AN ECOLOGIAL PERSPECTIVE OF WORLD-SYSTEM DYNAMICS

By

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Abstract: The application of ecological principles to human social systems is necessary if we are to properly understand the history and possible future(s) of our species and the biosphere we share. In this paper, I argue that they are also required for understanding world-systemic structures and dynamics, an assertion I support with data on energy production and consumption, CO_2 emissions, GDP, and population, as provided by the International Energy Agency for 2005. The data clearly depict the existence of a distinct core/semiperiphery/periphery hierarchy, consistent with the recent findings of Babones. More germane to this paper, a tiered-structure to the international system of states is predicted by the Eltonian pyramid, which expects to find trophic levels in ecosystems based on energy flow. The hegemon (and the core) in the world-system most efficiently "feeds" on the largest quantity of productive available energy, generating economic growth (negative entropy) while simultaneously stunting the periphery, who both exports that energy to the core and receives the worst effects of the waste (entropy) generated in its transformation.

If the Solar System is slowly dissipating its energies—if the Sun is losing his heat at a rate which will tell in millions of years…if Man and Society are similarly dependent on this supply of energy which is gradually coming to an end; are we not manifestly progressing toward omnipresent death?" That such a state must be the outcome of changes everywhere going on, seems beyond doubt.

~ Herbert Spencer (quoted in Carneiro 1973:93)

As we begin to move through the new millennium, human societies face a number of crises that threaten the future of our species as well as all other life on earth: environmental degradation (e.g., climate change, deforestation, desertification, salinization); water and energy shortages, famine and disease. I believe these apocalyptic signs have their origin in a fractured philosophy—the false dichotomy of man and nature. Its origin can be traced to the emergence of the universal religions in the Axial Age during the first century BCE and their proclamations of human dominion over the earth and the uniqueness of the soul, a message that first appeared in the Hindu scriptures the Upanishades. (Fernández-Armesto 2004). While no doubt it helped bring the wayward lamb into the flock, it is bad science and generates a misrecognition of material reality.[1] It is illogical, incorrect, and dangerous, to believe that the same physical forces and biological/geological processes that affect the non-human world do not apply to *Homo sapiens.* The Darwinian revolution has told us otherwise. And now advances in the natural and social sciences are creating another revolution by pulling back the illusory veil of human uniquenss and (re)placing *Homo sapiens* back in nature. In this question, and also in the one that follows, I will discuss the theory and data that attempt to provide a fuller understanding of the human social world by including our species in the ecosystem(s) we inhabit and then applying the known dynamics from ecology and the

[1] It must be noted that Marx wrote the following: "Men can be distinguished from animals by consciousness, by religion, or by anything else you like. They themselves begin to distinguish themselves from animals as soon as they produce their means of subsistence…" ([1962] 1978: 150).

physics of energy flow. This project, then, can contribute toward a unified theory of the world-system.

Theories about and attempts to uncover the role of energy dynamics in social systems have been around for over a century. Applications of energy flow to the social world have a long history. Marx's idea of social metabolism and the energy "rift" between town and country attempted to understand soil degradation stemming from urbanization and the resultant unequal energy flows, as well as their place of in historical materialism overall (Foster 1999; Burkett and Foster 2006; Moore 2000, 2003).[2] Spencer's incredible passage that began this essay demonstrates that he was clear in his *First Principles*, published in 1862, that increases, and decreases, in the heterogeneity and complexity that formed the basis of his evolutionary laws were constrained by energy flows from the physical through the social world.

Almost a century later, Leslie White (1943) extended Spencer's evolutionary complexity but focused more explicitly on energy:

> Culture is a kind of behavior. And behavior, whether of man, mule, plant, comet or molecule, may be treated as a manifestation of energy. Thus we see, on all levels of reality, that phenomena lend themselves to description and interpretation in terms of energy. (P. 335)

White defines energy as the capacity for performing work, and develops a formula to express the relationship of energy to "human-need-serving product:" E x T = P, where E is the amount of energy expended per capita per unit of time, T is the technological

[2] The extent of Marx and Engels' incorporation of energy dynamics in their historical materialism is debated. On one side are those that discount any ecological or thermodynamic appreciation by Marx and Engels. For example, a common story is that in 1880, Ukranian socialist Sergei Podolinsky wrote to Marx to stimulate his interest in applications of thermodynamics to political economy but Marx failed to comply. Engels later wrote that the "desire to re-import the thermodynamical category of work back into economics"…"is nothing but nonsense" (quoted in Adams 1988:xiv; see also Martinez-Alier 2007). On the other side are Burkett and Foster (2006), among others, who find the "Podolinsky Business" as they call it, to be misunderstood or seriously overstated. They find that Marx, possibly more so than Engels, did apply thermodynamic and energy principles to the study of political economy and to the human-environment relationship.

means of its expenditure, and P is the magnitude of the product per unit of time. By exchanging T for F, the efficiency of the mechanical means with which the energy is expended, and expanding on P as the degree of cultural development, White produces:

> *the* law of cultural evolution: culture develops when the amount of energy harnessed by man per capita per year is increased; or as the efficiency of the technological means of putting this energy to work is increased; or, as both factors are simultaneously increased (P. 338)

It is, then, the ability to efficiently harness increasing amounts of energy that are directly responsible for intra-societal development, as White explains the relative stagnation of "the great civilizations of China, India, Egypt, the Near East, Central America and Peru," they reached limits of growth and transformation of energy. This situation can occur from natural factors such as lack of available resources, or can occur because of the extraction of surplus [stored energy] by the ruling elite, effectively stifling incentive for production and innovation (here White uses China since the Han dynasty as an exemplar). The rise and fall of civilizations, from endogenous causes, is thus a product of energy capture and transformation.

