Ecological Economics 1[☆]

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Basic Worldview and Goals

Ecological economics starts with the observation that the human economy is a subsystem of society and the larger ecological life support system. It recognizes that humans are a part of this larger ecological system and not apart from it. Humans have shaped and modified their supporting ecosystems since the time of their appearance as a species, sometimes sustainably, sometimes not. In the past, this human presence (the economic subsystem) was relatively small in scale compared to the size of the rest of the supporting ecosystem. In the last century, due largely to the utilization of fossil fuels, the human subsystem has expanded so dramatically that it is now a major component of the overall system. Unlike the situation in the majority of human history, we now live in a relatively "full" world and have entered a new geologic epoch called the "anthropocene." This changes everything. In a full world context, the goal of the economic subsystem can no longer be simply expansion and growth with little regard to the rest of the system. We must now consider the whole system and the goal must shift from economic growth to sustainable development. Growth implies increasing in quantity or size, while development implies improvement in quality without necessarily increasing in size. In a full world context, the goal must shift from creating "more" to creating "better"—to create a sustainable and desirable future.

This shift in primary goals and vision for the future has profound implications for analysis and policy, across the full range of academic disciplines and human activities. For example, if one's goals include ecological sustainability then one cannot rely on the principle of "consumer sovereignty" on which most conventional economic solutions are based, but must allow for coevolving preferences, technology, and ecosystems. One of the basic organizing principles of ecological economics is thus a focus on this complex interrelationship between ecological sustainability (including system carrying capacity and resilience), social sustainability (including distribution of wealth and rights, social capital, and coevolving preferences), and economic sustainability (including allocative efficiency in the presence of highly incomplete and imperfect markets). The complexity of the many interacting systems that make up the biosphere means that this involves a very high level of uncertainty. Indeed, uncertainty is a fundamental characteristic of all complex systems involving irreversible processes, and ecological economics is particularly concerned with problems of uncertainty. More particularly, it is concerned with the problem of assuring sustainability under uncertainty. Instead of locking ourselves into development paths that may ultimately lead to ecological collapse, ecological economics seeks to maintain the resilience of the highly interconnected socioecological system by conserving and investing in natural and social capital assets in a balanced way with investments in human and built capital.

History

Ecology and economics share the same Greek root, *oikos*, meaning "house." Ecology is, literally, the "study of the house," while economics is the "management of the house," where the house is taken to be the world or any part of it. Thus ecological economics implies studying and managing the world in an integrated way, taking full advantage of our accumulated knowledge and understanding of both the natural and the social parts of the system.

Ecological economics has historical roots as long and deep as any field in economics or the natural sciences, going back to at least the 17th century. Nevertheless, its immediate roots lie in work done in the 1960s and the 1970s. Kenneth Boulding's classic *The Economics of the Coming Spaceship Earth* set the stage for ecological economics with its description of the transition from the "frontier economics" of the past, where growth in human welfare implied growth in material consumption, to the "spaceship economics" of the future, where growth in welfare can no longer be fueled by growth in material consumption. This fundamental difference in vision and worldview was elaborated further by Herman Daly, who in 1968 recast economics as a life science, akin to biology and especially ecology, rather than a physical science like chemistry or physics. The importance of this shift in "preanalytic vision" cannot be overemphasized. It implies a fundamental change in the perception of the problems of resource allocation and how such problems should be addressed. More particularly, it implies that the focus of analysis should be shifted from marketed resources in the economic system to the biophysical basis of interdependent ecological and economic systems and their coevolution over time.

Ecological economics is not, however, a single new paradigm based on shared assumptions and theory. It is instead a "metaparadigm." Rather than espousing and defending a single discipline or paradigm, it seeks to allow a broad, pluralistic range of viewpoints and models to be represented, compared, and ultimately synthesized into a richer understanding of the inherently complex systems it deals with. It represents a commitment among economists, ecologists, and other academics and practitioners to

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learn from each other, to explore new patterns of thinking together, and to facilitate the derivation and implementation of effective economic and environmental policies. Ecological economics is deliberately and consciously pluralistic in its conceptual underpinnings. Within this pluralistic metaparadigm, traditional disciplinary perspectives are perfectly valid "as part of the mix." Ecological economics therefore includes some aspects of neoclassical environmental economics, traditional ecology, and ecological impact studies, and several other disciplinary perspectives as components, but it also encourages completely new, more integrated ways to think about the linkages between ecological and economic systems.

