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The science of ecology entails an examination of nature in all its interconnected complexity. Human ecology, on the other hand, has a strong anthropocentric emphasis and is concerned more directly with man's interaction with the natural system. It is an integrative approach for looking at the world's economic system and the natural environment upon which it depends in the context of sustainability. Human ecology holds that one cannot understand either the economy or the environment without assessing the impact of each upon the other. A problem for analyses that link resource-based economic, environmental, and ecological considerations is the absence of a common numeraire. However, a procedure called natural capital accounting (NCA)[1] has been used to model an economy using an embodied energy numeraire.

FINDING A NUMERAIRE

In everyday life, our activities are quantified and interrelated in money terms; this has given rise to a set of conventions called "accounting practice" and is the numeraire of economics. In both of these, the money numeraire is used as a measure of value and as a reflection of preferences. In those spheres where a clear money valuation may be absent, such as many environmental resources or the value of goods and resources in the future, the standard response of the economics profession has been to utilize cost-benefit analysis. This is a sophisticated but highly subjective process whose outcome relies upon setting a discount rate and attaching value to those goods for which no market exists.

Development planning calls for estimates of how future choices will be made and valued. Thus forecasts based on cost-benefit analyses face considerable uncertainty, and they have been notoriously inaccurate. One consequence of this is a growing distrust of economic models as a guide to development planning, leading to a trend away from their use. This shift is serious, since it implies the replacement of an explicit statement of one's assumptions with hunches, prejudice and guesswork.

A means is needed for considering both the set of feasible options that are determined by the physical aspects of the system, and how each interacts with the environment. This requires a common numeraire, and it is proposed here that embodied energy be used rather than money. All transformations require energy, which must be available at the moment of use; there is no possibility of credit, and there is no substitute for energy. It is therefore desirable to make a model of the economy in which the flows of capital and conversions of raw materials are expressed in terms of their embodied energy.

RESOURCE ACCOUNTING

The distinction between NCA and economic analysis is essentially one of numeraire. Money as a reflection of value subsumes all human inputs to production. NCA, which reflects energy, subsumes only the work (in a thermodynamic sense) done. With few exceptions, physical resources are so abundant in the earth's crust as to be virtually inexhaustible, provided energy and capital are available. Resources may be used, but they are never used up. However, access to them may become increasingly costly in energy terms. It is therefore clear that a flow of energy must be sustained if a given standard of living is to be maintained.

It is possible to network back all of the inputs to a production process and show that each is traceable to the twin actions of prior energy and labor use. These two inputs are in turn the only inputs that are irretrievably dissipated in production processes. Capital inputs are themselves the product of a previous process of manufacture and of dissipated energy. Similar reasoning can apply to all other inputs, including the life support systems for labor, with the result that energy is the only resource that is irretrievably dissipated. Economists contend that this argument amounts to an energy theory of value, but it is not exactly that. It is an embodied energy theory of production. Thus the dissipation of energy in the production process is a measure of the nonrenewable resource consumption of all economic activities, and enables us to compare any action or policy that has a physical resource implication. Every economic activity thus becomes a sink for energy, and energy drives the economy rather than circulating the way money does. The procedures for evaluating economic activities in these terms are well established, and are know as "Energy Analysis."

APPLICATION OF NCA

Since all economic activity subsumes energy and is quantifiable, one may choose to model the development of an economic system in embodied energy terms. A common objection to this is that energy cannot be used as an allocation system since people do not make their decisions based on the differing energy inputs of economic alternatives. However, that is not its purpose, which is instead to quantify the long-term consequences of present day decisions. On the other hand, NCA has less to offer in short-term decision making.

In NCA, a set of wants (demands) incur a demand for resources and human-made (manufactured) capital. The evolution of the system is set by the rate at which resources can be turned into human-made capital, and provide for wants and liberate additional physical resources. This is not to say that wants or needs cannot be stipulated, or that there exists an inevitable future. It merely expresses a set of constraints - e.g., natural laws, resource endowments, climate, socio-cultural attributes - that will determine relationships and changes within the system. This is a more realistic view than the open-ended one implied by a purely economic approach, and it enables planners to probe for an acceptable future.

The approach of using energy resources as a starting point makes NCA suitable for studies of carrying capacity. Economic carrying capacity refers to the number of people who can share a given territory and be supported on a sustainable basis. Sustainability in the context of NCA can

be defined very precisely: "Economic growth depends on the growth of capital stock (= embodied energy) to enable labor to provide enhanced output (= dissipation of energy). If this is to be sustainable, then the rate of energy flow (more precisely, flux) must always be maintained."(433) Economic sustainability, then, is a state in which the rate of growth of energy flow into the economy is sufficient to harness the resources necessary to indefinitely maintain or improve the standard of living of those within the system.

Assessment of these issues is carried out through simulation rather than optimization models. NCA has been put to work through a dynamic simulation model called Enhancement of Carrying-Capacity Options (ECCO). This model has been tested in a number of contexts, first in Kenya, and subsequently in several Asian countries.[2] In a validation modeling of the UK from 1974-84, ECCO was eight times better than other conventional models in key areas. Among the uses of ECCO are studies to explore the consequences of policies for food and energy self-sufficiency, as well as assessments of the impact of population growth on the carrying capacity of an area and the resulting welfare of future generations. Many other policy options remain to be tested, and the potential for incorporating environmental factors has yet to be fully exploited.

Notes

[1]In the original text the term used is "resource accounting." This term is used in an entirely different context by economists, and in later and current publications, the term used is "natural capital accounting."

[2]Author's note: Since this paper was written, the model has also been tested in the UK, EC, Netherlands and New Zealand.