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ENERGY MODELING AND NET ENERGY ANALYSIS

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ENERGY ANALYSIS AND ULTIMATE LIMITS

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ABSTRACT

Since the basic objective of energy analysis is to identify the ultimate sustainable limits to human activities, it is appropriate to identify ultimate limits to the usefulness of energy analysis. Human activities can take many forms and any assessment of ultimate limits is not only a forecast of technical progress and resource availability but is also a statement about human values i.e., what activities can or ought to be sustained. Current applications of energy analysis are not merely attempts to find common units of measurement (BTU's rather than dollars) but are attempts to value current human activities in accordance with their believed long run sustainability.

Physical laws (including those of thermodynamics) constrain man's activities but do not dictate values by themselves. The problems addressed by energy analysis are of definite social relevance but the science of economics indicates that the objectives of energy analysis are unattainable by the methods employed.

ENERGY ANALYSIS AND ULTIMATE LIMITS

INTRODUCTION

Energy analysts are currently using a variety of concepts to assess energy problems and rank alternatives. These concepts include techniques which might be loosely labeled as net energy analysis, energy analysis, entropy analysis and even economic analysis. The term net energy analysis is generally used when the energy producing activity or industry is under study. Slesser (16) has defined energy analysis as an assessment of the "energy resource consequences of man's activities." Entropy analysts would simply substitute an entropy measure for BTU's and economic analysts would simply apply economic principles and generally use dollar measures.

While there are various gradations within each of these categories, it is clear that a fundamental conceptual difference exists between analysts using economic measures, such as market prices to value inputs and outputs, and analysts using physical measures, such as energy content. This cleavage is undoubtedly clearest to economists since they are aware that the direct allocation of resources (i.e., quantities of R & D manpower, etc.) by energy content principles has the same economic effect as an indirect allocation achieved by setting prices according to energy content principles. (The duality of resource allocation effects achieved by either price or quantity mechanisms was the subject of much of Leontief's Nobel prize winning work.) Indeed, Huettner (7) has shown that resource allocation based on net energy analysis is an energy theory of value and there is little doubt that Odum and possibly Hannon and Gilliland subscribe to an energy theory of value. Furthermore, it is not true that, given perfect markets, net energy analysis (or energy analysis) and economic analysis "can do the same thing" or "would yield the same perception of the future" as Odum (13) and Slesser (16) have respectively maintained. Energy analysts employing economic principles will generally reach different conclusions from energy analysts using non-economic principles and these differences will remain even if all markets are free or perfect. Claims that one method cuts through confusion or forecasts impending change faster or has more normative content could probably not be proven by proponents of any method since every discipline is rife with examples of poor research to be exploited by the opposition.

Under these conditions, I believe it makes more sense to examine the basic assumptions and logic of a discipline in an effort to determine where it will take us if we let it guide our decisions. It is on this basis that I argue that energy analysis guided by non-economic principles constitutes an energy theory of value. While there is general agreement that the Odum "school" embraces an energy theory of value, Slesser (16) maintains that his "school" does not. Yet if one "values" inputs and outputs in energy terms, ranks or compares alternatives in energy terms, and then acts on this informati[on] I believe that an old adage applies, "when in Italy, all roads lead to Rome." While it is clear that the energy analyses of Slesser, Odum and others guided by non-economic principles do differ, the concern of this study is not with their differences but with their similaritie[s].

For this reason, this study will lump all forms of non-economic energy analysis together and simply refer to them as energy analysis.

The basic objective of this paper is to assess whether energy analysis based on non-economic principles is a correct or even a useful way of determining values. This assessment will begin with a review of the basic assumptions and objectives of energy analysis. The next section will review some of the theoretical and methodological issues associated with energy analysis. The final section will review some of the claims of energy analysts and present some concluding remarks.

ASSUMPTIONS AND OBJECTIVES OF ENERGY ANALYSIS

Assumptions

As a former net energy analyst has noted (10), "Net energy analysis began with two reasonable suspicions and an apparently simple method for testing them." The first suspicion was that, as mankind turned to lower quality energy sources, gross energy output would increase but net energy, the amount available to final consumers, would fall and eventually approach zero. The second suspicion was that traditional disciplines, because of narrow viewpoints or the use of prices to measure energy flows, might overlook this ominous possibility. Energy analysis offered, as an alternative, that all energy flows directly or indirectly supporting an energy technology or system be measured in physical units such as BTUs.

