that is required to deliver this energy; and NEG is the energy that remains in surplus after enough energy has been used to extract or produce it (see table 3).

With the rapid spread of industrial production in the nineteenth and twentieth centuries, the first law of pressure conversion and the second law of heat waste have demonstrated that holding entropy as low as possible through a reasonable degree of social care or well-being has been a losing proposition for governments. Preventing harm in society requires more than offering utility or welfare to its citizens. Public taxes end up subsidizing businesses and bailing out banks for their ROI undervaluation of net energy losses through waste and pollution (Gilding, 184–93). As the costs for labor, products, transportation,

7 The urge of an individual to consume latent calories of energy to fuel internal processes and perform physical or mental labor is entropy expressing itself through the organic functions of the human body. This is why, as natural energy is consumed and its temperature declines into a less useful state, the desires of hunger and thirst are felt and experienced within individuals as heat loss, which prompts people to satisfy their physiological needs by eating and drinking.

8 Charles A. S. Hall developed the expression *energy return on investment* (EROI), which refers to energy that nature is "investing" to produce more energy. Because the business term *return on investment* (ROI) refers strictly to the investment of money, EROI can create methodological confusion since the inference is that the value of energy is being measured through benefit-cost accounting. This obscures the fact that energy has its own scientific value in joules and other forms of calibration. For this reason, we use a popular revision of EROI, which is energy return on energy investment (EROEI), which implies that energy may have both a scientific and a financial value depending on how it is computed.

Table 3. Thermonomic Measures of Energy

Thermodynamics	Economic Application	Abbreviation	Measure of Value Today	Sample Unit of Measurement
1st Law	Return on Investment	ROI	Gross Domestic Product	\$5 €5 ¥5 \$2 €2 ¥2 40% 40% 40%
2nd Law	Energy Return on Energy Investment	EROEI	Energy exchange ratio*	3:1
2nd Law	Net Energy Gain	NEG	Energy exchange deficit*	3 joules

EROEI = energy output to society ÷ energy input required to produce the output
NEG = energy output to society — energy input required to produce the output
*Measures used in biophysical economics that are expressed indirectly in fiscal redistribution, trade balance-of-payments, and monetary debt

Table 4. EROEI in US Oil Production and Average Land Surface Temperatures

Year	EROEI Ratio	US Land Temps	US Land Temps
1930	100:1	52.3°F	11.3°C
1970	50:1	52.8°F	11.6°C
2010	10:1	54.5°F	12.5°C
2030 est.	5:1 est.	55.9°F est.	13.3°C est.

EROEI data courtesy of Charles Hall and Kent Klitgaard (2018). Temperature data courtesy of NOAA (NCEI).

infrastructure, social programs, and heat-wave safety rise with increasing entropic waste and disorder, the continuous expenditures for maintaining social order become excessively high. This reveals why government's use of ROI in measuring fiscal redistribution policies, balance of payments deficits in trade, and long-term monetary debt are actually inverse forms of entropic accounting that signify the changes in temperature resulting from energy exchange.

Although governments have yet to discover fiscal tools for tracking energy flows beyond these inverted measures, EROEI and NEG could serve as guideposts for the future management of energy programs that estimate entropic increases over time, such as CO_2 emissions, nitrogen loss, and the heat risk to species. For example, let's examine EROEI as an indicator of the efficiency of oil production in the United States since 1930 (see table 4).

Consider that EROEI—the ratio between the amount of oil available from oil sources in the United States and the amount of oil that is expended to produce more oil—has been steadily declining for nearly a hundred years, during which time average land surface temperatures have increased. Also consider that to be cost-effective at 20 percent ROI, an EROEI no lower than 5:1 is necessary (C. A. S. Hall and Klitgaard 2018, 286, 402). The data in table 4 show that the efficiency of oil production is on a crash course with anthropogenic global warming. Calculations like EROEI are an incisive way of tracking energy conditions and planning ahead, but do not provide in-depth solutions.