Ecological economics has also developed a solid institutional base. After numerous experiments with joint meetings between economists and ecologists, the International Society for Ecological Economics (ISEE) was formed in 1988 and currently has over 3000 members worldwide. The journal of the society, *Ecological Economics*, published its first issue in February 1989 and is currently publishing 12 issues per year, with an impact factor taking it to the top one-fifth of all economics and all environmental journals. Major international conferences have been held since 1990, with attendance reaching as high as 1500. Several ecological economic institutes have been formed around the world, a significant number of books have appeared with the term ecological economics in their titles, and a fair number of university courses, certificate programs, and graduate degree programs have also developed.

Links With Natural Sciences

Ecological economics' explicit links with the natural sciences result in a more scientific approach, which is inherently more pluralistic and empirically grounded. It places humans and human behavior in a broader historical, evolutionary, and ecological context. Humans are seen as a part of the natural world, not abstractions in isolation from nature and each other. It is problem-based, not tool-based, and its methods include any that are applicable to the problems at hand. These include everything from participatory processes to envisioning alternative futures to complex systems simulation modeling. It recognizes the importance of envisioning and the limits of the positive-normative dichotomy. It goes well beyond interdisciplinary dialog. It aspires to be a truly transdisciplinary science.

The broad spectrum of relationships between ecosystems and economic systems is the locus of many of our most pressing current problems (i.e., sustainability, climate disruption, species extinction, income and wealth distribution) but it is not covered adequately by any existing discipline. Environmental and resource economics, as they are usually practiced, are subdisciplines of neoclassical economics focused on the efficient allocation of scarce environmental resources but generally ignoring ecosystem dynamics and scale issues, and paying only scant attention to wealth distribution issues. Ecology, as it has historically been practiced, sometimes dealt with human impacts on ecosystems, but the more common tendency was to stick to "natural" systems and exclude humans.

Ecological economics also focuses on a broader set of questions and goals than the traditional disciplines. Here, again, the differences are not so much the newness of the questions or goals, but rather the attempt to integrate them. They can be stated as both questions and goals, since they represent both complex questions requiring further research to fully understand and goals that most people would agree are worthy of the title:

1. Assessing and insuring that the scale of human activities within the biosphere are ecologically sustainable; how do we stay within the biophysical planetary boundaries?
2. Distributing resources and property rights fairly, both within the current generation of humans and between this and future generations, and also between humans and other species; and
3. Efficiently allocating resources as constrained and defined by (1) and (2) above, including both marketed and non-marketed resources, especially social and natural capital and ecosystem services.

These questions/goals are interdependent and yet need to be addressed hierarchically. The problem of ecological sustainability needs to be solved at the level of preferences or technology, not at the level of optimal prices. Only if the preferences and production possibility sets informing economic behavior are ecologically sustainable can the corresponding set of optimal and intertemporally efficient prices be ecologically sustainable. Thus the principle of "consumer sovereignty" on which most conventional economic solutions are based is only acceptable to the extent that consumer interests do not threaten the overall system, and through this the welfare of future generations. This implies that if one's goals include ecological and social sustainability then one cannot rely on consumer sovereignty, and must allow for coevolving preferences, technology, and ecosystems.

Material and Energy Flows

One focus of the work on joint ecological economic systems has been material and energy flows. A dominant theme in this body of work has been the grounding of conventional economic models in the biophysical realities of the economic process. This emphasis shifts the focus from exchange to the production of wealth itself. Cleveland traces the early roots of this work dating back to the physiocrats. The energy and environmental events of the 1960s and the 1970s pushed work in this area to new levels. Energy and material flow analysis in recent times is rooted in the work of a number of economists, ecologists, and physicists. Economists such as Boulding and Geogescu-Roegen demonstrated the environmental and economic implications of the mass and energy balance principle. Ecologists such as Lotka and H. T. Odum pointed out the importance of energy in the structure and evolutionary dynamics of ecological and economic systems. And physicists such as Prigogine worked out the far-from-equilibrium thermodynamics of living systems.

The principle of the conservation of mass and energy has formed the basis for a number of important contributions. The assumption was first made explicit in the context of a general equilibrium model by Ayres and Kneese and subsequently by Mäler, but it also is a feature of the series of linear models developed after 1966. All reflect the assumption that a closed physical system must satisfy the conservation of mass condition, and hence that economic growth necessarily increases both the extraction of environmental resources and the volume of waste deposited in the environment.