The exclusive emphasis on energy and the energy content of inputs in energy analysis rests on the concept of energy as the ultimate limiting factor, since substitutes for other inputs can always be synthesized from it. Energy may be divided into available energy (enthalpy) or unavailable energy (entropy). The second law of thermodynamics tells us that the entropy of a closed system increases continuously and irrevocably toward a maximum. In addition, Gilliland (4) has noted that (i) energy is the only commodity for which a substitute cannot be found, (ii) potential energy is required to run every type of system or production process, and (iii) energy cannot be recycled without violating the second law of thermodynamics.

As society uses up its higher-grade energy resources it will require more and more energy inputs (a larger energy subsidy) to produce a given amount of energy. While gross energy production may increase rapidly over the next few centuries as we consume our remaining fossil fuel resources, net energy will certainly increase less rapidly and may eventually begin to decline, particularly if one views earth, moon and sun as a closed system. Regardless of the exact scenario assumed, however, energy is clearly regarded as the ultimate limiting factor particularly since substitutes for other inputs can always be synthesized from it.

Objectives

The basic objective of energy analysis is to identify the ultimate sustainable limits to human activities (2) and (15). Since energy is viewed as the ultimate limiting factor, pursuit of this objective logically requires that all inputs be valued solely in terms of their energy content. This is particularly true of environmental inputs or services which many energy analysts feel are undervalued by traditional economic techniques.

In fact, the correct valuation of environmental services is essential if ultimate sustainable limits are to be properly assessed. This fact and the importance attached to environmental services by many energy analysts suggest that proper valuation of environmental services be regarded as a sub-objective of energy analysis.

THEORETICAL AND METHODOLOGICAL ISSUES

Theoretical Issues

Turning first to theoretical difficulties, it has been shown (7) that net energy analysis is an energy theory of value. Inputs such as labor, raw materials, machinery and so on are valued according to their direct and indirect energy content alone. More than just appropriate selection of the numeraire is implied, however; prices are formulated as if energy were the only relevant resource constraint, and the relative scarcity of nonenergy inputs becomes a factor only if it leads to a change in the energy content of these inputs. In essence, all nonenergy resources are viewed as transformed energy, and in this one-commodity world all derivative products are priced according to their energy content.

In essence, energy analysis assigns values based solely on supply considerations while totally excluding demand considerations. Georgescu-Roegen (3), however, has argued that low entropy (energy supply) is a necessary but not sufficient condition for assigning value. Sufficiency requires that one account for the enjoyment of life (demand factors). Georgescu-Roegen's statement that entropy is the true taproot of economic scarcity means that there are ultimate limits on supply given the state of knowledge assumed but does not imply that value is determined by supply alone. Furthermore, it does not even imply that energy scarcity is the only scarcity that should concern us since we do not live in a one commodity world where perfect substitutes for any given commodity can be synthesized from energy.

At best, net energy analysis can identify only a continuum of possible energy values (a supply curve) and not some unique value or ultimate limit for human activity. Gilliland (5) recognized this problem and argued that "over the long term, low entropy may provide the basis for defining the boundaries of utility and demand." Yet the ultimate, sustainable energy supply curve would undoubtedly stretch over a wide range of energy values (prices) and output levels. Furthermore, the position of this supply curve at any future point would depend on technological progress, hence the range of ultimately sustainable energy output levels and values is expanded enormously.

In fact, given our meager abilities to measure or understand past technological change, let alone forecast future changes (6), it appears safe to conclude that net energy analysis will offer no accurate prediction of the ultimate sustainable boundaries of energy

demand (or value). (Note that economic analysis would also fail to define these boundaries.) Once this is recognized, it is clear that current energy policy cannot be guided by pronouncements as to ultimate limits. As Leach (10) has noted, "The future is opaque, a dark mirror, and no less to energy analysis than to the rest of mankind. Ultimate limits can wait on more urgent and closer concerns."