NO SYSTEM PERSISTS IN TIME WITHOUT ACCESSING ENERGY: A THIRD LAW?

Since *On the Origin of Species* by Charles Darwin (1809–1882), there have been numerous discussions about the need for a new law of thermodynamics alongside the first law of energy pressure in physics and the second law of energy temperature in chemistry (Allen, Tainter, and Hoekstra 2003, 328–34). While different versions of a third law have appeared in books and on the internet, there is no agreement among scientists. Some of the strongest third law arguments come from the field of biology, where researchers have challenged the idea that the regulation of energy intake through the cells of living systems is primarily a physical action. One leading proposal in this area is the *constructal law* developed by Adrian Bejan, which expresses the biophysical principle of self-ordering and self-sustenance within thermodynamic systems (Bejan and Lorente 2004). This proposition, *no system persists in time without accessing energy*, would account for the sustainability of organic life. While its independence from the first two laws is not fully accepted by physicists and chemists (Georgescu-Roegen 1966, 47–82), common sense suggests that living things have their own form of power. We take it for granted that trees, plants, animals, and people exhibit biological increases in energy throughout their lifetimes. Our ancestors also observed this organic growth, experimented with it, and used it to their advantage in agriculture, reproduction, family life, and personal health (Allen, Tainter, and Hoekstra 2003, 328–34). Nonetheless, a law that explains the metabolic energy inherent in biological life has yet to become an accepted part of a mainstream narrative in science and economics (Snyder 2023). Some of the historical

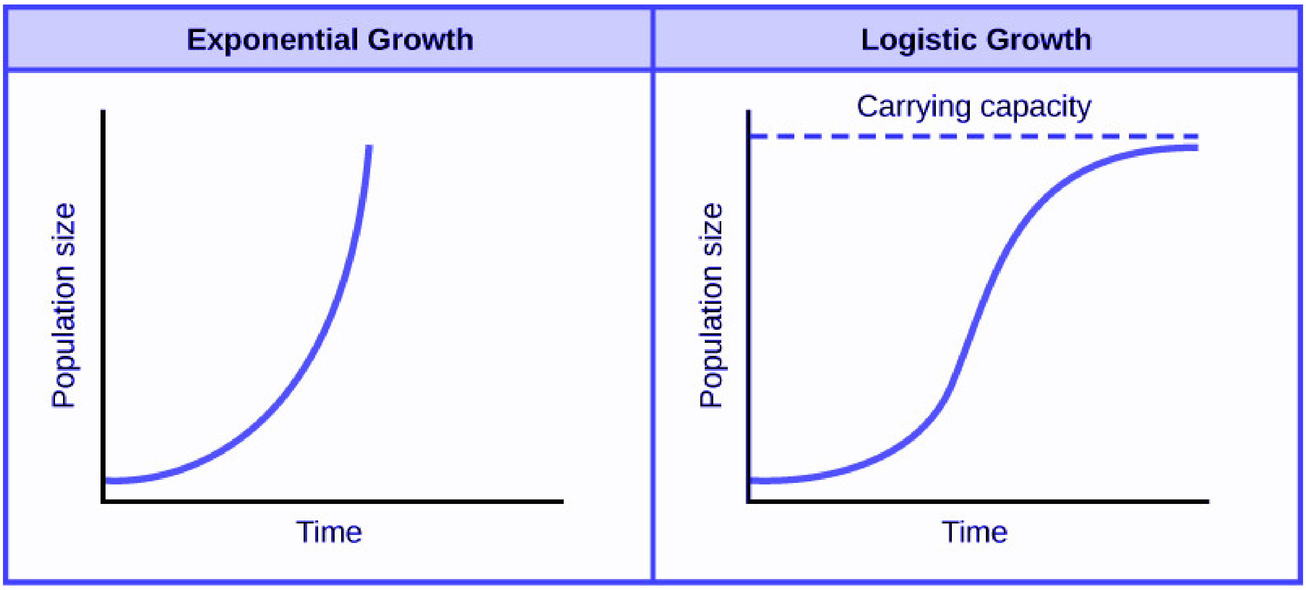

Figure 2. Logistic Growth Curve

From *Handbook of Regression Modeling in People Analytics*, by Keith McNulty. Licensed under Creative Commons Attribution for Non-Commercial Use.

foundations for a third law based in biology are summarized below.

