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NET ENERGY ANALYSIS AND THE THEORY OF VALUE: IS IT A NEW PARADIGM FOR A PLANNED ECONOMIC SYSTEM?

ERIC L. HYMAN
Research Associate
Department of City and Regional Planning
University of North Carolina

ABSTRACT

The recent concern with depletion of non-renewable energy stocks and rising real cost of fuels has revived interest in net energy accounting and the more extreme energy theory of value. Much of this concern arose out of the work of ecologists. Net energy analysis involves accounting of energy stocks and flows and a policy goal of maximizing available gross energy output less the energy costs of producing and consuming an energy source. The energy theory of value attributes to energy the entire source of wealth, implying that all prices should be expressed in terms of energy units. Proponents argue that environmental quality impacts can also be expressed in energy terms. Like the labor theory of value, the energy theory is spurious economics. Furthermore, it should not be used as a criterion of public policy because of its failure to address the multiple-objectives characteristics of social welfare. The energy theory of value also ignores variations in the quality of energy. Nevertheless, some useful policy information can be gleaned from energy accounting.

The sun is the basic source of the earth's energy. Energy is an essential part of the economic, social, political and institutional functional systems. Planning involves an alteration of the flows and stocks of energy in some part of the system. Protection of the interests of future generations is a frequently cited justification for planning. Natural systems also have an energy budget which is rarely incorporated in the energy accounts of man.

Energy accounting is the measurement of energy stocks and flows required to produce and distribute a good or service. Net energy analysis substitutes as a criterion for policy the maximization of thermodynamic potential. Is net energy

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a better indicator of material well-being and environmental quality than market prices? Only net energy can contribute to the satisfaction of economic and non-economic goals, but it is not a sufficient factor in guiding economic and non-economic well-being. Given that natural selection and long-run social survival favor efficient utilizers of energy, which is a better guide for efficiency:

1. imperfect market prices or
2. centrally planned allocations based on net energy analysis?

Can a value theory based on energy internalize environmental externalities and place a valid price on the "public service" functions nature provides for "free?" The answer to these questions is no; the net energy approach is fundamentally inconsistent with the mission of planning, which is multiple-objective in nature.

Just as labor was a predominant concern of the 19th century, energy is a concern today. The issue was raised as early as the 1930's by Howard Scott, leader of the technocratic movement. The technocrats wanted to replace the monetary system with energy units [1]. They believed that economic theory was incapable of handling technological change and prices did not adjust in smooth equilibria because of the S-shaped supply curve of resource availability. To keep production and consumption balanced, the energy-money units would be good for only a certain period of time before which they must be spent or invested. It is worth noting that the technocrats believed they alone had the proper legitimation for leadership; that policy should be based on "fact," not public opinion.

Recently, these issues have been revived by H. T. Odum [2]. His own formulation is a resurrection of the energy theory of value. It is not what the unit of value is that matters, that could be bricks. Instead, the question is what is the source of value? An alternate school of thought has also arisen, rejecting energy fundamentalism but retaining the concept of net energy analysis. What do these alternatives to the market system have to offer inter-generational equity in economic development and environmental planning? Should planning adopt the net energy criterion?

Odum advocates a strict energy theory of value, attributing prosperity to energy flows rather than human dedication or political design. Gilliland also sees a special role for energy which is based on the erroneous assumption that "the real GNP cannot increase unless the economy is driven by energy sources that require little energy to extract." [3, p. 1054] Capital, technology, information, labor and other resources can boost productivity. In this model, energy is not just a limiting factor but *the* source of all gains and is imputed the total value of the product, its marginal value product as well as that of other inputs whose transformation can take place only with energy consumption. Using the same logic, water could be attributed all of the value of production inputs because it is often an indispensable input, so there is really no clear demarcation here.

Still, Slesser claims, "In the last analysis, energy does what labor cannot do."

[4] Some proponents also incorrectly state that economics assumes "no shortages of any inputs to the production system" and does not allow for non-substitutability among inputs [5, p. 1]. Scarcity is the backbone of economic theory. In Odum's system, value is the total potential energy expended in creating the useful work done by a good and money is an "invented feedback fluid" which is a payment for work done. However, the causal linkages are imperfect. "The accumulated part of money in the network may be much removed from the work done, of the energy inflow, or of the forces causing stress." [2, p. 6] Odum asserts that the linkages are imperfect because they are imputed an energy price independent of the outmoded monetary price. Odum claims that our economic system has not withstood the billion year test of evolutionary time that an energy-based system has withstood. "The science of economics may profit by restating more of its theorems to include power principles . . . Studies of money alone are just as incomplete as studies of mineral cycles alone, both consider pathways and flow rates without examining the driving forces that are generated from the potential energy distributions." [2, pp. 182-184]

Because of his assertion that "it is not human beings and their money that determines what is important; it is all the world's energy," Odum substitutes a crude, energy measure of value [6, p. 50]. An average unit of energy is evaluated by dividing the total energy consumption in an economy by the GNP. For example, if 10^{16} kilocalories are used in an economy with a GNP of $\$10^{12}$, then 10^4 kilocalories are presumed to be worth \$1 [7]. The value of a manufactured good is the amount of energy used by the machines in making the good. Capital depreciation is usually excluded.