Perrings developed a variant of the Neumann–Leontief–Sraffa general equilibrium model in the context of a jointly determined economy–environment system subject to a conservation of mass constraint. The model demonstrates that the conservation of mass contradicts the free disposal, free gifts, and noninnovation assumptions of such models. An expanding economy causes continuous disequilibrating change in the environment. Since market prices in an interdependent economy–environment system often do not accurately reflect environmental change, such transformations of the environment often will go unanticipated.

Ayres described some of the important implications of the laws of thermodynamics for the production process, including the limits they place on the substitution of human capital for natural capital and the ability of technical change to offset the depletion or degradation of natural capital. Although they may be substitutes in individual processes in the short run, natural capital and human-made capital ultimately are complements, because both manufactured and human capital require materials and energy for their own production and maintenance. The interpretation of traditional production functions such as the Cobb–Douglas or constant elasticity of substitution (CES) must be modified to avoid the erroneous conclusion that "self-generating technological change" can maintain a constant output with ever-decreasing amounts of energy and materials as long as ever-increasing amounts of human capital are available.

Furthermore, there are irreducible thermodynamic minimum amounts of energy and materials required to produce a unit of output that technical change cannot alter. In sectors that are largely concerned with processing and/or fabricating materials, technical change is subject to diminishing returns as it approaches these thermodynamic minimums. Ruth uses equilibrium and nonequilibrium thermodynamics to describe the materials–energy–information relationship in the biosphere and in economic systems. In addition to illuminating the boundaries for material and energy conversions in economic systems, thermodynamic assessments of material and energy flows, particularly in the case of effluents, can provide information about depletion and degradation that are not reflected in market price.

There is also the effect of the time rate of thermodynamic processes on their efficiency, and, more importantly, their power or rate of doing useful work. H. T. Odum and Pinkerton pointed out that to achieve the thermodynamic minimum energy requirements for a process implied running the process infinitely slowly. This means at a rate of production of useful work (power) of zero. Both ecological and economic systems must do useful work in order to compete and survive, and H. T. Odum and Pinkerton showed that for maximum power production an efficiency significantly worse than the thermodynamic minimum was required.

These biophysical foundations have been incorporated into models of natural resource supply and of the relationship between energy use and economic performance. Cleveland and Kaufmann developed econometric models that explicitly represent and integrate the geologic, economic, and political forces that determine the supply of oil in the United States. Those models are superior in explaining the historical record than those from any single discipline. Larsson et al. also use energy and material flows to demonstrate the dependence of a renewable resource such as commercial shrimp farming on the services generated by marine and agricultural ecosystems.

One important advance generated by this work is the economic importance of energy quality, namely, that a kilocalorie of primary electricity can produce more output than a kilocalorie of oil, a kilocalorie of oil can produce more output than a kilocalorie of coal, and so on. H. T. Odum describes how energy use in ecological and economic hierarchies tends to increase the quality of energy, and that significant amounts of energy are dissipated to produce higher-quality forms that perform critical control and feedback functions which enhance the survival of the system. Cleveland et al. and Kaufmann show that much of the decline in the energy/real GDP ratio in industrial nations is due to the shift from coal to petroleum and primary electricity. Their results show that autonomous energy-saving technical change has had little, if any, effect on the energy/real GDP ratio. Stern finds that accounting for fuel quality produces an unambiguous causal connection between energy use and economic growth in the United States, confirming the unique, critical role that energy plays in the production of material wealth.

The analysis of energy flows has also been used to illuminate the structure of ecosystems. Hannon applied input–output analysis (originally developed to study interdependence in economies) to the analysis of energy flow in ecosystems. This approach quantifies the direct plus indirect energy that connects an ecosystem component to the remainder of the ecosystem. Hannon demonstrates this methodology using energy flow data from the classic study of the Silver Springs (Florida) food web. These approaches hold the possibility of treating ecological and economic systems in the same conceptual framework, one of the primary goals of ecological economics.