Thomas Malthus (1766–1834) was an English cleric who pioneered ecological evolutionary theory by examining why a population increases faster than its food supply. His views remain controversial. In emphasizing the conservation benefits of smaller families, for example, Malthus may have been promoting population reduction through eugenics. In addition, he underestimated the ways in which the discovery of new lands and new types of energy, transportation, industrial production, and technology would impact the rates of food and population growth. Yet, by applying the principles of population biology that were used for plants and animals directly to human beings, Malthus anticipated the principle of logistic growth: how the size of a population continually modifies its ability to provide enough natural energy for its survival. Pierre François Verhulst (1804–1849) was also a forerunner of this potential third law. In bridging the different domains of organic growth and population needs within a closed system of limited resources, Verhulst was the first to develop a measure of carrying capacity. His logistic growth curve, also known as the Verhulst curve, gave mathematical credence to Malthus's intuition of a dynamic relationship that distinguishes logistic from exponential growth (see figure 2).

Growth begins when a population is small and resources are abundant. As growth increases more rapidly and the population enlarges, the population growth rate becomes exponential. When population size nears the capacity of its environment to sustain it, the competition for resources intensifies and the growth rate slows. Eventually, the population levels off as resources become more limited and growth decreases to zero, indicating a stable population size at its carrying capacity. Thus, in determining a rate of sustainable yield for the natural energy that is consumed by living species, including human beings, the logistic growth curve demonstrates how units of measure from differing domains of analysis can be used to calculate the dynamic balance between the resources available in a habitat and the needs of its population for those resources. For example, the (first law) energy yield of soil within an area could be viewed in relation to the (second law) caloric needs of the population in that same area, indicating the dynamic metabolism (and possible third law) that exists between living bodies and the environment in which they live.

Other proponents of a third law, like Walther Nernst (1864–1941), recognized that because the first two laws constitute an isolated system, any energy exchange between them is bounded or limited. This implies that a third force is at work within bounded ecosystems, a principle that earlier researchers called *negentropy*. This term means that organisms like insects, animals, or humans, despite their exposure to steadily declining temperatures that result in material waste and disorder, continue to create and maintain highly ordered internal structures. Luigi Fantappie (1901–1956) explained why this third law of negentropy is not a "negation" of entropy. Just as Earth adheres to the first law of energy pressure and the second law of energy temperature, the third law establishes the independent conditions for organic growth, enabling the material elements of ecosystems to cohere by utilizing the energy that is available to them. Fantappie called this *syntropy*—the intentionality of living things to self-organize and sustain themselves (Prigogine 1980, 77–90). This self-producing quality of biological life exhibits the principle that *no living system is without energy*. All organisms concentrate radiant energy within their bodies to build resistance to energy dissipation, insulating them from the physical outcomes of entropy and transforming this specific form of sunlight into unique patterns of energy (T-W-Fiennes 1976, 43–56). For example, the natural self-ordering created through photosynthesis occurs through the absorption of solar energy and carbon dioxide by plants and trees, which is transferred indirectly to animals, humans, and other living organisms that consume the biomass of vegetation. This is how emergent, self-organizing systems work in syntropy with the second law that all material things move randomly toward waste and disorder. If a self-organizing physical being were not governed as much by syntropic as entropic qualities, the organism would not live for as long as it does (Prigogine 1980, 103–28).

