Ecosystems (2000) 3: 21–23
DOI: 10.1007/s100210000005

ECOSYSTEMS

The Energetic Basis for Valuation of Ecosystem Services

Howard T. Odum[1] and Eugene P. Odum*[2]

[1]*Environmental Engineering Sciences, University of Florida, Gainesville, Florida 32611;* [2]*Institute of Ecology, University of Georgia, Athens, Georgia 30602, USA*

Key words: valuation; ecosystem services; emergy; energetics.

Valuation is one mechanism by which humans organize occupancy and use of large-scale ecosystems and regions, such as watersheds, estuaries, cities, states, nations, and ultimately the whole earth (the global perspective). When human valuations do not measure the real contributions of natural ecosystems, as is currently the case, ecosystems are not protected, and the larger systems produce less when the natural ecosystems are lost to development. Ecologists working on small-scale studies are concerned with the loss of their study areas and biodiversity. Ecologists working at large scales, and society in general, have to be concerned that poor valuation is delaying the organization of a sustainable pattern of environment and people.

Ecosystems of the world are threatened because market prices are used to evaluate them. As Figure 1 shows, money is only paid to people for their contributions, and not to ecosystems. In fact, market values are inverse to contributions. When soils, wood, and other environmental products are abundant, they contribute the most, but market value is small. When environmental products are scarce, the market value is high. Economic valuation, as currently practiced, can never be used appropriately to evaluate environmental capital, its contributions, or its impacts.

Efforts by economists and others have been made in the last two decades to "internalize the externalities" or to modify market valuation to give more consideration to ecosystems. What is needed is the reverse: to "externalize the internalities" to put the contributions of the economy on the same basis as the work of the environment. We suggest that the best way to do this is to use one kind of energy as the common denominator.

As reviewed by Martinez-Alier (1987), beginning in the middle of the last century investigators have attempted to evaluate environmental products with energy. These attempts failed because different kinds of energies were considered equal. A calorie of sunlight, wind, coal, hydrogen, plants, animals, and people was considered equal, though they definitely are not equal. The early evaluations ignored the natural energy hierarchy of the universe in which many joules of one kind must be degraded to generate a few joules of another. Ecologists are familiar with the food chain example of energy hierarchy and know that a joule of a whale involves more prior work than a joule of phytoplankton.

Also, until recently, mainline economists ignored any suggestions for including nature's goods and services in economic valuation, even suggestions from members of their own profession, such as Kenneth Boulding's (1962) plea for a "reconstruction of economics" in the 1960s. The time had not yet come for reforms.

Starting in 1967, a method of valuation was developed based on the total amount of energy of one kind used directly and indirectly (and by all pathways) necessary to make something. For example, everything in an ecosystem can be expressed in the solar energy used to make each item by various direct and indirect pathways. Thus, fish have higher values per joule than phytoplankton.

The first of these valuations were of agroecosystems and marshes (HT Odum 1967, 1971; EP Odum and HT Odum 1972; Gosselink and others 1974). In 1975, the concept now called "transformity," which measures the quality of energy and its location in

Received 15 June 1999; accepted 4 August 1999.
**Corresponding author; e-mail:* odum@sparc.ecology.uga.edu

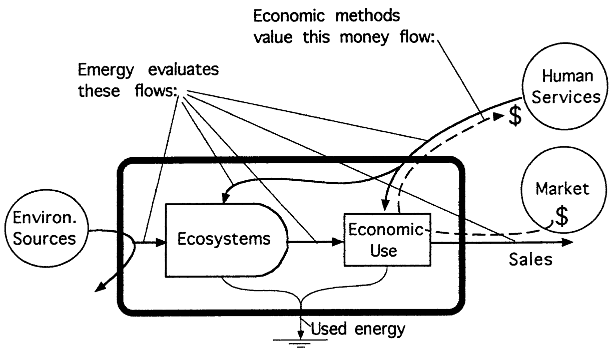

Figure 1. Interface between ecosystems and economics comparing evaluations. Current economic procedures place monetary values only on the market-to-human services flow, whereas Emergy evaluates all of the flows shown.

the energy hierarchy, was introduced in a response at a ceremony in Paris awarding the prize of the Institute De La Vie to the Odum brothers (HT Odum 1975).

In the Gosselink and others (1974) monograph "The value of the tidal marsh," total energy flow or gross production was used as the basis for valuation on the assumption that all the work going on in the marsh estuary provides nonmarket life-supporting goods and services as well as products such as shrimp. Because it takes energy to make money in the market economy, the ratio of gross national product (GNP) and energy consumption was used to convert gross production calories to dollars. The total nonmarket values of the ecosystem in its natural state estimated by these methods were several times greater than value-added market values for fish, shrimp, and oysters.

Dollar values for wetlands calculated in this way (up to $80,000/acre for productive Georgia or Lousiana marsh estuaries) were impressive enough to the general public to play a major role in coastal marsh protection legislation in the early 1970s. However, economists of that day objected strenuously to the energetic approach. They contended that value and price were determined by people's "willingness to pay" and not by the amount of energy required to produce a product or service. We and economists Shabman and Batie engaged in a point–counterpoint discussion of this difference in the pages of the *Coastal Zone Management Journal* (Shabman and Batie 1978; EP Odum 1979; HT Odum 1979).