These factors are also at the core of *inter-societal* relations, particularly the conquest of one society of another. In *Evolution and Culture* (1960), Kaplan, in an edited volume with a foreward by White, states "The Law of Cultural Dominance," writing:

> that cultural systems which more effectively exploits the energy resources of a given environment will tend to spread in that environment at the expense of less effective systems. (P. 75)

The view of cultural dominance here is specific to a given environment or niche and is therefore territorial. After noting the possibility of hunting and gathering in resource rich environments outyielding agriculture in others, Kaplan details the fate of both the Plains Indians in the United States at the hands of European agriculturalists and the northern

Chinese from the invading pastoral steppe nomads as equal instances of a society superior in energy management of an environment triumphing over one less effective at the same task.

Energy-dependence in the explanation of the rise and fall of societies is also found in Tainter (1988). Relying on case-studies from archaeological and anthropological data, and following Spencer, Tainter asserts energy flow is necessary for sociopolitical organization and complexity (evinced by larger and heterogeneous societies, with more governmental control over population and provision of defense and distribution of surplus). But rises in complexity, outcomes of institutional responses to perceived problems (what Jonathan Turner (1995) calls "Spencerian selection pressures" for institutional change), require energy and the amount increases together with population size. However, and this is Tainter's key proposition, there are decreasing marginal returns for the cost of each additional unit of complexity. Without new energy acquisitions (often through territorial expansion), increasing costs of complexity occur just to maintain the current level, not growth. If a society does not have excess capacity to handle unexpected stress (climate, invasion, etc.) the system becomes destabilized, weakened and can decline in complexity. Furthermore, the awareness of declining marginal returns to complexity can also lead to a desire to voluntarily reduce it, reducing the services and advantages of being a member of the society, while often increasing taxes to support it, leading to revolt at both the upper and lower strata. Ultimately, energy shortages create less flexibility for complex societies to maneuver when faced with stress. And, in a point stressed by Carneiro (1970), and later Chase-Dunn and Hall (1997), geographic or social circumscription impedes migration. The society collapses.

Tainter can be thought of as transitional between the single-society view of energy dynamics and a world-systems analysis that focuses more on interactions across societies. Podobnik (2006a, 2006b) focuses more explicitly on the latter. In revealing the patterns in the production, transportation, and consumption of primary energy resources that have fueled intra-societal growth and inter-societal competition, Podobnik's unifying concept is an energy shift: "the process whereby a new primary energy resource is harnessed for large-scale human consumption" (p. 4). The resource becomes the basis of an energy regime that includes technology, infrastructure, and the social, economic, and political structures.

He then traces geopolitical rivalry through attempts by city-states and states to obtain energy sources from outside their borders. For example, conquests for wood, one of the earliest primary energy resources, were conducted by fifth-century C.E. Athens, the Roman Empire, and China, India, North Africa, and Western Europe during the pre-modern period. The use of force to obtain energy, or prevent another from it, continued between Britain and France during the Napoleonic Wars and between the powers in WWI and WWII. The winner of these struggles achieved power, wealth, and sometimes hegemony, as the U.S. did by replacing Britain's coal-based dominance by an oil-based system. The losers are consigned to second place, or lower among the hierarchy of nations. Seen in this manner, Podobnik tells the conflict over oil, which pits those who control it or seek to against those struggling to meet their demands, as part of the story of declining U.S. hegemony. Similarly, the future of the world-system will be told as another energy shift, and the success and failure of states to exploit new energy sources as oil availability declines.

Like Podobnik, Bunker and Ciccantell (2005) assign energy flow as a critical factor in hegemonic sequences. They also provide explanations for the material intensification (energy throughput) and the spatial expansion of production and trade, utilizing the concept of generative sectors (technological and organizational innovations various political, economic, and social spheres) and a dialectic of increasing economies of scale in production and diseconomies of space in the extraction and transport of raw materials that have shaped the world-system for at least the last 500 years. The state that has been able to foster the growth of generative sectors has been able to utilize its advantage to reconstitute the world-system in its favor and become the hegemon. Thus, the Dutch did it with wood and ship building in the 17th century, the British with coal that fueled steam engines in factories and on ships in the 19th century, and the United States with timber, iron, copper and rail and steel production in the 20th century. They then explain the rise of Japan as a story of raw material access throughout South Asia and Australia that fueled steel production that coupled with the production of massive ships and deep-water ports to support trade (see also Bunker 1985, 2007).

Hornborg (2001), while surprisingly postmodern in tone, moves from the analysis of the materiality of energy to its chemistry and physics, the direction I need to follow to reveal the full extent of energy dynamics in the world-system. After defining power as "a social relation built on an asymmetrical distribution of resources and risks" (p.1), he explains industrialization as resting on unequal exchange in both ideas and materials. Drawing on classic Marxist concepts of use-value and exchange-value, the laws of thermodynamics, and also from chaos/complexity theory. Hornborg describes the theory that was the impetus for my research in this area. Simply put, there is a transfer of entropy in the energy flows of the world-system. The core states, the most powerful states using Hornborg's definition, are able to increase their wealth (and I would add complexity following Tainter) by importing energy in the form of raw materials from the weaker periphery. The core increases its negative entropy, or order, at the expense of the periphery where entropy, disorder, is increased. Because machine technology is able to create higher exchange values for finished products than the use-values of the materials from which they were transformed, due to what Hornborg calls "machine fetishism" (ibid 84-87), there is a perverse incentive for the wanton exploitation of nature. The process results in the "ecological and socioeconomic impoverishment of the periphery" (p.11).

Following Hornborg, Andre Gunder Frank (2007), in work published posthumously, was developing an application of the concept of entropy to the interactions of core and peripheral states in the world system. Frank contended that imbalances of trade and consequent development in the structure and functioning of the interstate system have, since at least the nineteenth century, allowed powerful states in the global North to import negative entropy and export or transfer entropy to the weaker states in the global South. The North extracted and accumulated capital while the South became the North's social and environmental wasteland.