Accounting for Natural Capital, Ecological Limits, and Sustainable Scale

Most current economic policies are largely based on the underlying assumption of continuing and unlimited material economic growth. Although this assumption is slowly beginning to change as the full implications of a commitment to sustainability sink in, it is still deeply embedded in economic thinking as evidenced by the frequent (but mistaken) equation of "sustainable development" with "sustainable growth." The growth assumption allows problems of intergenerational, intragenerational, and interspecies equity and sustainability to be ignored (or at least postponed), since they are seen to be most easily solved by additional material growth. Indeed, most conventional economists define "health" in an economy as a stable and high "rate of growth." Energy and resource depletion, pollution, and other planetary boundaries and limits to growth, according to this view, will be eliminated as they arise by clever development and deployment of new technology. The assumption is that we can completely "decouple" the economy from environmental impacts. This line of thinking often is called "technological optimism."

An opposing line of thought (often called "technological skepticism") assumes that technology will not be able to circumvent fundamental energy, resource, or pollution constraints and that eventually material economic growth will need to stop. It has usually been ecologists or other life scientists that take this point of view (notable exceptions among economists are Boulding and Daly), largely because they study natural systems that invariably do stop growing when they reach fundamental resource constraints. A healthy ecosystem is one that maintains a relatively stable level. Unlimited growth is cancerous, not healthy, under this view.

Technological optimists argue that human systems are fundamentally different from other natural systems because of human intelligence and that history has shown that resource constraints can be circumvented by new ideas. They claim that Malthus' dire predictions about population pressures have not come to pass and the "energy crisis" of the late 1970s is behind us. Technological skeptics, on the other hand, argue that many natural systems also have "intelligence" in that they can evolve new behaviors and organisms (including humans themselves). Humans are therefore a part of nature, not apart from it. Just because we have circumvented local and artificial resource constraints in the past does not mean we can circumvent the fundamental ones that we will eventually face. Malthus' predictions have not come to pass yet for the entire world, the skeptics would argue, but many parts of the world are in a Malthusian trap now, and other parts may well fall into it. This is particularly important because many industrial nations have increased their numbers and standard of living by importing carrying capacity and exporting ecological degradation to other regions.

The debate has gone on for several decades now. It began with Barnett and Morse's *Scarcity and Growth* in 1963, but really got into high gear only with the publication of *The Limits to Growth* by Meadows et al. in 1972 and the Arab oil embargo in 1973. Several thousand studies over the last 45 years have considered aspects of our energy and resource future, and different points of view have waxed and waned. But the bottom line is that there is still considerable uncertainty about the impacts of energy and resource constraints. We have already hit real fossil fuel limits, not so much because of supply constraints but because of their impacts on climate. Will fusion energy or solar energy or conservation or some as yet unthought of energy source step in to save the day and keep economies growing? The technological optimists say "yes" and the technological skeptics say "maybe." Certainly we can "decarbonize" the economy by shifting to solar and wind energy to deal with climate impacts. The price of these sources have dropped dramatically in recent years. They could certainly sustain a steady state economy with vastly improved quality of life and wellbeing, but whether they could sustain a materially growing economy on a finite planet is another question.

The more specific issues of concern all revolve around the question of limits: the ability of technology to circumvent them, and the long-run costs of the technological "cures." Do we adapt to limits with technologies that have potentially large but uncertain future environmental costs or do we limit population and per capita consumption to levels sustainable with technologies which are known to be more environmentally benign? Must we always increase supply or can we also reduce demand? Is there an optimal mix of the two?

Issues of sustainability are ultimately issues about limits. If material economic growth is sustainable indefinitely by technology then all environmental problems can (in theory at least) be fixed technologically. Issues of fairness, equity, and distribution (between subgroups and generations of our species and between our species and others) are also issues of limits. We do not have to worry so much about how an expanding pie is divided, but a constant or shrinking pie presents real problems. Finally, dealing with uncertainty about limits is the fundamental issue. If we are unsure about future limits the prudent course is to assume they exist. One does not run blindly through a dark landscape that may contain crevasses. One assumes they are there and goes gingerly and with eyes wide open, at least until one can see a little better.

Vitousek et al., in an oft-cited paper, calculated the percent of the Earth's Net Primary Production (NPP) which is being appropriated by humans. This was the first attempt to estimate the "scale" or relative size of human economic activity compared to the ecological life-support system. They estimated that 25% of total NPP (including the oceans) and 40% of terrestrial NPP was currently being appropriated by humans. It left open the question of how much of NPP could be appropriated by humans without damaging the life-support functions of the biosphere, but it is clear that 100% is not sustainable and even the 40% of terrestrial NPP currently used may not be sustainable.