Dollar costs include hidden subsidies, regulated prices and taxes. There is no money flow associated with most environmental subsidies. "We do not pay nature for each acre of land taken out of biological production, nor do we pay nature for the millions of years of work it did in making coal or oil." [3] Environmental subsidies and services are assigned an energy equivalent associated with their replacement. The conversion factor is the aggregate energy/GNP ratio and the calculation of energy is through loss of primary production. At any rate, market prices can be corrected easily to remove "distortions" caused by energy subsidies. Odum, Gilliland, and the Workshop on Energy Analysis Methodology of the International Federation of Institutions for Advanced Study assign energy values to the sun and labor. Huettner treats the sun as a free good and excludes labor since furnishing laborers with energy for living is one of the objectives of the economy [8]. Energy consumption of workers changes with taste and prosperity.

For goods produced jointly, some allocative mechanism has to be selected. Possibilities include:

1. Assign energy costs to the principal output—implies a judgment of purpose

or usefulness in a production process. This may yield inconsistent results when the same product is the principal output elsewhere;
2. Assign energy costs to all outputs of an industry so that each output has the same energy cost per dollar of final value—this technique mixes up the conflicting concepts of energy pricing and market pricing;
3. Assign energy costs on a weight basis so that each output has the same per ton energy cost—this alternative leads to illogical conclusions since energy cost could be decreased without changing energy consumption.
4. Assign energy costs so that each output has the same energy cost per kilocalorie—this method is most consistent with Odum's general rule [9].

Net energy analysis as a criterion for social action is actually a subset of explicit energy value pricing. Yet Slesser claims to reject an energy theory of value while embracing net energy analysis [4]. It has been recommended for determining the effective cut-off grade for mineral and energy resource decisions [5]. It is not necessarily true that to be economical, a process must yield more energy than the amount invested, consider pumped storage of electricity. But Gilliland rejects the economic criterion anyway [3]. Still, comparing physical units does not circumvent the choice of an acceptable pay-back period. Although the quantity of economically recoverable reserves as determined by financial costs changes each year, technology also changes the level of net energy reserves. Some energy used to build and operate gasoline stations, new towns for energy boom areas and run DOE contributes to GNP and is not a cost of energy production to be netted out.

Net energy analysis has also been proposed for planning what crops should be consumed and where they should be grown to minimize energy waste and subsidies [10]. Odum is correct in stating that "potatoes are partly made of oil" [2, p. 117], but that does not make energy minimization the ultimate goal in production efficiency. The more sophisticated agricultural and energy analysts recognize that nutritional content, climatic differences, soil, water and management practices complicate simple statements like if it takes X times more energy to produce the crop by method A than method B, then A is X times better than B [11]. Fuel used for private purposes like heating a farmhouse should not be charged to agriculture.

Thermodynamic input-output tables have been recommended as a way to trace energy flows in the system. Input-output charts draw out information which is only implicit in economic data [12]. The high degree of aggregation of available data is likely to be a problem.

Lack of standardization is a major drawback of net energy analysis at the present time. "Where, by chance, the same product has been analyzed by different methods, the results often vary widely." [5, p. 1]

Discrepancies arise in:

1. The way in which different types of energy are added together,

2. Whether or not solar energy is included,
3. The treatment of secondary energy sources,
4. Assumptions about efficiencies and losses,
5. Assumed kilocalorie values of the primary fuels and
6. The exclusion of certain inputs.

Certain resources are used as either a fuel or an organic chemical, petroleum, for example. When wood is used for construction, its energy content is in producing, transporting, and cutting the wood, not its calorie content. Net energy analysis chooses to ignore the fact that a good can have only one equilibrium price. Costs, in the economic sense of the word are opportunity costs, the value of the highest alternative use for the good.

Energy accounting is to be matched up with a series of value judgments which Odum calls "energy ethic commandments." A few of these are:

> Thou shalt not waste potential energy.
> Thou shall know what is right by its part in survival of the system.
> Thou shall do unto others as best benefits the energy flows of the system.
> Thou shall judge value by the energies spent, the energies stored, and the energy flow which is possible.
> Thou shall not take from man or nature without returning services of equal value [2, p. 244].