Both Frank and Hornborg, then, rely on entropy to explain the unequal exchange behind the disparities in financial and ecological wealth that exist in the hierarchy of states in the modern world-system. Since it is such a central concept, it requires a brief primer. The classic statement on entropy, and many of the ideas that are found in what is now called chaos/complexity theory, is found in Georgescu-Roegen (1971). While the First Law of Thermodynamics (the Law of the Conservation of Matter and Energy), stating that matter can be neither created nor destroyed, is likely more famous, but the second law is more germane to understanding the physical and social world. Breaking with the rigidity of Newtonian mechanics, the Entropy Law, as Georgescu-Roegen calls the Second Law, reveals time's arrow and irreversibility by stating that the amount of free energy, that which is "*available* to us for producing some mechanical work" dissipates over time (ibid 5). As energy is used for work, it is transformed from a state of low entropy, or an ordered state that is far from equilibrium, to one that has high entropy, or disorder, a portion of the free energy is lost as heat. The inability to recover the heat energy and convert it to free energy available for work produces time's arrow; energy use is an irreversible process. This is consistent with the First Law because the total energy remains the same: free energy + heat = total energy. Furthermore, because of the dissipative nature of structures not at equilibrium; i.e., they bleed energy over time as they tend toward equilibrium (what is often called heat death), increasing inputs of free energy are necessary to keep the process going (see also Adams 1988; Prigogine and Stengers 1984; Rifkin 1989).

Continuing along these lines, Prigogine (2000) traces the development of complexity in complex adaptive systems, such as human societies. In such systems, there are self-emergent transformations from one state to the next, a process that occurs as energy in a dissipative system is increased to a certain level. The system bifurcates and moves to one of two new levels. It is a discrete jump. (see also Ball 2004; Chaisson 2001, 2004; Gribbin 2004).

The ecologist Paul Colinvaux (1980, see also 1978) asserts a provocative thesis on the success and failure of nations in history. People have habits of reproduction that are similar to most large mammals; we fill available niche space (the profession of the animal) by having as many offspring as can be supported. Energy, utilized as food, is turned into offspring. The history of *Homo* sapiens has been one of periods of increasing food supply, or more correct, increasing available energy, and a corresponding increase in niche space. The transition from hunting and gathering to horticulture and agriculture was a move down the food chain, away from large animals that were rare and toward more abundant and stable plant sources and therefore more available energy.

Moving down the food chain allowed the human population to explode. It also increased population density as people became sedentary, necessitating governance to mange the resources. The government was also often able to increase the carrying capacity of the niche space. But the creation of surplus and control of that surplus by the governors created a wealth elite altered the dynamics of the previously relatively egalitarian societies, creating a small group at the top of the stratification system that required a broad niche space to satisfy their lifestyle, and a mass of peasants at the bottom who occupied the remaining, and much smaller per-capita, niche space. As population increases, as it is prone to do, the wealthy feel it first because of their utilization of the large niche spaces. This, for Colinvaux explains the fates of nations: the wealthy, and later together with the middle-class, will seek trade and conquest in order to maintain their slice of niche space in the face of threatened or real decline. It is the rich nations that are predatory and they seek weaker prey to exploit or conquer. Domestically, the rulers will extract more surplus to fuel their aspirations, the middle classes will revolt under the strain and relative deprivation, while the peasants feel the pressure the least because their niche is so narrow. All will continue reproducing as long as offspring can survive. The state either solves the population pressure by increasing niche space or collapses.

That is how Colinvaux explains national success of failure. But embedded in that argument is a concept he elaborated upon in an earlier work: the Eltonian pyramid (1978). As Colinvaux tells it, the ecologist Charles Elton noticed that artic foxes on St. George Island in the Bering Sea were a “size-jump” larger than their prey, birds. Some of the birds ate insects and worms that were another jump smaller and so on down the food chain. He theorized that this discrete, inverted, pyramid of body size was due to the necessity of being bigger than your prey, both to be able to catch and kill it, to be able to fit it in your mouth and body, and to avoid being eaten by larger predators. He further proposed that the population size of each inhabitant of each step, and therefore the total size of the step, was also a pyramid, but upright, so that the largest animals were at the top, but were the smallest in number. He believed that this was due to breeding strategy, large animals have fewer offspring with a relatively high percentage surviving (what Colinvaux calls the “large-young gambit” but is commonly known as a “K-selected species”), while smaller animals have many offspring, but fewer survive (“small-egg gambit,” or “r-selected species”).

Elton was right about the discrete-stepped pyramids but wrong about the reason why the upright pyramid exists. Breeding strategy is about maximizing surviving offspring but population numbers are set by competition for niche space, as mentioned earlier, not the number of offspring produced. Lindeman and Hutchinson discovered the correct explanation in the 1940s, over a decade after Elton’s pyramid was revealed: the Second-Law of Thermodynamics. In each step up the pyramid of body mass, energy, originally from the sun, is lost to entropy as heat. Plants are only able to fix about one to two percent of the available energy from the sun, and use much of it during respiration, herbivores capture only about ten percent of the plant energy, meat eaters probably less than that percentage of the animals they eat.[3] Large meat eating animals, those at the top of trophic webs, are only able to capture a portion of the total energy in the system. At each step of the food chain, energy is lost due to entropy from the transformation of energy necessary to produce (catch, harvest, cook) and then utilize the energy as nutrition by those at the next higher level. Large animals are only as big as possible to survive in their niche, but no more. Lions cannot get any bigger because their hunting efficiency is low (all other sources of energy use in their niche must be considered as well). Those are the reasons "why big fierce animals are rare." But there are exceptions, such as some very large herbivores (e.g. baleen whales, elephants). The reason for their unpredicted size, as Colinvaux explains, is that they have "cut out the middleman" in the pyramid by eating low on the food chain but are able to support such a large body mass because they are efficient predators. Tyrannosaurus rex crawled.