A related idea is that ecosystems represent a form of capital—defined as a stock yielding a flow of services—and that this stock of "natural capital" needs to be maintained intact independently in order to assure ecological sustainability. The question of whether natural capital needs to be maintained independently ("strong sustainability") or whether only the total of all capital stocks need to be maintained ("weak sustainability") has been the subject of some debate. It hinges on the degree to which human-made capital can substitute for natural capital, and, indeed, on how one defines capital generally. In general, conventional economists have argued that there is almost perfect substitutability between natural and human-made capital, while ecological economists generally argue on both theoretical and empirical grounds that the possibilities for substitution are severely limited. They therefore generally favor the strong sustainability position.

Another critical set of issues revolve around the way we define economic income, economic welfare, and total human welfare or wellbeing. Daly and Cobb clearly distinguish these concepts, and point out that conventional GDP is a poor measure even of economic income. Yet GDP continues to be used in most policy discussions as the definitive measure of economic health and performance, and will continue to be until viable alternatives are available. According to Hicks, economic income is defined as the quantity we can consume without damaging our future consumption possibilities. This definition of income automatically embodies the idea of sustainability. GDP is a poor measure of income on a number of grounds, including the fact that it fails to account for the depletion of natural capital and thus is not “sustainable” income in the Hickian sense. GDP is an even poorer measure of economic welfare, since many components of welfare are not directly related to income and consumption. The Index of Sustainable Economic Welfare (ISEW) devised by Daly and Cobb (and its renamed, but almost identical successor, the Genuine Progress Indicator (GPI)) is one approach to estimating economic welfare (as distinct from income). GPI starts with Personal Consumption Expenditures (a major component of GDP) but adjusts them using 24 different components, including income distribution, environmental costs, and negative activities like crime and pollution, among others. GPI also adds positive components left out of GDP, including the benefits of volunteering and household work. By separating activities that diminish welfare from those that enhance it, GPI better approximates sustainable economic welfare. However GPI is not the perfect indicator of societal wellbeing and needs to be viewed alongside biophysical and other indicators.

Past national GPI studies have indicated that in many countries, beyond a certain point, GDP growth no longer correlates with increased economic welfare. An important function of GPI is to send up a red flag at that point. Since it is made up of many benefit and cost components, it also allows for the identification of which factors increase or decrease economic welfare. Other indicators are better guides of specific aspects.

For example, Life Satisfaction is a better measure of overall self-reported wellbeing. By observing the change in individual benefit and cost components, GPI reveals which factors cause economic welfare to rise or fall even if it does not always indicate what the driving forces are behind this. It can account for the underlying patterns of resource consumption, for example, but may not pick up the self-reinforcing evolution of markets or political power that drives change.

Valuation of Ecological Services

All decisions concerning the allocation of environmental resources imply the valuation of those resources. Ecological economics does not eschew valuation. It is recognized that the decisions we make, as a society, about ecosystems imply a valuation of those systems. We can choose to make these valuations explicit or not; we can undertake them using the best available ecological science and understanding or not; we can do them with an explicit acknowledgment of the huge uncertainties involved or not; but as long as we are forced to make choices about the use of resources we are valuing those resources. These values will reflect differences in the underlying worldview and culture of which we are a part, just as they will reflect differences in preferences, technology, assets, and income. An ecological economics approach to valuation implies an assessment of the spatial and temporal dynamics of ecosystem services, and their role in satisfying both individual and social preferences and their broader contribution to wellbeing that may not be perceived by most people. It also implies explicit treatment of the uncertainties associated with tracking these dynamics.

Ecological economics is different from environmental economics in terms of the latitude of approaches to the ecosystem valuation problem it allows. They include more conventional Willingness To Pay (WTP)-based approaches, but they also include other more novel methods, including deliberative and participatory approaches and approaches based on explicitly modeling the linkages between ecosystems and economic systems.

Preference formation is influenced by limited information in estimating WTP-based values for biodiversity preservation. Empirical studies show that a significant portion of individuals exhibit “lexicographic” preferences, that is, they refuse to make tradeoffs that require the substitution of biodiversity for other goods. This places significant constraints on the use of stated preferences, as used in contingent valuation studies, for valuation of ecosystem services and decision-making. It places more emphasis on the need to develop more direct methods to assess the value of these resources as a supplement to conventional WTP-based methods.