In a two-year study of a 50-year ecological history of the Georgia, USA landscape (EP Odum and Turner 1990), Turner and others (1988) used energy analysis in a subproject to compare market and nonmarket values for the entire state. Annual nonmarket production of natural ecosystems was estimated to be $2.6 billion, a value comparable to the annual marketed value of agriculture.

In 1983 the term "emergy" (spelled with an "m") suggestive of "energy memory" was proposed to eliminate confusion with other energetic valuation concepts, such as embodied energy and exergy, the latter defined as the sum of available energies of *all* kinds. Emergy, in contrast, expresses all numbers in *one* kind of energy (for example, solar energy) required to produce designated goods and services. Thus, it measures the work of the environment and economy on a common basis.

EMDOLLARS, the economic equivalent of emergy, is defined as the GNP equivalent to emergy contributions (conversion: 1.16 trillion solar emjoules per 1997 US dollar). A recent calculation by Brown and Ulgiati (1999) found two-thirds of the global wealth produced each year to come from emergy of fuel use and one-third from the emergy of renewable energy of nature.

Emergy evaluations appear in more than a hundred publications and include applications to a wide variety of ecosystems, watersheds, alternative technologies, information, species, environmental impacts, states, countries, and causality in history [for example, Swedish power in the 16th century (Sundberg and others 1994); United States Civil War, (Woithe 1994)]. Emergy analysis concepts and literature are summarized in HT Odum's (1988) *Science* article and his 1996 book, *Environmental accounting: EMergy and environmental decision making* (HT Odum, 1996).

Energetic evaluation is a way for ecological data to influence environmental policies. Environmental management that maximizes emergy production and use ("maximum empower") is a way to develop more real wealth in the combined system of humans and environment. The presentations of those using exergy, emergy, energy input–output, and more traditional economic evaluations at a vigorous workshop at Porto Venere, Italy in 1998 have now been published (Ulgiati and others 1999).

In conclusion, timing is of the essence. After several decades of theoretical discussions and many real-world applications, we judge that the time has come for serious consideration of the energetic approach to valuation of ecosystem services and market goods and services on a common basis. As we have emphasized in this commentary, we need not only to extend market valuations to include more consideration of ecosystem services, but ultimately we need to put the economy on the same basis as the work of the environment (that is, externalize the internalities).

REFERENCES

Boulding K. 1962. The reconstruction of economics. New York: Science Editions.

Brown MT, Ulgiati S. 1999. Emergy evaluation of the biosphere and natural capital. Ambio. 28(6):468–493

Gosselink JG, Odum EP, Pope RM. 1974. The value of the tidal marsh. Baton Rouge: Center for Wetland Resources at Louisiana State University. 30 p.

Martinez-Alier J. 1987. Ecological economics. New York: Basil Blackwell. 286 p.

Odum EP. 1979. Rebuttal of "economic value of natural coastal wetlands: a critique." Coastal Zone Manage J 5:231–237.

Odum EP, Odum HT. 1972. Natural areas as necessary components of man's total environment. Washington, DC: Wildlife Management Institute, North American Wildlife and Natural Resources Conference, Proceedings 37.

Odum EP, Turner MG. 1990. The Georgia landscape: a changing resource. In: Zonnevald IS, Forman RTT editors. Changing landscapes: an ecological perspective. New York: Springer-Verlag. p 131–163.

Odum HT. 1967. Energetics of world food production. In: Problems of world food supply. President's Science Advisory Committee Report. Volume 3. Washington, DC: The White House. p 55–94.

Odum HT. 1971. Environment, power, and society. New York: Wiley-Interscience.

Odum HT. 1975. Energy quality and the carrying capacity of the Earth. Trop Ecol 16(1):1–8.

Odum HT. 1979. Principle of environmental energy matching for estimating potential value: a rebuttal. Coastal Zone Manage J 5:239–241.

Odum HT. 1988. Self organization, transformity, and information. Science 242:1132–1139.

Odum HT. 1996. Environmental accounting: EMergy and environmental decision making. New York: John Wiley.

Shabman LA, Batie SS. 1978. Economic value of natural coastal wetlands: a critique. Coastal Zone Manage J 4(3):231–247.

Sunberg JH, Odum HT, Doherty. 1994. Forest energetic basis for Swedish power in the 17th century. Scand J For Res Suppl 1–150.

Turner MG, Odum EP, Costanza R, Springer TM. 1988. Market and nonmarket values of the Georgia landscape. Environ Manage 12(2):209–217.

Ulgiati S, Brown MT, Giampietro M, Herendeen RA, Mayumi K, editors. 1999. Advances in energy studies, energy flows in ecology and economy. Rome: Museum of Science and Scientific Information. 642 p.

Woithe R. 1994. Emergy evaluation of the United States Civil War [dissertation]. Environmental Engineering Sciences, University of Florida. 206 p.