Basically, this is an efficiency-oriented system, with a different measure of what constitutes efficiency. The only equity ethic pertains to equilibrating energy flows, it is not necessarily correlated with the actual well-being of each sector because energy quantities of each type are not inherently useful. Man is not allotted a right to expropriate energy from nature, for instance tapping oil deposits without returning an equivalent value of energy. In fact, this restriction is impossibly rigid because energy cannot be created and is degraded in use by man and by nature. By the same reasoning, man or other animals would not be allowed to consume animals; just plants which receive their renewable energy supplies from the sun. No development of any kind would be permitted.

Energy costs do accrue at different points in time and some forms of energy are not easily storable (e.g., solar energy, heat, and electricity). The literature does not address the matter of discounting time preference or inflation. Is the time horizon perpetuity?

Some light can be shed on the energy theory of value by examining its historical analogue, the labor theory. Adam Smith distinguished between two types of value—"value in use" and "value in exchange." [13] The first concept can be related to the marginal utility of the good and the second to the market price. Adam Smith used this distinction to explain the "diamonds-water" paradox of value. Classical economic theory saw short-run price as a result of supply and demand while in the long run, a "natural price" based on costs of production prevailed. Although the "natural price" concept was discredited, it is closely related to the enthalpy or entropy price concept.

Smith, following Hume, characterized the value in exchange of a good as being "equal to the quantity of labor which enables him to purchase or command it. Labor is the real measure of the exchangeable value of all commodities." [13] Actually, Smith was using labor here as a numeraire with a money equivalent. His theory did not imply that labor was the source of all value.

Ricardo proposed a real-cost theory of value in which labor was seen as the most important factor based on empirical evidence for his own time [14]. Ricardo saw capital as embodied labor. "Fixed" capital used up in production adds to product value and "circulating" capital must be paid a return to compensate for the greater length of time between initial investment of the embodied labor and the completion of production. Ricardo erroneously excluded land rent which should be zero only if land has no alternative uses. Energy value theorists make this same mistake in not recognizing the opportunity cost of all non-energy inputs. Ricardo listed as an exceptional case, "non-reproducible goods" whose value is determined by scarcity, e.g., a da Vinci painting.

At the extreme, Marx saw labor as the sole source of all wealth. The proletariat receives only a small part of the value generated, just enough to keep them working. The "surplus value" which arises from production not exchange was appropriated by the capitalists. In contrast to neo-classical theories which rest on a subjective value basis (utility to man), Marx believed value is an *objective* property of all commodities with a materialist (physical) basis i.e., consumed labor. The energy value theorists also see value as an inherent, physical property but they focus on the items Marx left out as a gift of nature: non-human energy and natural resources. A predecessor of Marx, Sir William Petty, synthesized these two viewpoints, describing labor as the "father" and nature the "mother" of wealth. Still, Petty's theory is also incomplete [15]. Both Marx and Odum are fuzzy on the qualitative aspects of different types of labor or energy.

Neoclassical economic theory provides a more complete explanation of the sources of value. Walras, Wieser, Menger and Jevons made contributions to the theories of utility and marginalism. Marshall developed the basic core of microeconomics used today [15]. Value is derived from all of the inputs in the production function including land, labor, capital, energy, resources, technology, and expertise. The services provided by nature may contribute to value in use, but not in exchange if the quantity supplied is greater than the quantity demanded at a zero price. Georgescu-Roegen recognizes this:

> The bare truth is that we need both matter and energy to obtain either matter or energy. And since matter and energy cannot be brought to a

> common denominator; there is no way to reduce our economic balance sheet to a single coordinate—even if we were to ignore the other important factor, the disutility of labor. There is . . . no such thing as net energy . . . [16, p. xvii].

What is wrong with the energy theory of value? The most serious flaw in the approach is that it maximizes net energy while we are really interested in maximizing social welfare. Net energy has no necessary connection to social welfare whatever. Energy analysis does not yield a satisfactory decision rule for private or public investment since it does not help us satisfy human wants.

The energy theory of value incorrectly forgets that all energy comes in many different qualities. The concentration factor is defined as the quality of energy relative to the sun's energy [3].

