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COMMENTARY

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Energy systems concepts and self-organization: a rebuttal

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Abstract The following rebuttal concerns energy systems concepts misrepresented in published critiques (Hagen 1992; Golley 1993; Mansson and McGlade 1993; Patten 1993). Commentary here defends the energy systems approach and shows limitations of exergy. The commentary tries to explain why analytic study of parts and mechanisms is only half of basic science. Part of the confusion created by critics lies in trying to describe phenomena at one scale by discussing systems parts separately on a smaller scale. "Straw dummies" (points of view that are misrepresented and thus easily faulted) which are important to ecology are corrected.

Introduction

Mansson and McGlade (1993) tried to review our energy systems concepts, but only cite 7 papers out of 43 on energy concepts (none since 1988). My summary of classical energetics including optimum efficiency for maximum power is in Chapters 7 and 26 in "Systems ecology" (Odum 1983a), republished recently by the University of Colorado Press under its original name "Ecological and general systems" (Odum 1994). Chinese and Indonesian translations were printed in 1993. For the most recent ecological use of our energy systems concepts, I suggest the Springer book on "Ecological microcosms" (Beyers and Odum 1993), which concerns self-organization in ecology. The new energetics is in press with John Wiley: "Environmental accounting, emergy and decision making" (Odum 1995).

Upscale systems synthesis

The energy systems approach synthesizes parts and processes by representing them in network designs, but these are not easily represented with words alone. Much ecological literature, including the Mansson and McGlade (1993) discourse, is a semantic quagmire because systems theories and models were only described verbally. These authors try to discuss energy systems concepts without using the energy systems diagrams in which they are defined. Systems descriptions are ambiguous unless represented by a network language that includes mathematical relationships and energy constraints.

Different people aggregate parts and wholes of systems in different ways. Whether emphasizing measurements or theory, every paper should give the energy systems diagram of the model so that other people can know what was aggregated or omitted at that time for that purpose.

Because traditional disciplinary training in many fields of biology, chemistry, etc., teaches people to concentrate on component mechanisms, they often deny that the system to which they dedicate their interest is part of and controlled by mechanisms of the next larger scale. In the real world, every level of hierarchy (scale) is coupled and controlled by the one larger, which includes, filters, and controls the ones smaller. In self-organization, after an initial uncontrolled growth period where parts are little organized, systems develop larger-scale reinforcement mechanisms. For example, many forests develop tight materials recycle. Because disciplines tend to concentrate on one scale, they may forget that each scale is coupled to and controlled by the next larger one. So long as one works with one relationship at a time, there may be little compulsion to know how these are part of something larger. But until the parts are put together in a system of the next scale, there is little understanding, predictability, or ability to manage.

Energy hierarchy, "emergy", and transformity

System patterns include a universal energy hierarchy in which energy transformations can be arranged in series that depends on the available energy of one kind required

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to form another kind. Energy transformations are hierarchical, since much of the availability of energy from one level is degraded in any work transformation to form a smaller quantity of energy at higher level (second law). Although food chains are the example most familiar to ecologists, the principle of energy hierarchy is apparently universal to all of science. If we accept Lotka's (1922a, b) proposition that self-organization for maximum power is a fourth law, the energy hierarchy principle is probably deserving the status of a fifth energy law.

The core of our work is the transformity ("Emergy" per unit energy) that defines position in universal energy hierarchy. (*Emergy* is the available energy of one kind previously used up directly and indirectly to generate another kind (Odum 1988, 1995).) My presentation at the Second Ecological Congress (Odum 1986) gave numerical ecological examples. Because people were mixing up energy and other embodied energy concepts, we redefined emergy (spelled with an "m") and the emjoule in 1983. Although renamed, this concept had been used in our energy analysis papers since 1966 and in the books "Environment, power, and society" (Odum 1971) and "Energy basis for man and nature" (Odum and Odum 1982; first published in Odum 1976).