Mathematical formulas for a third law were further explored by Ludwig Boltzmann (1844–1906), Raymond Pearl (1879–1940), and Lowell Reed (1886–1966) as biophysical activities that can be measured through time. They recognized that the cells and organisms of life-forms are in a long-term process of exchanging energy and matter with their habitats, consuming and dissipating their own forms of entropic waste back into the local environment. This concept was further developed by Alfred J. Lotka (1880–1949), who recognized that the two laws of thermodynamics by themselves could not account for the rate at which energy is used within organisms. Calling this the *maximum power principle*, Lotka explained that the self-regulation of living things involved more than energy pressure and changes in temperature. He demonstrated how the measures of time and power could be used to track the metabolic exchange between the natural energy resources available in an ecosystem and the physiological needs of its population.

In 1953 brothers Eugene Odum (1913–2002) and Howard Odum (1924–2002) examined these biophysical processes in *The Fundamentals of Ecology* (Odum and Barrett 2005). Elaborating on Latka's maximum power principle, Howard Odum developed an *optimum power principle* based on useful energy per unit of time. This focused on the calculation of *transformity*, the rate of available energy of one kind that is needed to obtain a specific rate of energy output of a different kind—for example, the transformation of sunlight into oil, or oil into electricity, or electricity into digital information. Odum demonstrated that besides energy production and energy waste, every living organism exhibits a *rate of metabolic transformation* that self-organizes the sustainability of its system. Thus, for a species to endure, it requires the embedded power or quality of useful energy to sustain it over time. This variable of energy yield is used in the formula of carrying capacity, where K (*Kapazitätsgrenze*) is the capacity limit of the system. Hence, carrying capacity is the optimal rate and efficiency that will allow a species to meet its needs through the specific yield of an energy resource in a bounded area per unit of time.

Odum's work marked a significant turn in the history of carrying capacity as a practical method of computation. First applied in the shipping industry during the eighteenth century, measures for carrying capacity were then used in the 1870s to determine the mass of meat that pack animals could transport, and in the 1880s to estimate the amount of livestock that could be supported within a specific area of land (Sayre 2008, 122). During the late twentieth and early twenty-first centuries, new applications for carrying capacity were introduced in complexity science, demography, agriculture, wildlife and range management, biology, anthropology, engineering, and other fields. Following the 1987 Brundtland Commission report, *Our Common Future*, the field of biophysical economics emerged to study the transformations of natural systems in producing energy and material flows and generating wealth. Carrying capacity has found an audience with social and ecological activists and policymakers who are interested in measuring the metabolic balance of natural resources and the species that depend upon them. Carrying capacity has had its share of critics, but recent innovations in the methodologies and measures of carrying capacity have broadened its range and made the formula, its data, and its applications more accurate.[9]

Perhaps civilization can learn its way forward into a culture of biophysical economics by using the economic applications in table 5 for the governance of Earth's energy systems, where

- Physical energy transfers gradually convert the energy of a periphery (food, wood, or oil) into the matter in a core (goods, buildings, infrastructure), as measured by **ROI**
- Chemical heat transfers from core to periphery with a boost, generates heat waste, and degrades infrastructure and society in both areas, as measured by **NEG** and **EROEI**
- Biological transfers of embodied sunlight within a bounded ecosystem take place adjacent to, but in syntropy with, portions of the core and periphery, as measured by **K**

It appears that the renewal of energy-value will take place only when a framework for energy pressure conversion and entropic heat waste is coalesced within a framework of biophysical metabolism. Supervising these processes on a planetary and a regional basis is essential. In the concluding sections, we propose planetary negotiations for the political regionalization of energy and a transregional campaign for the ecological and economic regeneration of energy resources.

9 Critics of carrying capacity say that the top of the logistic curve does not incorporate the variabilities of population dynamics because only the upper limit of growth is measured, not the dynamic equilibrium of a bounded system (Sayre 2008). But recently, Odum's transformities—the amount of available energy of the same kind needed to obtain a specific output of energy of another kind—have been newly elaborated and improved by Liu et al. (2021), the National Environmental Accounting Database, and others as a standardized continuum of the sunlight quality of various forms of energy, making qualitative energy easier to compute and much more accurate.