Tying all of this together results in the following propositions: Niche space and complexity are dependent upon energy, and the expansion of niche space and complexity requires increasing energy supply and/or efficiencies in its transformation. The biggest predators in the world-system, the core states, cannot maintain their standards of living without increasing energy flows (barring population decline). Colinvaux predicts that aggressive war will take place capture resources, and ultimately energy, particularly when the expansion created during the fossil fuel age wanes.

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[3] Colinvaux estimates that wolves on Isle Royale in Lake Superior only about 1.3% of calories theoretically available to them due to the inefficiency of hunting (1980:61-62)

But the core states are the dinosaurs. They are able to maintain a high standard of living by using their power to extract the high-energy resources from the peripheral states and denying the periphery they change to develop. *The core states in this sense have cut out the middleman and are eating low on the food chain, capturing a disproportionate share of the energy in the system*. They are also the lions, feeding at the top of the food chain, as they utilize their power in the international system to maximize the energy throughput, resulting in the creation of high-value commodities and a complex society (negative entropy), while suffering a disproportionate share of the consequences of environmental degradation (entropy). Furthermore, the core must continue to capture energy to support their level of complexity because they are farthest from equilibrium. The poor, low-energy using periphery is much closer to an equilibrium state. The periphery is feeding off of degraded energy, they are receiving the entropy as it moves through the system.

The Eltonian pyramid is thus inverted. If you look at measures of standard of living, there is a small number of very highly ordered states at the top (US, W Europe, with China headed that way) and a large number of disordered states at the bottom (the Global South). Here, the mass is more accurately measured by the ecological footprint, which measures the amount of productive land necessary to generate the resources and store the wastes produced by the economy of a state. If a state was using resources solely from its own land, and its biosphere was absorbing all of its pollution, the footprint would be proportional to its size. But when a state is benefiting from unequal exchange by importing its resources to make up for its own shortfalls and its waste is being absorbed beyond its borders, its footprint becomes disproportionately large (see Wackernagel and Rees 1996).

A body of research supports the existence of this phenomenon. For example, Jorgenson (2003, 2004, 2005) finds that states with large ecological footprints also tend to have relatively lower levels of ecological degradation than those with smaller footprints. Furthermore, Jorgenson and Rice (2005, 2007) have found that non-core countries with high levels of exports to the core (in the latter study using weighted export flows) have lower ecological footprints, suggesting that these countries are sacrificing development while simultaneously suffering a disproportionate share of environmental ills. The core is eating the periphery, or at least their potential energy.

Evidence also comes from Eisenmenger and Giljum (2007), who use material flow accounts and social metabolism studies to demonstrate that unequal trade benefits developed countries through their importation of goods produced through ecologically harmful methods in undeveloped countries. Further, they find that while the undeveloped countries experience the negative ecological effects of extraction, they receive little benefit from their exportation of the goods due to their relatively low-value (see also Bunker 2007; Hornborg 2007; Martinez-Alier 2007; Muradian and Giljum 2007; Weisz 2007).

The hierarchy of size and wealth/power in Colinveaux obtains further theoretical and empirical support from Howard Odum (1996), who provides a number of energy values that are of use as he develops an energy accounting of ecosystems, including human societies. First, he distinguishes between e**n**ergy, like Georgescu-Rogen, as the potential to do work, and "e**m**ergy" (with an "m") as the measure of all previously used energy that went into the transformed product. For example, as discussed by Colinvaux, plants receive energy from the sun, some of which is lost during the process. Emergy measures the captured energy as well as that lost to entropy during its transformation. What is most interesting for resolving the issue of a discrete versus continuous hierarchy is that each step in the transformation of energy from low to high entropy is a decline in order of magnitude. In a simple system such as an aquarium, sunlight enters the system (tank) at 2000 $x10^3$ Joules/day, is reduced by a factor of 1000, to 2 $x10^3$ Joules/day as it is captured by the plants, then an even small amount of energy is released by the plants, . 002 $x10^3$ Joules/day.

A similar phenomenon is exhibited by Giampietro and Pimentel, when looking at measures of energy flow and complexity in human social systems:

Table 1.2 Internal Structure of Different Societies

	Body Size (avg kg)	Population Size	Society Mass (kg)	Pop. Density (persons /ha)	Energy Expenditures (kcal/day/per capita)	Energy Input Needed for Stability	Level of Com-plexity
Chimps	20	8	160	0.002	1500	580	0.00001
Hunters / Gatherers	35	30	1050	0.004	7000	10172	0.0001
Pastoralist	40	30	1200	0.100	10000	14531	0.004
Forest Gardening (village)	40	204	8160	0.250	10000	98812	0.012
Traditional Ag (village)	45	994	49700	3.870	15000	722203	0.28
Japan (whole)	50	117×10^6	5850×10^6	3.250	150000	482×10^9	2.36

Source: Giampietro and Pimentel (1991:136)

