Energy Analysis

Martha Gilliland, in her article "Energy analysis and public policy" (26 Sept. 1975, p. 1051), challenges the techniques of economists as a means of valuing natural resources and environmental impacts. Nonpecuniary externalities do create serious measurement problems for the economist, since there are no well-defined markets in which man can reveal his preferences. However, the ideas put forth by Gilliland confuse rather than clarify the issue.

The general theme of the article is that an energy theory of value is needed. This same idea but in the form of a labor theory of value was put forth by Adam Smith (*1*) 200 years ago and extended somewhat by David Ricardo (*2*, chapter 1) and others who changed it to a cost of production theory of value. The idea was abandoned in the last three decades of the 19th century as a result of developments in marginal utility analysis (*3*, book 3; *4*).

The theory proposed by Gilliland, which is based on net energy, is comparable to a cost theory of value but omits the concepts of utility and demand, supply in a functional sense, and the use of marginal analysis. "Opportunity cost" is another useful economic concept that does not have a clear counterpart in Gilliland's proposals, although there are a few references to alternative resource uses.

It is inconsistent for Gilliland to use dollar values to transform different forms of energy to a common energy value unit while rejecting monetary units as a measure of value. This transformation only creates an opportunity for error and reduces the exercise to an attempt to solve a complex problem by merely changing definitions.

The concept of net energy is certainly an improvement over gross energy for the purpose of decision-making. But it is difficult to see in what ways it is an improvement over the concepts of value added, net benefits, and net income when these concepts are properly qualified in terms of effects that are not subject to quantification in monetary values. In fact, in several ways net energy seems an inferior concept. An attempt to use energy as the ultimate criteria for value without regard to its usefulness to man is not valid from a social scientific point of view. Man invests in nature to discover and develop its assets to satisfy his own needs—not to maximize in some sense a return to nature. This is not to say that people should ignore their life support system through shortsighted exploitation.

The idea that ". . . as we extract more dilute, deeper, and dirtier energy sources, the energy subsidy required to extract and upgrade the new sources increases" was expressed much more clearly over 150 years ago by Ricardo (*2*, chapter 2) in his discussion of economic rent and increasing marginal cost in the cases of mining and land use. As man's demands for the services of natural resources increase, the use of lower quality resources becomes economical as costs increase at the margin for existing active sources, and values of those more productive resources inside the margin rise. Technological change can produce the opposite effect, which may be observed in the substantial reduction of the total land input into U.S. agriculture since 1930.

Why should labor be valued on the basis of its energy consumption? Is the time of the engineer who designs the power plant, but probably consumes fewer calories, of less value than the time of the janitor who cleans the toilets?

Why should an energy value or an economic value always be placed on the services provided by nature? They are "valuable" in terms of use but may be of no value in exchange. An example is air, which has many uses, but no exchange value (*3*, p. 153). Here again marginal cost and marginal utility theories tell us that no monetary value should be placed on them as long as the quantity supplied exceeds the quantity demanded at zero prices. Such is not the situation, however, in Gilliland's example of North Dakota's wheatlands being mined for coal. Here, an economist would also consider the net income given up from not growing wheat as a cost.

According to Gilliland, the value of energy provided by nature (environmental subsidies) is determined by the reduction in the gross primary productivity (as measured by the amount of sunlight captured and concentrated by plants) caused by land disruption or ecosystem change. In this case, there would be no distinction between a unit of the sun's energy captured by a weed and that captured by a corn plant. Economic theory, however, provides a very clear explanation of the difference between the positive value of corn, and the negative value of weeds. The energy from some ecosystems has a negative value, and we incur costs to reduce their damaging effects—floods, soil erosion caused by wind and water, and so forth.

What is the significance of the fact that the consumer receives the smallest amount of energy for his dollar? The energy inputs at the different stages in the process of production might be compared with the economic concept of value added. In the case of nonrenewable resources, the problem is really one of trade-off between present and future use.

The effects of depth of drilling, and so forth, on net energy could be explained much more precisely in terms of marginal costs and marginal revenues, which are also more rigorous concepts for choice decisions than average ratios. An economist would not likely say that, in all cases, "The purely economic calculations . . . include the effects of government policy in subsidizing some resources . . . ." There may be reason to determine the effects of subsidies and taxes, but all economic analyses do not distort the results when the objective is to determine what the economic values would be in the absence of such subsidies and taxes.

Gilliland appears to be unfamiliar with the economic literature. There is a good deal of work in which social costs and subsidies are considered. The main limitation of this work is that it does not include the computation of technical input-output coefficients, the development of which has most appropriately been in the fields of engineering and the physical and biological sciences.

As a rule, dollar values are adjusted for inflation and deflation and, when dealing with matters affecting humans, there is good reason to recognize that costs and benefits accrue to different people at different times and that there is a sound basis for discounting future values to arrive at comparable current values.

On the positive side, the lack of factual physical and biological input-output information, and of the relationships that connect them, places serious limitations on the effectiveness of economic analysis. An accounting system for energy may help in this regard.