Table 5. Thermonomic Measures of Energy

Thermodynamics	Economic Application	Abbreviation	Measure of Value Today	Sample Unit of Measurement
1st Law	Return on Investment	ROI	Gross Domestic Product	\$5 €5 ¥5 \$2 €2 ¥2 40% 40% 40%
2nd Law	Energy Return on Energy Investment	EROEI	Energy exchange ratio*	3:1
2nd Law	Net Energy Gain	NEG	Energy exchange deficit*	3 joules
3rd Law	Carrying Capacity	K	Biophysical metabolism	48%

K = (maximum sustainable yield ÷ resource need per individual) in a bounded area

*Measures used in biophysical economics that are prefigured in fiscal redistribution, trade balance-of-payments, and monetary debt

DEVOLVING SOVEREIGNTY: PLANETARY COOPERATION FOR REGIONAL SELF-ORGANIZATION

As the ecological limits of humanity's demand for energy are crossed and ecosystem deficits expand across the planet, many people are questioning the capacity of state sovereignty to address the relentless disintegration of planetary habitability (Chakrabarty 2021, 196–204; Blake and Gilman 2024, 8–9). The main problem is that sovereign states cannot account empirically for the sources of natural energy that empower their economies because the social data that is measured within their political boundaries is not aligned with the ecological data measured within their ecosystem boundaries (B. J. Cohen 2000, 131–49). The areas don't match. Nations contain ecosystems, but nations are not ecosystems (except for some tiny nations and small island states). Because this data must be computed within a naturally bounded ecosystem, national measurements like energy extraction or economic growth cannot be used to evaluate the carrying capacity of a nation's resources for its population (B. J. Cohen 2008, 214–22).

Little wonder that people are losing trust in their economic and political systems. Nation-states cannot act responsibly because the principle of sovereignty was never designed to measure or allocate the natural energy that empowers their economies. The industrial, technological, and financial forms of state organization that emerged from the first two laws of thermodynamics were intended to guarantee material goods and security to people within their political borders, not to create energy sustainability locally or transregionally within bioregions. This lack of scope and specificity in the measurement of natural borders goes back to the human myth of material progress through economic growth, the vision of agricultural/agro-industrial societies that relied on the transfers of thermodynamic value from a periphery to a core, wherein the energy-value in a periphery is replaced with money in a core. Through two distinct processes, net energy is transported from one physical place to another, and an assigned value for net energy is conveyed from one financial account to another. In this way, the logistic value of net energy in the periphery is turned into exponential exchange-value in the core. Restricted to this rural-urban paradigm, sovereign nations are struggling to foster organic growth and self-sufficiency, limit entropy, and meet the collective needs of their population through existing policies and institutions.

With the clash between China and America, these concerns are being raised across the planet. Both civilizations are rooted in the traditions of aggressive empire building by a core for the financial control and exploitation of the human and natural environment in its periphery (Bonner and Wiggin 2006, 247–72). In their struggle for global dominance, mercantilist China and imperialist America have both attained unprecedented levels of political centralization and economic coercion. For the foreseeable future, we can expect the rising Eastern periphery and waning Western core to continue pushing their exponential use of energy beyond the limits of cost, efficiency, and sustainability, while drawing other nations into their competing political orbits. Instead of slowing the continuous depletion of net energy resulting from their quest for hegemony, the major powers will strain energy resources beyond their capacity and further degrade the planet's infrastructure by unleashing more entropic waste. The twenty-first century may turn out to be the most turbulent era in human history. The world's major multilateral institutions (United Nations, International Monetary Fund, World Bank, World Trade Organization) are withering, and existing forms of sovereign governance are ill-equipped to manage the supply chain inefficiencies, transnational deficits, and massive shortfalls of energy and materials created by deglobalization and the elite overconsumption and financial competition that this generates. No single government, sovereign alliance, or multipolar framework is capable of filling this political and economic vacuum or easing the possibility of confrontation between the superpowers of the twenty-first century.