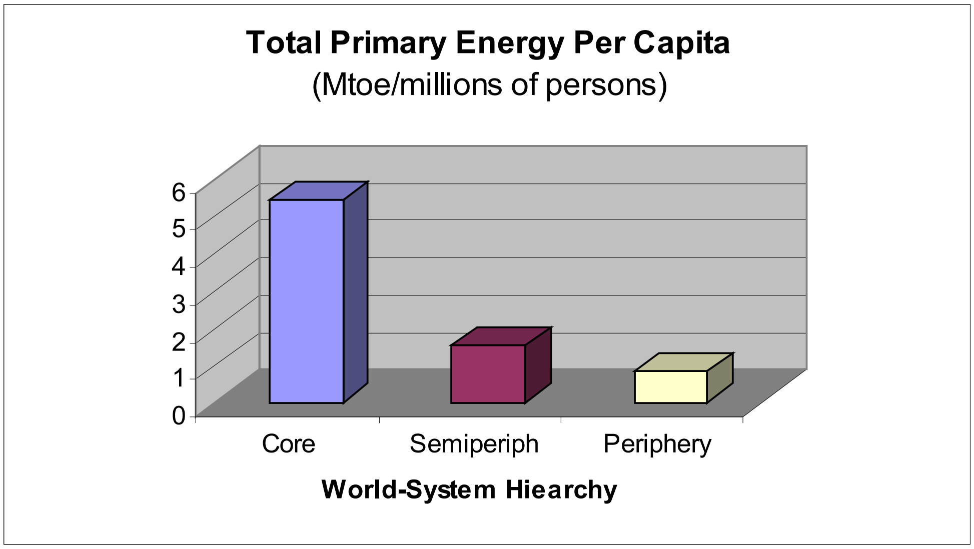
Again, note the discrete steps in the system. The energy needs of the society increase, along with its mass and density. This energy jump is needed to support the increase in complexity, which also increases by orders of magnitude. Similarly, Chase-Dunn et al.

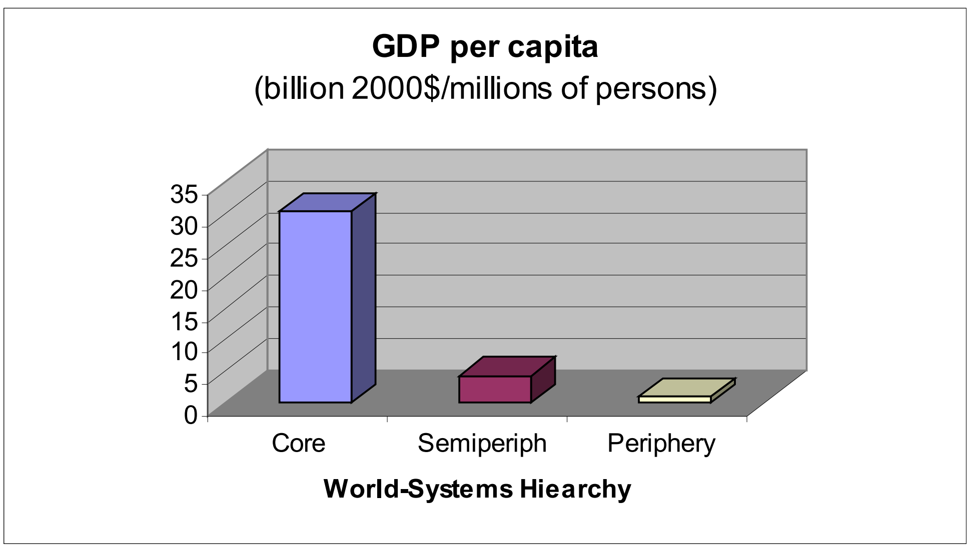
(2008c) have discovered steps in city and empire sizes, a finding that may reflect the ecological/energy dynamics.

There is no reason to believe that the world-system hierarchy would be exceptional. And research is proving that to be the case. Babones (2005), reports evidence of discrete zones of countries in the core, semi-periphery, and periphery by plotting income per capita and population. Furthermore, he finds that the zones are very stable. I have extended Babones' findings to the ecological model, by utilizing the countries in his hierarchy and new data on energy production and consumption (total primary energy supply[4] and total final consumption), CO_2 emissions, GDP, and population from the International Energy Agency (IEA 2007) for the year 2005. Quite simply, I applied the data from the IEA to the countries in the world-system hierarchy that Babones produced. The IEA had information on 51 of those countries [the raw data is available in the attached spreadsheet].

Graphical depictions of the results are provided below. In the first set, GDP, total primary energy supplies, electricity consumption, and CO2 emissions (all per capita) are plotted for each level of the hierarchy.

[4] Total primary energy supply consists of indigenous production + imports – exports – international marine bunkers +/- stock changes. International marine bunkers are quantities delivered to ships engaged in international shipping (IEA 2007).


Total Primary Energy Per Capita
(Mtoe/millions of persons)
6
5
4
3
2
1
0
Core
Semiperiph
Periphery
World-System Hiearchy