MAX R. LANGHAM
W. W. MCPHERSON
Department of Food and Resource Economics, University of Florida, Gainesville 32611

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Should Gilliland have convinced the reader otherwise, I hasten to point out that the reason a Rembrandt painting is more valuable than a Picasso drawing is *not* because oil paint contains more Btu's than ink.

The energy theory of value, like its predecessor, the labor theory of value, reflects the concerns of its proponents. Labor was a major concern in the mid-19th century; energy is a major concern in the mid-20th. Whether either theory adequately explains value or provides a sound basis for public policy is another matter. Western societies have rejected the labor theory on both grounds. I suspect that, after careful analysis, the energy theory will follow the same route—for largely the same reasons.

The difficulty with Gilliland's criticism of dollar measures of value is the fallacious assumption that the reason economists measure things in dollars is merely to solve the "apples and oranges" problem. Actually, the choice of the money measure has a more fundamental basis. In market-oriented economies, people reveal their preferences in terms of monetary transactions for goods and services. It is, of course, true that dollar values are not constant over time; but, neither are preferences. Consequently, there is no reason to be surprised or for Gilliland to be critical of the fact that the U.S. Geological Survey estimate of economically recoverable reserves changes from year to year.

Gilliland is quite correct in pointing out that dollar measures are difficult to determine when markets do not exist. This partially accounts for the fact that the services of the environment and the disamenities of pollution have been inadequately treated in policy decisions. We all support efforts to find measures of value in these areas. However, energy accounting research represents only one of these efforts. There is a large and growing literature covering many other approaches to the problem (*1*). Other researchers have shown that, like the energy unit, dollars also provide, in the words of Gilliland, "a comprehensive but simplified set of consistent measures drawn from a single external conceptual system."

The disagreement is over the "conceptual system." The conceptual system of Gilliland is based on maximizing "net energy." The conceptual system of the other investigators is based on maximizing individual and social welfare. These concepts are not equivalent, even though in a materialistic society it is easy to confuse the two.

HENRY M. PESKIN
Resources for the Future, Inc.,
1755 Massachusetts Avenue, NW,
Washington, D.C. 20036

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I read with some interest Gilliland's article on energy analysis and public policy, in which an attempt was made to determine the energy inputs that affect environmental quality during energy resource development.

I encountered certain aspects of this problem when I attempted a more general approach of environmental thermodynamics (*1*). This analysis convinced me that the one unifying element by which the effects of the diverse pollutants could be understood and measured was their energy content—in particular their free energy content—relative to their low energy degradation products. It is apparent, however, that energy quality factors analogous to those used in dealing with radioactive materials would be required for all pollutants (*2*). An extension of this approach also shows that a thorough treatment of the problem would have to include the entire energy flux, both technological and natural, through the region under study, since it is this entire energy flux, exceeding that of the primary biological productivity by several orders of magnitude, which is potentially available for environmental degradation. In fact, the value of this flux places an upper bound on its availability. Thus the restriction of an assessment of environmental impact to a loss of gross biological productivity or even to any potential "work" of natural systems would grossly underestimate the potential environmental degradation. In fact, careful consideration will show that the concept of heat engine (Carnot) efficiency has only an indirect impact on environmental quality through its effect of reducing the total technological energy flux (*1*).

To see how large quantities of natural energy become available for environmental degradation we need only consider specific examples. If a region is denuded of its vegetation, there is not only a drop in biological productivity but also an acceleration of run-off which generally results in environment-degrading erosion and siltation which may occur off the site in the future. In this context, silt particles and even pure water become pollutants through the energy they acquire. A detailed analysis shows that unforseen (high entropy) energy concentration mechanisms have destructively channeled climatic energy that was previously beneficially dissipated on the vegetated watershed. Other examples include the deleterious effects of hydropower projects, heat dissipation around power plants, and the destruction of ozone by human-produced chemicals which allows penetration of ultraviolet rays to ground level. In all these cases a relatively small quantity of technological energy activates much larger quantities of climatic energy into destructive paths.

The approach above identifies the major contribution to environmental degradation as energy resulting from both technological flows and from natural flows which have been destructively misdirected through human intervention, rather than from the absence of beneficial flows, such as primary biologic productivity or any conceivable "work" done by the natural system. Diminution of the latter may cause a poverty of certain resources, but only energy flows can bring about pollution and environmental degradation. This may be shown by noting that environments of high environmental quality exist in regions with low biologic productivity.

The determination of net energy in energy resource analysis is a considerable advance over previous approaches to the problem. However, the energy flows involved in this type of analysis are clearly too small to correctly assess the environmental impact of energy development. Also there is no inclusion of a quality factor to gauge the true environmental impact, since the term quality as used by Gilliland refers solely to energy conversion ratios. Furthermore, it is highly unlikely that the major environmental effects of technology, which in the end determine the viability of civilizations, can be estimated on a time scale of years or even centuries.