A second theoretical issue identified by Yokell (17) is whether an energy industry should produce net energy or (by implication) whether one should rank alternatives solely on energy considerations. Since the objective of production is to produce services or products with characteristics useful to humans, society should maximize economic value and not net energy. In addition, society should rank alternatives based on economic value and not energy content considerations.

Economists recognize that renewable and non-renewable resources cannot be treated the same due to the greater and technologically based uncertainties associated with future availability of non-renewable resources. (See Lee (11) for an example.) This does not mean, however, that energy or any other non-renewable resource should be selected for conservation and used for ranking of alternatives. Again, it is the value of that resource vis-a-vis other economic values that should be considered i.e., is the current use of this non-renewable resource of greater value to society than postponing its use? Questions of this type (including intergenerational equity) are never easily resolved but energy analysis masks most of the important issues in this regard instead of dealing with them. In fact, the common distinction economists and others make between renewable and non-renewable resources also tends to assume that renewable resources are in fact renewable. For example, energy from biomass assumes that topsoil will not continue to be lost and that fresh water will be available and not contaminated with deleterious chemicals.

Methodological Issues

Given that energy analysis cannot achieve its basic objective of defining ultimate limits to human activity, one can still inquire whether the value weights it produces contain other information useful to decisionmakers. Again, however, there appear to be both methodological and theoretical reasons to question the information content of net energy calculations.

Turning first to methodological issues, Leach (10) has identified several of concern. (Problems created by uncertainty and joint production are not discussed here. The reader is referred to Leach (10) for treatment of these issues.) The most important of these methodological issues is the extent to which external inputs should be counted in net energy calculations, i.e., where should the boundary between supply and demand be drawn? At one extreme, the predominate opinion is to draw the boundary between the energy supply system or facility and the rest of GNP as conventionally defined. For example, the energy used to build and run gasoline stations or new towns for oil shale workers produces "goods" within GNP and is therefore not to be counted as a cost on the energy supply sector.

At the other extreme, the prevailing opinion is to capture all possible direct and indirect effects including many remote multiplier and "knock on" effects (12). As noted in (10), however, this would include "the additional energy associated with higher living standards for well paid Alaskan oil workers, the energy to provide all social facilities and infrastructure for new energy developments, and all hidden subsidies provided by natural ecosystem changes."

Clearly, the latter approach, favored by Odum and others, will generate much larger energy subsidies and hence lower net energy calculations than does the GNP approach. Leach concludes (10) that until this boundary problem is settled, "net energy analysis will be arbitrarily inconsistent, uncertain and show large variations.... (making)....Public Law 93-577 virtually unworkable....and (suggesting) that net energy analysis has no magic answers to some dilemmas."

A second methodological problem identified by Leach (10) and amplified by Yokell (17) is the problem of valuing physically disparate types of energy. Some energy resources are purchased for their enthalpies hence BTU measures are most relevant yet even this measure omits the fact that a kilowatt hour produced at one place and time of day is not equivalent to another produced elsewhere at a different (or the same) time of day. In addition, some energy resources are purchased for their ability to do electrical or chemical work and for these it is the Gibbs Free Energy (not BTU's) which is relevant. Energy analysis has its apples and oranges problems and one can see how dollar values can circumvent many of these problems.