GDP per capita
(billion 2000$/millions of persons)
35
30
25
20
15
10
5
0
Core
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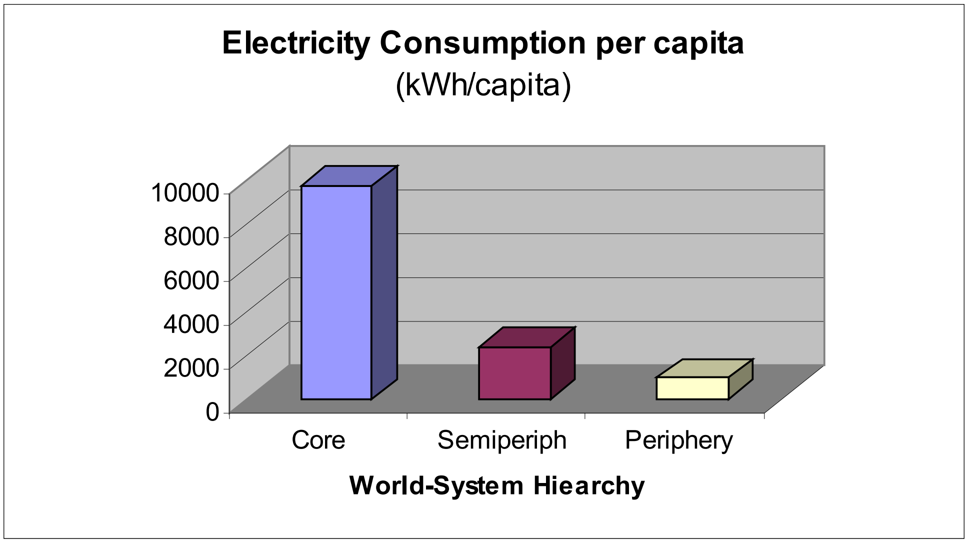
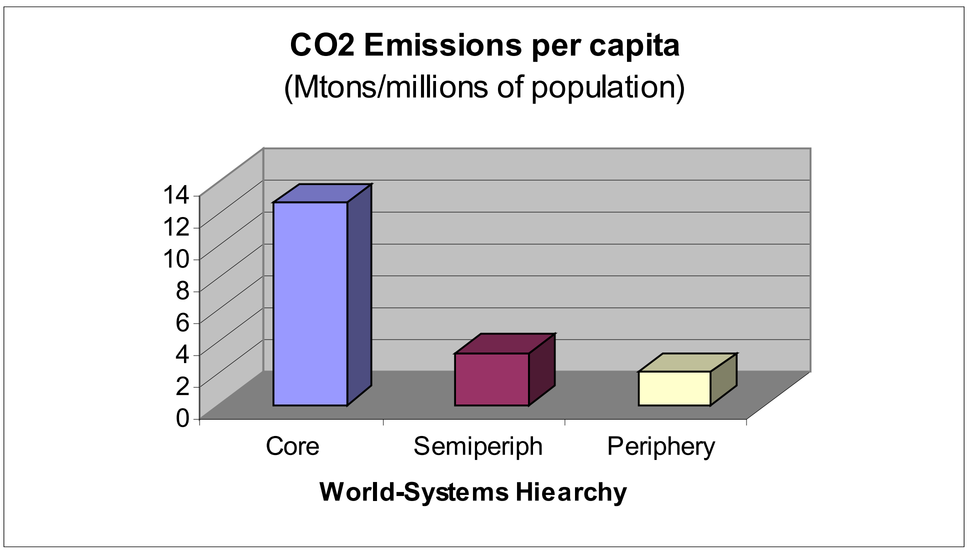
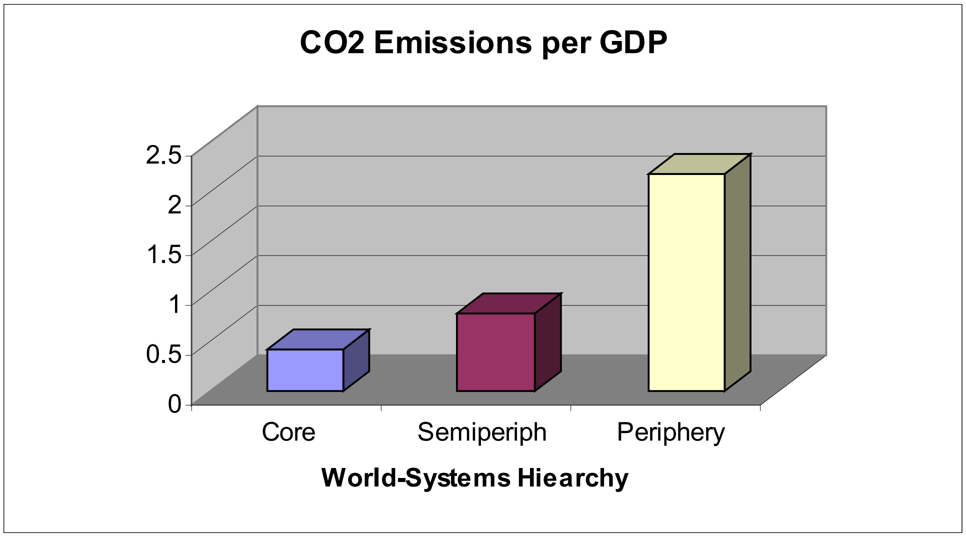
World-Systems Hiearchy

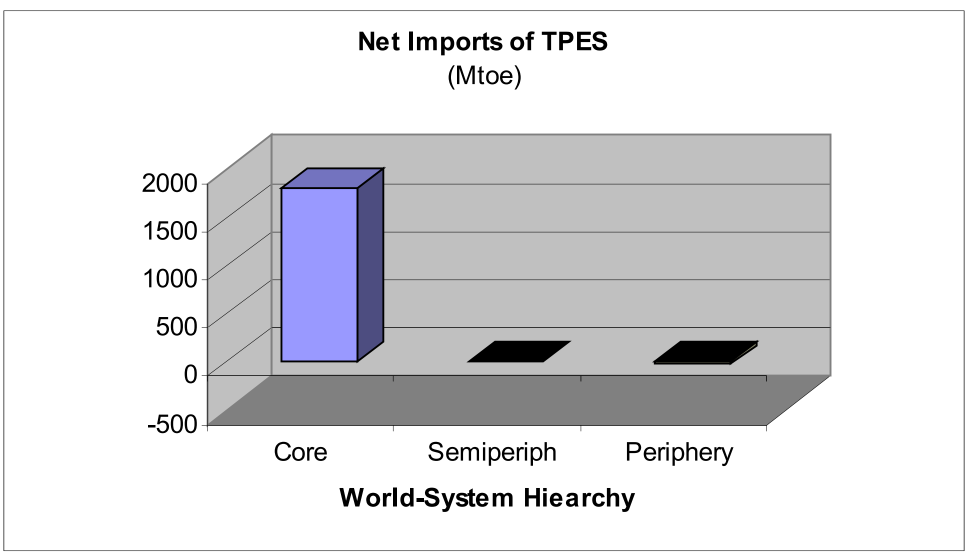

Electricity Consumption per capita
(kWh/capita)
10000
8000
6000
4000
2000
0
Core
Semiperiph
Periphery
World-System Hiearchy