Energy Form	*Concentration Factor*
Electricity	7000/1
Petroleum	2000/1
Photosynthetic sugar	100/1
Wind energy	50/1

A thousand BTU's of wind energy is not as easy to harness as a thousand BTU's of petroleum. Similarly, certain types of energy are more versatile; electricity is more useful to humans than firewood. The difference becomes even more striking for "natures services." Applying the $1 = 10^4 kilocalories conversion factor to the gross primary production of a salt marsh (1850 kilocalories biomass produced per acre), the marsh has an annual energy value of $4070 per acre [7]. But that dollar figure says nothing about how useful that energy is to man and what the value of services provided by the marsh really is. It is obvious that 10^4 kilocalories of marsh cordgrass is not worth as much as 10^4 kilocalories of petroleum because of the quality difference in the two forms of energy. The energy value conversion factor assumes homogeneity of energy quality, ignoring relative usability and scarcity of different energy forms. A kilocalorie of domestic coal is not as worth saving as a kilocalorie of imported oil or human labor.

The energy value conversion factor changes over time and is different from country to country. It differs within sectors of a given economy. In kilocalories per dollar, the average ratio of total energy to real GNP was 21,200 in 1963, 17,300 in 1970, and 15,800 in 1972. In 1963 the ratio was 28,665 for the primary metals sector and 22,050 in the mining sector [3, p. 1053]. The conversion factor combines energy and money units in a way lacking any good justification. It is inconsistent to make that conversion while rejecting monetary units as measures.

Use of energy values does not give us the information needed for allocation of resources in the present or across time. The marginal physical product per dollar for each resource should be equated, not just for energy resources. Also if a shift in demand for a good occurs, in the energy value system, there is no price change since the energy content of the good remains constant. Therefore, supply and demand are not equilibrated by market forces. When demand or supply shifts, efficient resource allocation depends on a price change or costless rationing in a system of perfect information and certainty. When supplies of any input are scarce, the price of a final good should increase in proportion to the amount of that input used in the product. Energy pricing is inappropriate in the short run or long run. Unfettered market price changes encourage substitution, recycling, and resource-intensiveness shift for all resources including energy. Speculation rations supplies over time. Intertemporal allocation is a normative issue that has to be faced directly.

Energy pricing leads to absurd results. For instance, at 10^4 kilocalories per dollar and a 5% discount rate, the perpetual value of hayland in Virginia is $6960/acre. Measured by willingness to pay, hay is not worth that much to human users. The average price of farmland in Virginia in 1974 was $556/acre including buildings, and hay is a low value crop [17, p. 7]. Does 1000 BTU's of hay have the same value as 1000 BTU's of soybeans? Is a child's oil painting worth more than a Picasso watercolor because oil paint contains more BTU's than watercolor paint? Is a Whooping Crane with the same biomass as a Canada Goose worth the same amount? Floods and wind erosion are high energy natural phenomena which we do not ascribe values to. At the same time, there is no reason to believe that energy values capture the truth worth of valuable ecosystem functions such as operation of the hydrologic cycle, nutrient cycles, waste assimilation, amenity values, et cetera. "To attempt to value calories . . . does an injustice to the important contribution ecological systems analysis can make to regional decision-making." [17, p. 7] Arguing that energy or environmental services are underpriced and over-utilized is a different matter entirely.

If the Odum approach is invalid, can anything be salvaged from its mandate for physical and natural system accounting? We have tended to characterize conservation in an anthropocentric way. The OECD definition of environmental quality omits any ecosystem effects which do not directly or indirectly affect human well-being [18]. Generally, we have applied this principle myopically, with a very short time horizon. The first step is to extend the time frame of concern. "A Blueprint for Survival" calls for a merging of economics and ecology [19]. Georgescu-Roegen believes such a merger would result in a swallowing up of economics, because economics is only capable of handling resource and pollution problems within the present. Yet, he also feels that even a simple analysis of material and energy availability can help. A subsequent step forward into valuing ecosystems for their own sake is highly controversial. Andrews and Waits see ecosystem functioning as a goal on its own [20]. Stone wants natural objects to be accorded legal rights [21]. Odum concurs with this value judgment: "Higher animals and to some extent plants that have complex behaviors and life cycles all with vast power requirements, were not developed for man's enjoyment, by accident, or even through some quirk of evolutionary procedure." [2] Other ecologists dismiss Odum's view as nonsense. Holling et al. call it a myth of ecology–life forms have always changed, become extinct and are replaced to the evolutionary betterment of the system [22].

The most noble attempt at reconciling natural systematics and economics was done by Georgescu-Roegen. He sees the economic process as "not a mechanical analogue, but an entropic, unidirectional transformation." [16, p. xiv] Matter and energy are gradually degraded to unavailable forms, only the accessible forms are economically useful. Entropy is a consequence of natural phenomena but is accelerated by human activity. Complete reversibility of economic processes is impossible due to qualitative changes. The first law of thermodynamics states that energy is neither created nor destroyed. The second law states that the entropy of a closed system continuously and irreversibly increases toward a maximum. The law does not specify the rate of degradation. Humorously, the laws have been described as 1) you can't win, and 2) you can't break even either.