The pulsing paradigm emphasized since 1983 includes the hypothesis that pulsing oscillators predominate at all scales simultaneously because they maximize empower. (Rather than production and consumption rising during growth and succession and leveling off at a sustainable level, pulsing is an alternation of production and sharply concentrated consumption, which may be sustainable in the longer run.)

One of our hypotheses is that maximizing empower (rate of *Emergy* production and use) also maximizes power. For example, photosynthesis with flashing light generates more product for the same energy than steady light. Another hypothesis is that adjustments for chaotic fluctuation improve the loading for maximum power.

The weakness of "Exergy" as a measure of work

Mansson and McGlade (1993) suggest that "exergy" is the correct measure of work. Exergy is defined as the sum of the available energies of several kinds. However, energies of different kinds do not do equal work. Much of the confusion comes from the erroneous initial definition often given to students in their first energy course that "energy is the ability to do work." Degraded energy cannot do any work. Nor does work define energy. The operational real definition of energy is the first law, defining a quantity as energy by its degraded heat equivalents, to which energy by definition is 100% convertible.

A joule of whale's work is not equivalent to a joule of phytoplankton work. Much of process analysis and other efforts in current thermodynamic practice is a crude approximation because of the incorrect assumption that energy transformations of different kinds are equivalent work. Available energy is a correct measure of the ability to do work only when energy of one form is concerned.

Dynamite and glucose, with the same available energy (and thus same *Exergy*), are not equivalent. More emergy goes into the making of dynamite than of glucose, and the effect which it can produce in use is greater. Transformations that are selectively retained in systems organization are those that have effects commensurate with what was required in their making.

Straw dummies

The following misrepresentations of my published works need to be corrected so that concepts are not confused.

Types of selection in self organization for maximum power

Mansson and McGlade (1993) refer to reinforcing actions in self-organization as group selection. Not so. During early succession, simple early-Darwinian competitive species selection may occur and contribute to maximum power. I call this self-selection. For example, pioneer weeds may cover the ground in the first year. Later in succession, and described in Darwin's later book (Darwin 1874), network reinforcement loops of high transformity action develop, usually feeding back with multiplicative interactions to increase the system's production and use efficiency. This is not group selection. See, for example, our computer simulations, which show the way alternate pathways are selected by the inherent mathematics of autocatalytic loops, depending on the available energy (Richardson and Odum 1981; Odum 1982). Our computer simulation of evolution of the taxonomic categories shows how to use autocatalytic designs to connect macro-evolution and micro-evolution (Odum 1989, 1995).

Energy is not a currency

In several places the authors state that we want energy to be a "universal currency". Not so. A currency is a counter current of special information (money) that goes in the opposite direction to energy. A main research question in ecological economics concerns the quantitative relationships of currency and energy. Mansson and McGlade (1993) try to use one for the other or think that we do. All our diagrams keep these entirely separate but deal with coupling functions.

Thermodynamic roots

The authors think we are basing concepts on classical thermodynamics, and they spend a lot of paragraphs trying to find or deny a connection. Not so. Closed system equilibrium thermodynamics is not relevant to the open systems of the real world. Our energy systems concepts are new contributions to open system, network thermodynamics.

Energy and materials

The authors say we "equate materials such as scarce resources with energy." Not so. We do evaluate the energy and *Emergy* carried with the matter. The emergy necessary to concentrate a material from its background level is measured as the emergy per unit mass. In an evaluation table we multiply the data on materials flows by the emergy per unit mass to obtain the emergy contribution. Emergy is not energy. A recent paper has network diagrams relating energy, emergy and materials (Odum 1991).

Useful energy

These authors criticize our term "useful energy" as not defined. Not so. An energy transformation pathway is "useful" when its output contributes to the power or efficiency of a production process elsewhere in the system. (Useful is defined in energy systems language when a feedback pathway enters an interaction symbol of a production process.) Bees pollinate flowers. Carnivores may improve genetics of prey. Although there is less energy flow at higher levels in energy hierarchy, these become useful when they feed back with multiplicative, amplifying, often controlling actions.