CO2 Emissions per capita
(Mtons/millions of population)
14
12
10
8
6
4
2
0
Core
Semiperiph
Periphery
World-Systems Hiearchy



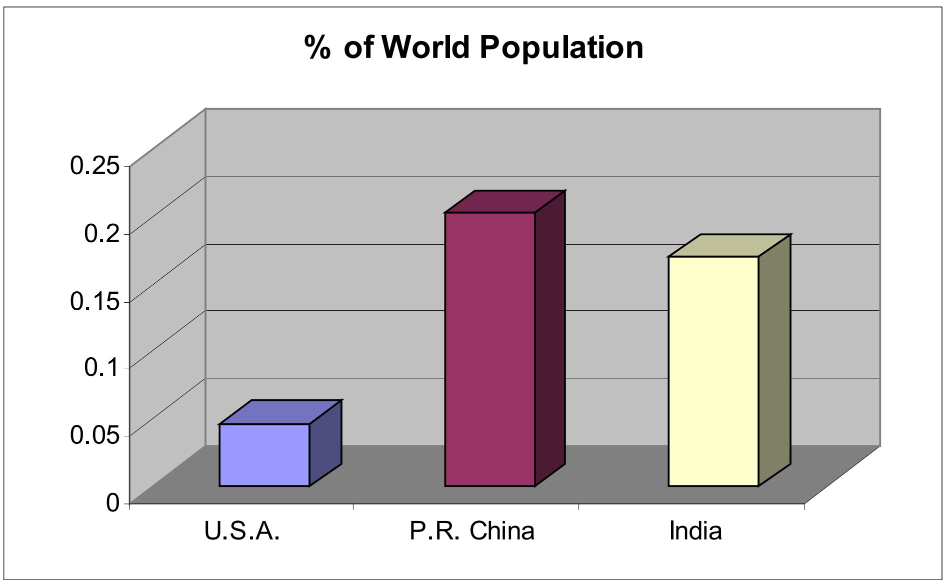
Clearly, the hierarchy is replicated in each measure, although GDP per capita remains markedly lower for the semi-periphery and periphery. As expected, the core has the highest energy supply and is translating that into the highest GDP, both per capita.

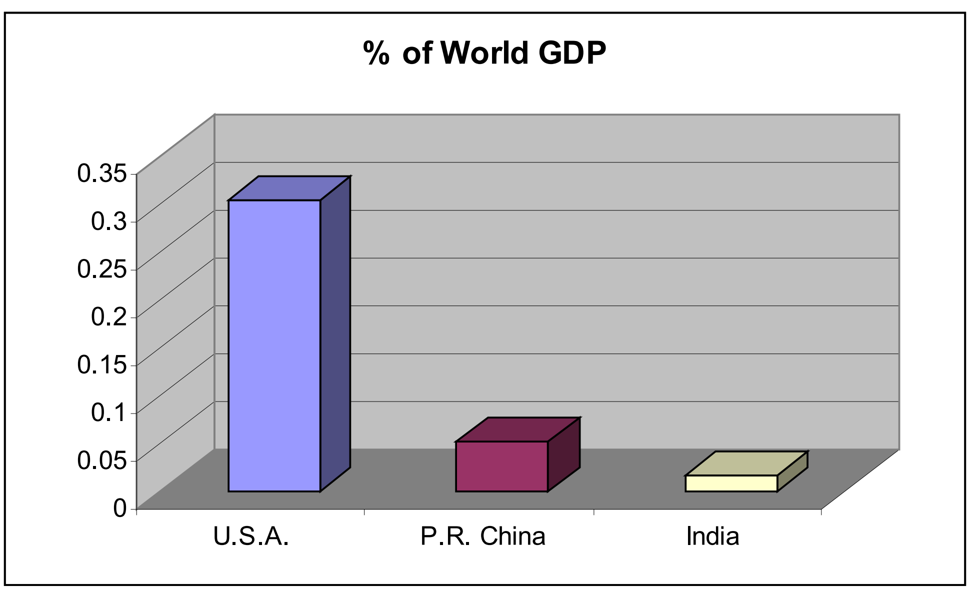
Where is the energy coming from? If you look at net imports, the hierarchy remains, only this time the differences are even more dramatic.