There is a way forward. Against all odds for peaceful cooperation, China and America are well positioned to transform the global security dialogue of instability and risk into one of planetary protection for regional ecologies. Faced with the stagnation of cross-border trade and investment, and the hazards of isolationism, war, and climate crisis, China and America would consult with all partnering and opposing nations about restructuring, peacefully and orderly, according to the level of resources that their regions can sustain to satisfy the needs of their populations. The superpowers would set an example for other nations by announcing plans to reduce their own resource overshoot through ecological restoration and regeneration, and proposing arrangements for a planetary monetary system based on regional carrying capacity. This is a plea for the ages. Improbably, the Global East and West must not only engage in unprecedented diplomacy to demilitarize and decentralize their political and economic power; they also must extend their generosity and trust across the planet by linking society with ecology through a system of value based on net energy gain. How, indeed?

China, America, their allies, and public authorities come to a bargaining table to review the premise of sovereignty, that a nation should focus on its own domestic affairs and not intervene in the internal politics of another. First, they discuss Earth's decreasing rates of energy availability, the declining quality of energy, its increasing costs, and the dysfunctional sovereign model in which energy and economies are now embedded. They discuss the possibility of transforming sovereignty through a system of energy self-sufficiency for every habitable region in the world. They propose a mutual plan for NEG to safeguard all regional communities from global warming, shrinking habitats, loss of biodiversity, and species extinction. They encourage all nations to decentralize by reengaging with their own places of experience, traditions, cultures, and histories, entrusting their citizens to develop new forms of governance that reconnect regional credit with regional development.

Next, China and America would focus on the development of legal and institutional structures to support this devolution of sovereign authority to citizens. They discuss the formal adoption of *subsidiarity*, where decisions for ecological integrity, energy equity, and economic well-being are made closest to where they have impact (Baslar 1998; Blake and Gilman 2024, 116–38). They discuss how this principle would be the centerpiece of a planetary charter that downsizes the power of sovereign states to the bioregional communities within and between them, allowing these regions the independence to govern their own energy resources. They discuss how this charter could establish a basis on which to negotiate the decentralized practices, systems, and institutions to build trust and cooperation for energy security and sustainable value across the Global East-South and Global West. They discuss how effective citizen management within bioregions would enable nations to cede power to regional bodies, such as stewardship councils or trusteeships, for the protection and generation of sustainable yield in their ecosystems (Brown 2001, 436–45; Cato 2013, 145–81). They discuss how these stewards could be elected by the voters in each region and given power and authority by its nation(s) to measure and maintain a sustainable supply of resources for their bioregion, while making decisions for NEG and energy distribution in coordination with citizens, business, and government (Archibugi 2008, 88–101; B. J. Cohen 2008, 225–40). Lastly, they propose that when bioregional communities cooperate in the development of their habitats by generating their own net energy according to the basic necessities of their population, their subsidiary activities would be supported by a planetary monetary system based on the sustainable value of energy.

ORGANIZING SUBSIDIARITY: A PLANETARY MOVEMENT TO MATCH SUSTAINABLE YIELD WITH HUMAN NEED

Nearly five hundred years ago, the Treaty of Westphalia applied the ancient system of core and periphery to a governance structure, which later evolved into sovereign international law. But managing the real wealth of resources according to their energy potential has never been possible in a core-periphery regime. Today, the planet's steady rise in temperatures, extreme weather, and declines in net energy require a system of logistic growth to maintain the sustainable yield of its habitats, for which few leaders are now prepared (Brown 2003, 131–50). If, as in the past, a core like China/Russia or America/Europe were to establish control of the world's net energy by exploiting their periphery endowed with cheap and plentiful sources of energy, the newly arrived hegemon will immediately encounter the challenges of declining resources, food and water rationing, roaming populations, and overwhelming dissent. The system of core-periphery is decaying, and any attempt to recreate the historical mismatch between hegemon and energy will bring on diminishing returns and autocratic shambles. The next core power would destroy its own capacities in taking on the role of planetary administrator for a new ecological, cultural, social, political, and economic order under daunting emergency conditions.