All aspects of ecosystems covered by energy

The authors say my conjecture is "All significant aspects of ecosystems can be captured by the single concept, energy." Not so. The energy systems approach starts with aggregated diagrams including every aspect of an ecosystem within a module or pathway, so that it can be appropriately related to materials, energy, information, money etc. (Odum 1995). Since everything, even information, has some energy associated, an energy systems network does represent the energy systems hierarchy and the constraints of energy laws.

Energy circuit language

The authors make several errors concerning the energy symbols language:

A. *Modules are linear.* Not so. Most of the modules and the designs are non-linear (multiplicative for the reason given in "Useful energy" above).

B. *Language is for holistic approaches.* Not so. The language is both synthetic (holistic) and analytic (relationships of parts) at the same time.

C. *Language is equivalent to equations.* Not so. The language defines system equations but is stronger than that. As Oster and Auslander (1971) wrote, differential and difference equations alone are ambiguous in regard to systems because there are many different network designs and mechanisms that have the same mathematical equation (when that equation is reduced to its simplest form). To be rigorous about a system, its energy constraints have to be built in. For example, we know of 18 different systems mechanisms which are mathematically logistic. In other words, one cannot be rigorous about systems with equations alone.

Paradigm dependent on the maximum power principle

The authors state that our paradigm relies "totally on the universal validity of the maximum power principle." Not so. It is not essential to the energy systems evaluations and simulations. However, the maximum power principle (better stated now as the maximum empower principle) is a hypothesis that explains much of science. The principle explains the common designs found in diagramming hundreds of systems in many fields. The corollaries of the principle (Odum 1975) are hypotheses about systems designs.

You cannot prove that a principle is general – but it becomes more and more useful if and as more and more areas are found to fit. Those who ignore it may lose years in unnecessary measurements just to find the right hypotheses that the maximum power principle often shows in advance. One of the weaknesses of some empirical science traditions has been the unwillingness to use quantitative theory to define hypotheses a priori.

Hierarchical structures, system boundaries and compartments

These authors attribute to us: "system boundaries and compartments can be simply deduced." Not so. All systems are connected to all other systems. Boundaries in systems diagrams are arbitrary choices the human makes to define his focus. Likewise, compartments are the arbitrary choice of a human mind aggregating the system in a particular way for a particular purpose. However, position in energy hierarchy is given by the transformity, which operationally relates the compartments and boundaries to the real world energy hierarchy.

Succession, biomass, and climax

The authors attribute to me, succession as "culminating in stabilized systems with maximum biomass per unit of available energy." Not so. Succession is one stage in the general plan of pulsing oscillation (see Odum 1983a, Figs. 22-3). I use the word climax for the peak of the oscillation, not a stabilized steady state. Systems develop the biomass necessary to maximize power—not maximum storage. Processes that take more energy than necessary will tend to be displaced by those that do not. That the authors have a confused view of our concepts is shown when they attribute stable climax to us in one place and discuss our pulsing theory in another.

Optimum efficiency for maximum power

The authors say we believe 50% efficiency is universal. They misrepresent our 1955 contribution which has the graphs and equations to show how the efficiency of a single energy storing transformation process varies with loading and energy leakage. If the transformation process is in steady state, maximum power loading is 50% of the available energy. For heat engines this is obtained by multiplying the Carnot ratio (delta T/T Kelvin) by 50%, as given in our original papers which Mansson and McGlade (1993) misquoted. This result has been independently published in a half dozen papers in chemical, physical, and engineering journals. Curiously, the authors don't cite my later discussion paper on this subject (Odum 1983b).

Trophic compartmentalization necessary

Authors say our formulation requires that divisions be made either at the trophic or functional size level. Not so. Energy systems approach applies to any compartmentalization of any system (Odum 1983a, 1995). It has now been applied in hundreds of different kinds of systems, by species, by information, by areas, by materials, by information, by money, etc. Since energy is in everything, there are no restrictions on the approach.