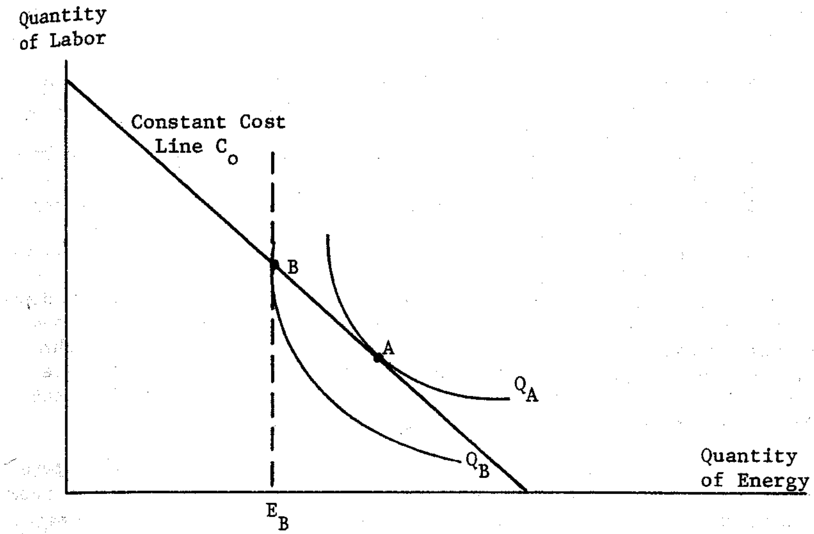
Some of the boundary problem may be solved by eliminating much of the double counting implicit in the "Odum" approach. For example, much of the infrastructure (such as schools) for a new energy development would have been needed anyway assuming that children would require schooling wherever they lived and that the new schools associated with the energy development are offset by school construction postponements in other cities.

One can, however, assume that boundary and other problems will be solved and still criticize the resultant calculations as irrelevant for two reasons. First, as has been shown above, these calculations have no information content as to the ultimate limits to human activity (long run policy). Second, if short run rather than long run policy is of concern, then of what use are these calculations? Should decision makers pay attention to them and in effect allocate resources according to energy content value weights?

As Huettner (7 and 8) has shown, even if we could synthesize perfect substitutes for any input from energy, efficient allocation of resources would require deviations from energy content pricing. Furthermore, an economy with decisions guided by energy analysis would be far different from one guided by economic analysis in terms of level of GNP and types of outputs produced. Indeed, a recent paper by Berry et. al. (1) illustrates the reduction in output accompanying the shift from an economic optimum to a thermodynamic optimum (holding costs constant). As shown in Figure 1, the thermodynamic optimum occurs at B, i.e. output level Q_B is produced with the minimum amount of energy technically feasible under current technology. The total cost of producing this level of output is C_o. The maximum amount of output that can be produced for cost C_o is shown at A, the economic optimum. By substituting energy for labor, costs can be

Figure 1

ECONOMIC OPTIMUM (A) VERSUS THERMODYNAMIC OPTIMUM (B)



Where:

Q_A is an isoquant of output level Q_A

Q_B is an isoquant of output level Q_B

C_o is the constant cost line (i.e. with input prices fixed, total costs are constant as input levels vary along the cost line)

E_B is the minimum amount of energy required to produce output Q_B under current technology

Source: Berry et. al. (1)

held constant yet output increased (output per unit of labor input is also increased as is energy use). Clearly, an economic optimum involved an economically optimal amount of thermodynamic waste.

Valuation of Environmental Services

The above paragraphs have argued that energy value weights contain virtually no information of use to decision makers. There still remains, however, the question of whether it can improve the valuation of services provided mankind by the environment. At one end of the spectrum are some economists who argue (incorrectly) that no energy or economic value should be placed on nature's services as long as quantity supplied exceeds quantity demanded (see (9) for an example).

At the other end of the spectrum are some, (4) and (14), who argue that the value of environmental services can be measured, in order of increasing preference, as:

1. the energy value of the products and services provided by the environment;
2. the solar energy used by the ecosystem in providing these products and services;
3. the energy that would be required to provide these services by alternate means.

A correct economic analysis would start with the fact that man's demand for services provided by the environment will grow through time and ultimately exceed nature's supply. Beyond that point in time, the value of these services is the cost of providing them by alternate means. Discounting this future stream of costs back to the present yields the present value of future environmental services.

Yet the cost of providing environmental services in the future (and the timing of when they must be provided by man rather than nature) is dependent on how well man protects his environment today. In effect, the ecosystem may be regarded as a complicated machine that provides mankind services through time. By keeping that machine properly maintained in the present, mankind can avoid higher maintenance costs in the future. Today's environmental services should not be valued at zero simply because today's supply provided by nature exceeds today's demand. Rather, today's services should be valued at zero only if it is the optimal solution, i.e., it minimizes the discounted present value of the costs of providing a flow of environmental services through time. One would, of course, have to project future demand for and supply of these services to obtain these future cost estimates.