ROBERT F. MUELLER
NASA/Goddard Space Flight Center,
Greenbelt, Maryland 20771

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Gilliland's poignant article argues for a holistic concept of evaluating the worth of technological alternatives based upon a net energy or "value received" concept. However, her generalization that "the energy value of the environment is the amount of the sun's energy used by the ecosystem in providing services and products . . ." should be clarified. An evaluation based upon energy used by the ecosystem will increase the value of the system by at least an order of magnitude above that based upon products alone. But in evaluating the value of ecosystem services, Gilliland does not explicitly invoke her net energy concept. The energy cost of ecosystem services is not only that used by the ecosystem but also the energy costs of providing those services (soil stabilization, quality water resources, wildlife habitat, integrity of biogeochemical cycles, and so forth) by alternative means.

Technology cannot substitute for ecological systems, but it may help replace those destroyed or damaged. However, as Gilliland appropriately points out, such reestablishment requires subsidies of time and energy (both negative net energy terms). This places an intrinsic value upon ecosystems in terms of "net energy" which is orders of magnitude higher than one based simply upon energy use. Ecosystems have evolved as biological systems capable of converting and utilizing a diffuse, low-grade energy input. As Gilliland says, most technologies are energy intensive and require high-grade energy inputs. Net energy analysis will also demonstrate the converse, that low-grade energy resources are often the most costly to exploit. The "services" of ecological systems, if at all replaceable, are high-cost investments—but commensurate with the value to society of a persistent and quality environment.

DAVID E. REICHLE
Environmental Sciences Division,
Oak Ridge National Laboratory,
Oak Ridge, Tennessee 37830

The comments and criticisms in the above letters address four main topics: the concept of an energy theory of value, the utility of net energy analysis, the use of dollar to energy conversion factors, and methods for calculating environmental costs and benefits in energy units.

Both the letters from Langham and McPherson and from Peskin presume that my article argues for an energy theory of value. To the contrary, I consciously rejected making such an argument.

The utility of an energy theory of value remains, for me, an open question. I believe it is premature to either accept or reject such a theory. I am influenced by two conflicting lines of argument. First is that of Georgescu-Roegen (*1*), who argues that energy (more precisely, low entropy) is a necessary, but not sufficient, condition for assigning value. He contends that sufficiency requires the ability to account for the enjoyment of life; net energy clearly does not provide for such accounting. On the other hand, over the long term, low entropy may provide the basis for defining the boundaries of utility and demand, that is, the boundaries for what is socially acceptable. In so doing, it may offer a value theory. In the short term, it would be useful if macroscale economic models of the production function included low entropy as well as labor and capital. A major purpose would be to investigate to what extent labor and capital are functions of low entropy.

I make the above points because the purpose of my article is to argue that net energy analysis, as defined by Odum (*2*), offers the policy analyst another way of assessing options. Energy analysis should not be a substitute for economic analysis precisely because both of them have deficiencies (at least at the present time) and because each provides information not provided by the other. It may be possible to identify and examine policy issues by noting the points where the two types of analyses diverge. An obvious example occurs in the case of price regulation of natural gas, where many processes which utilize natural gas are economical, yet are net energy losers. An analysis and comparison of the economic costs and energy costs of the nuclear and coal fuel cycles for electric power generation could focus the policy issues involved in each. The point is that policy decisions benefit from several kinds of information (environmental, economic, and net energy) and that, as yet, no single unit measures the multitude of trade-offs.

Langham and McPherson criticize the use of dollar to energy unit conversion factors in net energy calculations. My article does not advocate using dollar to energy conversions; it only points out that some procedures use them. Whether or not it is inconsistent in energy analysis to convert from dollars to energy units depends on the kind of information desired. It is often useful to know where in the economy a dollar buys a disproportionately large or small amount of energy. As such, the conversion factors themselves may identify policy problems. On the other hand, if the analyst wishes to separate the subsidies explicitly into direct energy, energy embodied in materials, and value-added components, such as labor and financial services, dollar to energy conversions are of little use. I would prefer not to use these conversions because they obscure some important information. In reality, the lack of physical input-output information for most industries often requires first approximations using conversion factors. Fortunately, there is some congressional interest in establishing a physical input-output data system similar to the dollar system of the Bureau of Economic Analysis.

Both Mueller and Reichle argue that environmental subsidies may still be underestimated by the procedures discussed in my article. I agree with Mueller that a thorough treatment of the problem would have to include the entire energy flux through the region under study. Odum (*3*) has proposed and used such an "energy cost/benefit analysis." Mueller's suggestion (reference 1 in his letter), that pollutants can be compared by evaluating their energy at the point of emission relative to the entropy of their degradation products, is intriguing and merits investigation. The procedures for measuring environmental costs and benefits directly are in their infancy. I argue only that environmental subsidies are not externalities and that energy analysis can internalize them directly. In energy analysis, the "weed" in Langham and McPherson's letter could, under some circumstances, have a positive value because it has low entropy. Its value may be less than that of the corn, but economic analysis gives the "weed" a zero or negative value, while environmental energy accounting recognizes the work the "weed" does.

MARTHA W. GILLILAND
Science and Public Policy Program and
Department of Civil Engineering and
Environmental Sciences,
University of Oklahoma, Norman 73069

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