General concepts or analogies

Authors say our results are based on analogies. Not so. It is the other way around. Our energy systems approach is a general systems formulation of which there are examples in each field. There are special cases of the general principles in electrical, mechanical, biological, geological, and economic systems, which is why the various examples are analogous to each other. The energy systems approach allows the designs in one field to be used as hypotheses for another area.

Emergy, transformity operational

Authors say these concepts are not operational, and transformities have a wide range of values. Since they are based on regular scientific data for energy they are as operational as any energy measurement. Thousands of calculations by dozens of people show that transformities of the same entity fall in an order that you expect from their turnover time and territory of support and influence.

Systems diagrams augment mathematics

Some suggestion was made by Patton (1993), in discussing the Mansson and McGlade (1993) discourse, that we substitute network diagrams for mathematics. Not so. Rather they are a new component of mathematics. They are a powerful interface between verbal thinking and mathematics. Applying mathematics to the real world requires systems overview and material and energy constraints. We have worked many years in collaboration with applied mathematician Ben Fusaro, Salisbury State University, Salisbury, Maryland, giving short courses for mathematicians, helping them connect their equations to the real problems through the energy systems language. In this process we also translate the models in equation form back to energy systems diagrams for more insights. That process forces the introduction of the energy and material constraints.

Editors rarely publish computer code, and published simulation papers in ecology don't often give systems models in an understandable form. I suggest an international joint project to convert as many ecological models as are now in fragmented equation form into energy systems diagrams, with the help of each author, so that they can be overviewed, compared and understood.

Thermodynamics from ecology

Ecologists ought to be excited when their science helps develop fundamental paradigms for all science. Our theories, first developed out of ecological study, are being found to be general (Hall 1995). Our *organization of autocatalytic structure for maximum power* is a better and earlier, if reverse but equivalent statement, to Prigogine's *building structure by maximizing dissipation.* Both are maximum power statements. Mansson and McGlade (1993) attack our 1955 paper (Odum and Pinkerton 1955) on maximum power efficiency, misrepresenting its result, and then cite as authority the duplicate derivation much later by Curzon and Ahlborn (1975). Our 1955 result was brought into the thermodynamics literature in a review book by Tribus (1961).

Systems ecology

The discourse and rebuttal discussed here may be a symptom of a widespread antagonism toward systems ecology and the larger scale. At one time the Ecological Society of America refused to form a Systems Ecology section, while forming sections for many other branches. That field has been served by the Society for Ecological Modeling and Systems Ecology and environmental science journals.

Evidence for the differences among ecologists has been recently published in two books: Hagen's (1992) "The entangled bank" and Golley's (1993) "A history of the ecosystem concept in ecology." Both these new historical books seem to reflect an emotional struggle by their authors trying to rationalize the mainstream emphasis on smaller scale ecology as OK.

Usually a system is defined as an arbitrary window of attention that is convenient for synthesizing relationships. Many, who are biologically trained to emphasize organisms, are uncomfortable without a natural boundary. There are two aspects to "systems ecology."

A. One overviews a segment of the environment holistically using overall measures like productivity, energy flow, metabolism, diversity, and nutrient contents. Its models are largely verbal, with emphasis on measured data. This part gets included in elementary ecology books.

B. The complex part of systems ecology connects the parts and processes to the larger whole with mathematical models, network concepts, simulation and emergent properties. This part of systems ecology is left out of most ecology teaching. Partly, there is a different tradition regarding the role of theory.

Realizing that ecology involves several scales of size and time, perhaps it is time for the ecologists whose earlier training emphasized the smaller scale to embrace also the ideals of synthesis, the larger scales, network thinking, and the complex part of systems ecology.

This rebuttal is not intended for systems ecologists who are already advancing that science rapidly with various approaches and languages.

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