The valuation of ecological resources requires a deeper understanding of the ways in which economic activity depends on biogeophysical processes than is usually recognized. However, the issue of ecosystem valuation is far from solved. In fact, it is probably only in the early stages of development. Conventional WTP-based approaches have severe limitations. Key directions for the future include integrated ecological economic modeling, as elaborated in the next section.

Integrated Ecological Economic Modeling and Assessment

The emphasis on both (1) issues of scale and limits to the carrying and assimilative capacity of ecological systems and (2) underlying dynamics of those systems imply the need for a new approach to the modeling of joint systems. It is not surprising that this is an active area of research in ecological economics. Indeed, combining (sometimes implicit) models of ecological processes and economic decision models in a new that makes the feedbacks between the two sets of processes transparent is where we most expect new advances to be made as a result of the ongoing dialog between economists and ecologists.

Ecology and economics have long diverged both methodologically and conceptually. One reason for the difficulty in bridging the modeling gap is that economics, as a discipline, has developed almost no tools or concepts to handle spatial differentiation beyond the notions of transport cost and international trade. The spatial analysis of human activity has been seen as the domain of geographers, and has had remarkably little impact on the way economists have analyzed the allocation of resources. This makes collaboration between economists and disciplines based more directly on spatial analysis difficult. Since the development of spatially explicit integrated models is one of the areas in which ecological economics is expected to develop most rapidly, it would seem that geographers are likely to become an increasingly important part of the research agenda in ecological economics.

A second characteristic of ecological–economic models concerns the way in which the valuation of ecological functions and processes is reflected in the model structure. The point was made in the previous section that valuation by stated preference methods (estimation of willingness to pay or accept using contingent valuation or contingent ranking) may capture the strength of people's perceptions and their level of income and endowments (their ability to pay), but it generally fails to capture the impact of a change in ecosystem functions and processes on the output of economically valued goods and services. Unless the role of non-marketed ecological functions and processes in the production of economically valued goods and services is explicitly modeled, it is hard to see how they can be properly accounted for in economic decision making.

A third characteristic concerns the role of integrated modeling in strategic decision making. One of the challenges to ecological economics has been to devise methods to address strategic "what if" questions in a way that reflects the dynamics of the jointly determined system. The general problem confronting anyone attempting to model long-run dynamics explicitly is that ecological–economic systems are complex nonlinear systems. The dynamics of economic systems are not independent of the dynamics of the ecological systems which constitute their environment, and that as economies grow relative to their environment, the dynamics of the jointly determined system can become increasingly complex. Indeed, the development of ecological economics can be thought of as part of a widespread reappraisal of such systems.

In ecology, this reappraisal has influenced recent research on scale, complexity, stability, and resilience, and is beginning to influence the theoretical treatment of the coevolution of species and systems. The results that are most important to the development of ecological economics concern the link between the spatial and temporal structure of coevolutionary hierarchical systems. Landscapes are conceptualized as hierarchies, each level of which involves a specific temporal and spatial scale. The dynamics of each level of the structure are predictable so long as the biotic potential of the level is consistent with bounds imposed by the remaining levels in the hierarchy. Change in either the structure of environmental constraints or the biotic potential of the level may induce threshold effects that lead to complete alteration in the state of the system.

In economics there is now considerable interest in the dynamics of complex nonlinear systems. Economists have paid less attention to spatial scale and its significance at or near system thresholds, but there is now a growing body of literature with roots in geography which seeks to inject a spatial dimension into nonlinear economic models. There is also an economic analog to the biologist's interest in evolution and the significance of co-dependence between gene landscapes. The steady accumulation of evidence that economic development is not a stationary process, that human understanding, preferences, and technology all change with development, and that such change is generally nonlinear and discontinuous, has prompted economists to seek to endogenize technological change. Although the adaptation of this work by environmental economists has been rather disappointing, the treatment of technology and consumption preferences as endogenous to the economic process is a fundamental change that brings economics much closer to ecology.

The challenge to ecological economics in the future is to develop models that capture these features well enough to incorporate at least the major risks in economic decisions that increase the level of stress on ecological systems.

Summary and Conclusions

This is a sample of the range of transdisciplinary thinking that can be put under the heading of ecological economics. While it is difficult to categorize ecological economics in the same way one would a normal academic discipline, some general characteristics can be enumerated.