Georgescu-Roegen asserts that the entropy law, applicable to materials as well as energy, is "the taproot of economic scarcity." [16, p. 9] Unlike the energy value theorists, he recognizes that economic efficiency implies energetic efficiency, while the converse is false. He criticizes the extrapolation of Barnett and Morse's data which pertained to an exceptional period in which our discovery of natural resources exceeded the amounts we could use [23]. This exception in the long-run trend led to the "myth of continual technological progress" which is subscribed to by Marxists as well as neoclassical economists. In fact, coal mining began 800 years ago and we have extracted half of the total quantity ever mined in the last thirty years [16, p. 20].

Although *The Limits to Growth* has been correctly criticized for assuming a simple proportional relationship between pollution and output and for extrapolating results without considering price effects on demand, many conventional economic models are equally guilty [24]. The "accelerator principle" assumes output is proportional to capital stock and prices are not explicitly contained in the static and dynamic Leontief models, Harrod-Domar models, and the Solow model, etc.

Man cannot construct a new environment. Although one dead lake may be revived by oxygenation and restocking at a high money and entropy cost, we cannot hope to do this for every lake.

Georgescu-Roegen concludes:

> All this calls for a radical change of the values everywhere. Only economists still put the cart before the horse by claiming that the growing turmoil of mankind can be eliminated if prices are right. The truth is that only if our values are right will prices also be so. We had to introduce

> progressive taxation, social security, and strict rules for forest exploitation, and now we struggle with anti-pollution laws precisely because the market mechanism by itself can never heal a wrong [16, p. xix].

Since prices cannot reflect bids of future generations and are a function of the current distribution of income, they are not objective quantities divorced from a social setting. Thus, monetary prices can and should be manipulated to reflect social concerns about natural resources according to some inter-generational policy. Although Georgescu-Roegen himself disapproves of an energy theory of value, his readers have suggested as a standard of value the ratio of free energy to energy degradation products.

So far, Georgescu-Roegen's policy prescription is similar to that of the modern economic theory of resources, pollution, and externalities [25-28]. This approach does not imply a unitary origin of value, but accepts the existence of market failures in pricing which can be corrected by intervention. However, Georgescu-Roegen differs on the ultimate implications. Eventually, any pricing system will fail when the theoretical limits of *available* energy and matter are reached. Price manipulations can only delay the inevitable. Georgescu-Roegen has not operationalized an extended conceptual framework. Hannon, although a firm advocate of an energy standard of value, sees energy severance taxes as the next best option [29].

As it now stands, energy analysis has not been linked up with systematic behavioral hypotheses. Perhaps energy analysis could be used in specifying constraints to production according to some policy. It can be used in delimiting boundaries on consumption and the means of production for designating what is socially acceptable.

Energy analysis can be used to suggest ways of improving efficiency, substituting or decreasing consumption of energy-intensive materials, and recycling. Consumption and conservation of energy on a macro-level can be forecast. The information can aid in demand management, and assessing consequences of technological trends and acute or chronic shortages. One of the most important reasons for energy accounting is the identification of comparative energy efficiencies, hidden or embodied energy consumption, and energy subsidies. As a form of technology assessment, energy analysis can provide warning of crises, although the timing is subject to uncertainty. It also recognizes that an increase in energy consumption does not imply an increase in energy available to do work.

The concept of "carrying capacity" and maximum sustained yield is implicit in energy theories of value and this important concept can be separated from the invalid parts of the theory so that we can avoid damaging the network of ecosystem support and also develop adaptive mechanisms for incorporating feedback. An analogy to the social learning school of planning theory may be noted [30].

The energy theory of value also tries to eliminate looking at common property resources as free goods by imputing energy values to them. This is a desirable goal, but is done via a fallacious methodology. The first step in assigning economic values may be discovering an ecosystem production function or set of physical measures.

Although it may serve as one policy input, decisions made solely on the basis of energy accounting are incomplete. It can never replace economic analysis which is the most complete policy input. Proponents who urge adoption of net energy analysis as *the* only criterion for management of public lands, energy resources, regulating energy rates, setting tax incentives, and creating research development and demonstration priorities are wrong.[1] Energy diagrams are not, by themselves, a rational base for planning since they are not inter-generational or intra-generational welfare functions [31].

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Direct reprint requests to:

Eric Hyman
Research Associate
Department of City and Regional Planning
University of North Carolina
Chapel Hill, N.C. 27514