Yet the passage from global to planetary identity need not be a strategic calamity for businesses, governments, or the public (Chakrabarty 2021, 68–92). It is an opportunity to find new meaning and purpose in a *value-renewed* society that organizes the energy stocks and flows necessary for living beings while generating new forms of political and economic security. The solution is less about a geopolitical balance of power between sovereign states and more about planetary cooperation between each individual government and the people within its regional areas. If China and America seem unlikely or unable to spearhead these initiatives, it's all the more reason for citizens across the world to discuss and organize this new platform for the governance of habitability and biodiversity. If the public will is there, a planetary compromise is within reach.

Decentralizing power from nations to the bioregional communities within and among them may take generations, probably longer, but it must begin in this solemn moment. Creating a planetary framework that integrates the biophysical sciences with social and economic laws and structures requires profound courage and humility. The world community must find its own collective voice and mobilize as never before. We must develop a transdisciplinary movement of coalitions through committed dialogue and action for the stability of our ecosystems and species.

A planetary citizens campaign for energy sufficiency and habitability will call upon the strategic capacities and skills of people and groups from a variety of movements, organizations, and fields. These include governmental leaders; business leaders; scientists; economists; educators; regional planners; civil and environmental engineers; media representatives; artists; indigenous leaders; women's advocates; religious communities; organized labor; social activists; community-based organizations; public utilities; local, state, and national policymakers; and all who recognize that energy and need must empower the production and distribution of wealth, not resource dependency or exchange-value. Developing this planetary citizens movement will also require a transformational curriculum and innovative ways of learning.

Looking back now at the myth of infinite resources and economic growth, the annals of civilized development may be read in a new light. The origin stories of material progress, which taught us to remove energy without restoring it, would now be presented as a narrative for planetary cooperation. Compensating for the planet's diminishing resource base will mean realizing how, throughout our vast history, the value of everyday things we have borrowed from the elements of nature is recounted and repriced over and over to add greater value, but seldom given back to the natural world and reimbursed. Tallying up this collective debt of net energy-value, left unaccounted for countless millennia, will mean returning what we have taken from the biosphere by restoring human credit through conservation, entropy reduction, regeneration, and habitability (Graeber 2011, 386–91). To fulfill this planetary bargain, we must pay back the Earth by renewing our energy resources and turning them into continuous dividends for people and for all of life. Replenishing net energy now to satisfy the needs of the future is how the story begins again.

COMPETING INTERESTS

The author has no competing financial or nonfinancial interests to disclose that are relevant to this material.

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With MAs from Kent State University, Michigan State University, and University of Pennsylvania, James Quilligan began his career as a program supervisor with the United States Labor Department in 1976. In the 1980s–1990s, he worked in various roles as monetary analyst, researcher, publicist, and speechwriter for the Brandt, Palme, Brundtland, Nyerere, and Carlsson-Ramphal commissions, making presentations to committees at the United Nations, US House of Representatives, UK House of Commons, and Council on Foreign Relations. During the 1990s–2000s, Quilligan served as a manager and speechwriter for international organizations including Brandt 21 Forum, Center for Global Negotiations, Globalization for the Common Good, Global Marshall Plan, Commons Cluster at the United Nations, and WANA Forum. With his experience in asset value analysis, he became a monetary consultant for governments in the Middle East and Africa in this same period. In 2000, he began using carrying capacity metrics to calculate the thermodynamic value of monetary currencies within specific bioregions. Over the past two decades, Quilligan's work in biophysical economics has led to positions in management, research, and writing with Maglis El Hassan in Amman, Jordan; Economic Democracy Advocates in the United States; and Center for New Critical Politics and Governance at Aarhus University in Denmark. He is a trainer in carrying capacity measurement, husband, and fitness enthusiast.

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