- The core problem is the "sustainability" of interactions between economic and ecological systems.
- An explicit attempt is made at "pluralistic dialog" and integration across disciplines, rather than territorial disciplinary differentiation.
- An emphasis is placed on "integration" of the three hierarchical goals of sustainable scale, fair distribution, and efficient allocation.
- There is a deep concern with the "biophysical underpinnings" of the functioning of jointly determined ecological and economic systems.
- There is a deep concern with the relationship between the "scale" of economic activity and the nature of change in ecological systems.
- Since valuation based on stated willingness to pay reflects limitations in the valuer's knowledge of ecosystems functions, there is an emphasis on the "development of valuation techniques" that build on an understanding of the role of ecosystem functions in economic production and wellbeing.
- There is a broad focus on systems and "systems dynamics, scale, and hierarchy" and on "integrated modeling" of ecological economic systems.

These characteristics make ecological economics applicable to some of the major problems facing humanity today, which occur at the interfaces of human and natural systems, and especially to the problem of improving humanity's wellbeing and assuring its survival within the biosphere into the indefinite future. It is not so much the individual core scientific questions that set ecological economics apart—since these questions are covered independently in other disciplines as well—but rather the treatment of these questions in an integrated, transdisciplinary way, which is essential to their understanding and effective use in policy.

See also: Human Ecology and Sustainability: Resilience; Ecosystem Services Evaluation; Ecological Systems Thinking

Further Reading

Barbier, E.B., Burgess, J.C., Folke, C., 1994. Paradise lost? The Ecological Economics of Biodiversity. London: Earthscan, p. 267.

Boulding, K.E., 1966. The economics of the coming spaceship earth. In: Jarrett, H. (Ed.), Environmental quality in a growing economy. Baltimore, MD: Resources for the Future/Johns Hopkins University Press, pp. 3–14.

Boumans, R., Costanza, R., Farley, J., *et al*., 2002. Modeling the dynamics of the integrated earth system and the value of global ecosystem services using the GUMBO model. Ecological Economics 41, 529–560.

Costanza, R., 1991. Ecological economics: The science and management of sustainability. New York: Columbia University Press.

R. Costanza. Visions of alternative (unpredictable) futures and their use in policy analysis Conservation Ecology 4 1 2000 5, http://www.consecol.org/vol4/iss1/art5/ (accessed October 2007).

Costanza, R., 2001. Visions, values, valuation and the need for an ecological economics. Bioscience 51 (2001), 459–468.

Costanza, R., Wainger, L., Folke, C., Mäler, K.-G., 1993. Modeling complex ecological economic systems: Toward an evolutionary, dynamic understanding of people and nature. Bioscience 43, 545–555.

Costanza, R., Voinov, A., Boumans, R., *et al*., 2002. Integrated ecological economic modeling of the Patuxent River watershed, Maryland. Ecological Monographs 72, 203–231.

Costanza, R., Cumberland, J.C., Daly, H.E., Goodland, R., Norgaard, R., Kubiszewski, I., Franco, C., 2014. An introduction to ecological economics, second edn. Boca Raton: Taylor and Francis.

Costanza, R., de Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., Farber, S., Grasso, M., 2017. Twenty years of ecosystem services: How far have we come and how far do we still need to go? Ecosystem Services 28 (2017), 1–16.

Daly, H.E., 1968. On economics as a life science. Journal of Political Economy 76, 392–406.

J. Farley, R. Costanza. Envisioning shared goals for humanity: A detailed shared vision of a sustainable and desirable USA in 2100 Ecological Economics 43 2002 245–259.

Jansson, A.M., Hammer, M., Folke, C., Costanza, R., 1994. Investing in natural capital: The ecological economics approach to sustainability. Washington, DC: Island Press, p. 504.

Krishnan, R., Harris, J.M., Goodwin, N., 1995. A survey of ecological economics. Washington, DC: Island Press.

Martinez-Alier, J., 1987. Ecological economics: Energy, environment, and society. Oxford: Blackwell, p. 287.

Norton, B., Costanza, R., Bishop, R., 1998. The evolution of preferences: Why “sovereign” preferences may not lead to sustainable policies and what to do about it. Ecological Economics 24, 193–211.

Ward, J., Sutton, P., Werner, A., Costanza, R., Mohr, S., Simmons, C., 2016. Is decoupling GDP growth from environmental impact possible? PLoS One 11 (10), e0164733