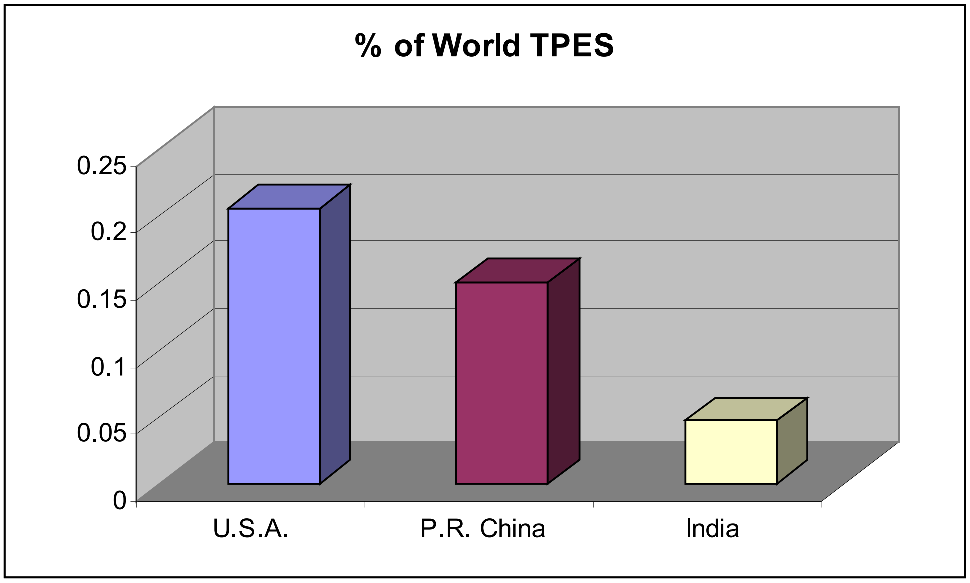


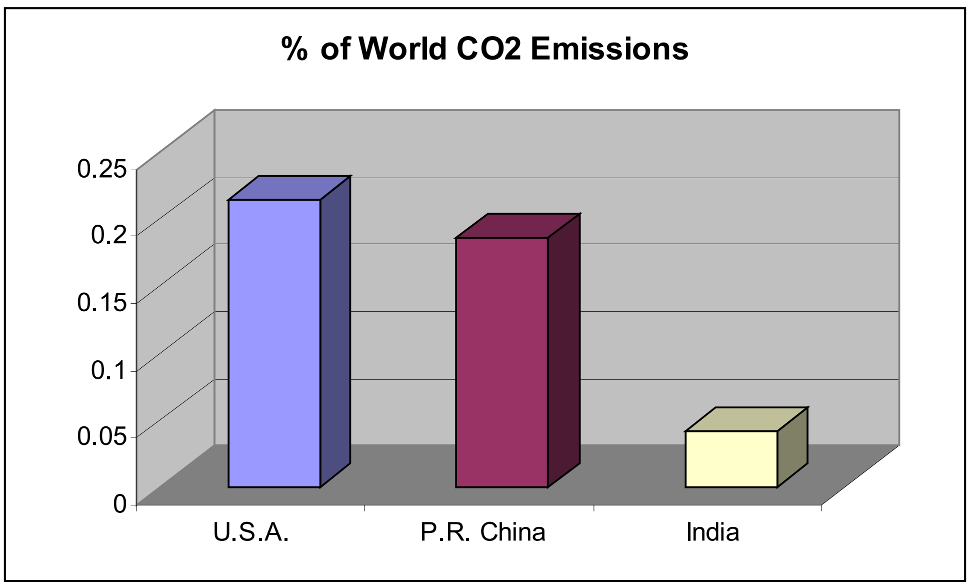
The core is importing a large amount of its energy, and that energy is coming from the semiperiphery and periphery who are exporting their energy.

But the elephants in the room are the United States, China, and India, who distort the international picture due to their population size and related energy throughput. Together, the "big three" account for 42% of the world population, 37% of the world GDP, 40% of TPES, and 44% of CO_2 emissions.









Babones placing both the Peoples Republic of China and India in the periphery, with Hong Kong in the core. I have done the same, but, particularly in the case of China, consideration should be given for locating it at least in the semiperiphery. Its population and energy use clearly place it near the top of the world's nations. Its GDP, however, is still weak compared to the core due to its production of low-value commodities. Moving

China, and to a lesser extent India, from one tier to another would dramatically alter the makeup of the hierarchy.

The analysis provided here is admittedly quite simple, but it does provide initial support for the suggestion that the world-system follows ecological principles, at least energy flow. There is a clear core/semipheriphery/periphery structure and it exists in steps, essentially forming a three-tiered pyramid. Unfortunately, I did not have access to the longitudinal data from the IEA when producing this paper, but hope to attain they information they hold on many countries from 1970. Data going back in time will be more difficult to acquire, but I would like to study energy flows since the Paleolithic. There is also much more that can be done with the data, such as regression analysis of the factors impacting TPES, CO2 and GDP. A "natural" depiction of the hierarchy could also be produced by looking for distinct breaks in the ranked distributions of countries.

Odum's modeling and accounting system are quite complex, and I will need additional time to fully digest them. But he seems to provide the framework necessary to accomplish the task at hand. Simply put, energy values must be assigned to input, transformation, and output, including entropy. This must be done for each step as energy moves through the world-system. Due to unequal exchange and the evidence from the ecological footprint, it will be necessary to trace the origin of energy flows and the location of the sinks. The quantity of energy must be calculated, but also the quality of the energy—its intensity as a measure to perform work—and the effiency of its transformation. I believe that his energy accounting can be manipulated to do just that. Continuing down this path will require further research into the theory of energy dynamics and also the gathering of data on energy values, of which the latter I am currently amassing.

The theories discussed in this essay from ecology and chaos/complexity all point to discrete steps in world-system organization and energy dynamics as the source of inequality between states. The world-system is part of the earth-system and thinking seems to be moving in that direction. I hope that this research can contribute to what Abel (2007) calls for as the need for a reconceptualization of world-systems as “complex human ecosystems” bound according to their energy and material flows. I couldn’t agree more.

Appendix

Babones' Organic World-System*

Core	Semiperiphery	Periphery
Australia	Brazil	Bangladesh
Austria	Chile	Benin
Belgium	Hungary	Bolivia
Canada	Jamaica	Peoples Republic of China
Denmark	Malaysia	Democratic Rep of Congo
Finland	Mexico	Ghana
France	Panama	Haiti
Germany	South Africa	Honduras
Greece	Tunisia	India
Hong Kong (China)	Turkey	Indonesia
Iceland	Uruguay	Kenya
Ireland		Nepal
Israel		Nigeria
Italy		Pakistan
Japan		Philippines
Luxembourg		Senegal
Netherlands		Sri Lanka
New Zealand		Sudan
Norway		Togo
Singapore		Zambia
Spain		
Sweden		
Switzerland		
United Kingdom		
United States		
N = 25	N = 11	N = 20

* Note: Babones had an additional 18 countries that did not appear in the 2005 data from the International Energy Agency, only those listed that appear in both are above and in my analysis. The other countries were: Semipheriphery (Belize, Fiji, Seychelles) and Periphery (Burkina Faso, Burundi, Cent African Repub, Chad, Gambia, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mauritania, Niger, Papua New Guinea, Rwanda, Sierra Leone, Solomon Islands).

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