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The biophysical systems perspective sees the economy in terms of the physical activities that take place in it, while the political-economic perspective focuses on the social aspects of the activities of society. From the biophysical point of view, the continuing transformation of available and unavailable energy resources in accordance with the Second Law of Thermodynamics is the fundamental fact of life in the functioning of all economies; there is no known economic process that does not begin by using some sort of raw material and eventually generate waste. The interaction between energy and matter is the basis for life itself, including human life and culture. The inclusion of energy in a world view based on a physical systems perspective can therefore help to clarify the relationship between a social system and its environment. Energy analysis may also help us see where the biophysical and political-economic viewpoints differ, and indicate areas in which conventional assumptions may need deeper examination.

ENERGY ANALYSIS

Matter normally enters an economic system as raw materials from the environment. The flow of useful matter into and through an economic system can be characterized in terms of the available energy expended in carrying out the transformation processes in which the matter is involved. Thus, energy can be used as a numeraire or unit of account, enabling a wide variety of goods to be accounted for in terms of the quantity of the energy used in the process of transforming them into marketable products. From the biophysical systems perspective, it is the amount (the physical cost) of energy embodied in a product that is important, not its market price. Therefore, only physical processes of production are considered, and not the social valuation of the product in the market place.

The branch of physical science that follows economic production and consumption through their energy consequences is known as energy analysis. It involves the determination of the amount of primary energy that is dissipated in producing a good or service and delivering it to market. There are two common techniques for accomplishing this: process analysis and input-output analysis. Process analysis systematically determines the energy requirements for each stage of a productive process, and by summing the energy added at each stage, it provides the total energy requirement of the product. Input-output analysis is a modification of a standard economic tool. It requires a detailed survey of the economy with an explicit accounting of the direct and indirect energy requirements for producing goods and services. "Thus, all of the energy inputs to the processes that precede the output of a given good or service in the economy are evaluated, right back to the coal mine, oil well, power station or gas field."(87) As a rule, input-output analysis is appropriate when examining events that affect an entire economy, whereas process analysis may be more appropriate for the study of a specific process.

NET ENERGY AND PHYSICAL ACCESSIBILITY

Energy transformation systems normally begin with a coal mine or an oil or gas well from which the resources are physically extracted, followed by facilities that generate power and produce fuels. Thus, in this approach the energy transformation sector is treated exogenously, not simply as another part of the productive sector of the economy. An important characteristic of this sector is that it absorbs capital as well as operating and maintenance inputs from the economy, which themselves absorb energy. It is when the flow of useful energy to the economy exceeds these input energy flows that there is a supply of net energy to the economy.

The net energy criterion is a means of indicating the physical accessibility of an energy resource; it is a measure of the effort required to extract and deliver a resource expressed in energy terms. The evolution of the industrialized economies over the past century has witnessed a progression to cheaper and increasingly accessible energy sources, but only after the development of the technologies necessary to extract these new resources. Not surprisingly, societies have exploited the resources that were most accessible first.

There is increasing evidence, however, that energy is becoming more difficult to obtain and process into readily usable forms. This implies that escalating resource inputs (and higher pollution levels) will be required to maintain the same net energy supply into the economy. Improvements in technology will not resolve this dilemma. The Second Law of Thermodynamics states that there is an absolute minimum energy requirement for any process - e.g., lifting a ton of coal to the surface or pumping a liter of water - that is absolutely unalterable by technology. Thus, in time, the energy transformation industry will have to grow and absorb a steadily increasing quantity of economic activity just to maintain the system at its current level.

Neither should much faith be placed in new energy technologies. For example, much of the optimism surrounding "breeder" type nuclear reactors, a process that allegedly produces more fuel than it consumes, has proved to be illusory. These reactors were merely converting non-fuel uranium (U-238) into fuel grade plutonium (Pu-239) for use in conventional (fission) nuclear power plants, not creating new fuel out of nothing. Nuclear fusion (rather than fission) is seen as the ultimate unlimited energy source, which is supposed to duplicate the reactions that occur in the sun at millions of degrees, transforming hydrogen into unlimited amounts of energy. However, so far these efforts have succeeded only in absorbing vast sums of money and energy, producing no tangible results.

Technology, then, will not provide any relief, and the consequences of this are clear: "When resources are relatively inaccessible, the primary resource flow will be greater than it was for the earlier, high-accessibility case. Thus, the rate of depletion of primary resources will also increase for a given (constant) flow of net energy to the economy. Pollution and other externalities will also be greater due to the increased rejection of unavailable energy."(90) As primary resources become less accessible, it is possible to predict very rapid rises in energy input for very modest increases in non-energy output. Under conditions of rapid energy-intensive capital investment, it is possible for energy supply programs to be net consumers of energy.

AIMS OF THE BIOPHYSICAL SYSTEMS WORLD VIEW

The implications of the foregoing analysis are that:

1) the long term economic costs of energy resource development are likely to be much higher than currently believed; and
2) costs are likely to increase at an accelerating rate over time.

Energy analysis provides strong indications that there are limits to economic growth, and that current predictions of future energy prospects seriously underestimate the current value of energy resources and encourage wasteful use. If these insights were incorporated into economic analysis, sustainable alternatives would be viewed in a more favorable light.