While the above argument establishes a rationale for valuing today's environmental services at more than zero (even if the current supply provided by nature exceeds current demand), it does not provide guidelines for placing actual values on these services. Given the difficulties of forecasting man's demand preferences and supply capabilities far into the future, one must conclude that both economic analysis and energy analysis cannot achieve reliable answers. Yet it should also be clear that, even if accurate forecasts were available, energy analysis would not provide mankind the answers he seeks.

CONCLUDING REMARKS

The above sections have argued that non-economic energy analysis cannot achieve its primary objective of defining ultimate, sustainable limits to man's activities. In addition, energy value weights were shown to be inappropriate for short run decision making such as resource allocation. Finally, a review of various methodological problems indicated that the actual value weights calculated by energy analysis are arbitrarily inconsistent and highly variable.

Yet proponents of energy analysis frequently argue that economic values are arbitrarily inconsistent and highly variable particularly when compared to energy values. Indeed, Slesser (16) has argued that future energy requirements are more predictable than prices. In part, this notion is due to the mistaken belief that the energy required to produce a good is a purely physical phenomenon and not an economic phenomenon. Yet energy content is clearly affected by the choice of technology or plant location. Prices influence these choices and therefore energy content. Indeed, the isoquant analysis of Berry et. al. (1) shows that cost minimization involves an economically optimal amount of thermodynamic waste (Figure 1).

The greater stability or predictability of energy content values relative to economic values is also questionable in many specific cases (i.e., how accurately would anyone in 1955 have forecasted the energy required to run a computer in 1977). Furthermore, the annual quantity of oil and gas to be produced over the next 10 to 30 years is highly unpredictable while the selling price is easily predicted. The long term (10 to 30 year) price of oil and gas is clearly \$25 - \$30 per barrel (in today's dollars) since vast quantities of oil and gas substitutes and synthetics (shale oil, coal-oil, coal-gas, and so on) are producible at that price. In the short term, OPEC will increase its oil and gas prices to this level as rapidly as Western economies can absorb the price increases.

Physical laws (including those of thermodynamics) constrain man's activitites but do not dictate values by themselves. For example, many elements occur as minute fractions of the earth's crust hence are rare yet scarcity (value) can only be determined relative to man's desires for these elements and his ability to extract them. Since these desires and abilities change through time, society's values also change hence so should its cost-benefit ratios or other analytical measures of the desirability of its options. Changing economic values are merely a reflection of these changes and not an inherent defect.

The objective of this paper was to assess whether energy analysis is a correct or even a useful way of determining values. Economics tells us that values are determined by the interaction of supply and demand i.e., market values (perhaps corrected for market imperfections). From this perspective, energy analysis is woefully incomplete since it ignores many supply factors and all demand factors.

The above criticisms are not meant to downgrade the importance of questions regarding ultimate limits nor the vital insights of non-economists. On the contrary, it is clear that the insights and expertise of ecologists, environmentalists and others must be integrated into traditional economic analysis if appropriate values for environmental services and energy resources are to be obtained. Yet, even with the integration of these additional insights, economists should fare no better than non-economists in the game of defining ultimate limits. Shorter term economic analysis would be improved but there is no assurance that a series of improved short run decisions produce optimal long run decisions. Statements regarding ultimate limits are beyond the grasp of any discipline regardless of claims to the contrary.

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THE ORNL ENGINEERING-ECONOMIC MODEL OF RESIDENTIAL ENERGY USE: STRUCTURE AND RESULTS*

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ABSTRACT

The ORNL residential energy use model was developed to simulate energy use in the residential sector from 1970 through 2000. The model provides considerable detail on annual energy uses by fuel, end use, and housing type; and also estimates annual equipment installations and ownership, equipment energy requirements, structure thermal performance, fuel expenditures, equipment costs, and costs for improving thermal performance of new and existing housing units. Thus, the model provides considerable detail on residential energy uses and associated costs. These details are useful for evaluating alternative energy conservation policies, programs, and technologies for their energy and economic effects during the next quarter century.

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