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A0005 *Value Theory and Energy*

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Glossary

G0005 **diminishing marginal utility** The desire for one additional unit declines with successive units of the good.

G0010 **embodied energy** The direct and indirect energy required to produce a good or service.

G0015 **evolution** In natural systems it has three components: (i) generation of genetic variation by random mutations or sexual recombination, (ii) natural selection by relative reproductive success, and (iii) transmission via information stored in the genes.

G0020 **valuation** The process of assessing the contribution of a particular object or action to meeting a particular goal, whether or not that contribution is fully perceived by the individual.

G0025 **value** The contribution of an object or action to specific goals, objectives, or conditions.

G0030 **value systems** Intrapsychic constellations of norms and precepts that guide human judgment and action. They refer to the normative and moral frameworks people use to assign importance and necessity to their beliefs and actions.

P0005 The concepts of value system, value, and valuation have many meanings and interpretations and a long history in several disciplines. This article provides a survey of some of these meanings to set the stage for a discussion of the relationship between energy and value. There is clearly not one "correct" set of concepts or techniques to address this important issue. Rather, there is a need for conceptual pluralism and thinking "outside the box." After a long and interesting history, the issue of value is now going through another period of rapid development that should help us to make better, and more sustainable, decisions, not only as individuals but also as groups, communities, and stewards of the entire planet.

1. DEFINITIONS OF VALUE S0005

P0010 The terms value system, value, and valuation have a range of meanings in different disciplines. The definitions provided here are used in this article in order to impose some consistency and to put the range of prior and current definitions in context.

P0015 Value systems refer to intrapsychic constellations of norms and precepts that guide human judgment and action. They refer to the normative and moral frameworks people use to assign importance and necessity to their beliefs and actions. Because value systems frame how people assign importance to things and activities, they also imply internal objectives. Value systems are thus internal to individuals but are the result of complex patterns of acculturation and may be externally manipulated through, for example, advertising.

P0020 Value refers to the contribution of an object or action to specific goals, objectives, or conditions. The value of an object or action may be tightly coupled with an individual's value system because the latter determines the relative importance to the individual of an action or object relative to other actions or objects within the perceived world. However, people's perceptions are limited, they do not have perfect information, and they have limited capacity to process the information they do possess. An object or activity may therefore contribute to meeting an individual's goals without the individual being fully (or even vaguely) aware of the connection. The value of an object or action therefore needs to be assessed both from the subjective standpoint of individuals and their internal value systems and from the

objective standpoint of what we may know from other sources about the connection.

P0025 Valuation is the process of assessing the contribution of a particular object or action to meeting a particular goal, whether or not that contribution is fully perceived by the individual. One can thus (and must if one hopes to be comprehensive and accurate) do valuation from multiple perspectives, using multiple methods (including both subjective and objective), against multiple goals.

P0030 Intrinsic value refers more to the goal or basis for valuation and the protection of the "rights" of these goals to exist. For example, if one says that nature has intrinsic value, one is really claiming that protecting nature is an important goal in itself. Values (as defined previously) are based on the contribution that something makes to achieving goals (directly or indirectly). One could thus talk about the value of an object or action in terms of its contribution to the goal of preserving nature but not about the intrinsic value of nature. Therefore, intrinsic value is a confusing and unnecessary term and will not be used further. One should more accurately refer to the intrinsic rights of nature to qualify as a goal against which to assess value, in addition to the more conventional economic goals.

S0010 2. HISTORY OF ECONOMIC CONCEPTS OF VALUE

P0035 The history of economic thought is replete with struggles to establish the meaning of value, both what is it and how is it measured. Aristotle first distinguished between value in use and value in exchange. The distinction between use and exchange value has been "resolved" several times, but it remains an important issue even today. For example, the diamond–water paradox observed that although water has infinite or indefinite value, being necessary for life, its exchange value is low, whereas unessential diamonds bear a high exchange value. Following this observation, there was widespread recognition of the distinction between exchange value and use value of goods. Galiani defined value to mean a relation of subjective equivalence between a quantity of one commodity and a quantity of another. He noted that this value depends on utility and scarcity (*utilita et rarita*). Two hundred years later, Adam Smith distinguished between exchange value and use value of goods by citing the diamond–water paradox but used it to dismiss use value as a basis for exchange value. Smith formulated a cost of production theory of value, whereby wages, profit, and rent are the three original sources of exchange value. In his famous beaver–deer example, he suggested a labor theory of exchange value: If it takes twice the labor to kill a beaver than to kill a deer, one beaver will sell for as much as two deer. He also suggested a labor-disutility theory of exchange value, noting that goods exchange based on the unpleasantness of the labor required to bring the goods to market. However, it is significant that Smith limited his labor theory to "that early and rude state of society which precedes both the accumulation of stock and the appropriation of land." In other words, when labor is the only scarce factor, goods will exchange based on the ratio of labor use.

P0040 In addition to formulating his hypothesis regarding the origins of exchange value, Smith sought to establish a unit of measure of value or what he termed the real measure or real price of a good. He proposed that "labor alone … never varying in its own value, is alone the ultimate and real standard" of the values of all commodities. Hence, labor could be a numeraire, and it had special properties of invariant value.

P0045 Ricardo also sought an invariant unit of measure for value. He believed that there was no commodity, including labor, whose exchange value could serve as an invariant standard to measure the variation in exchange values of other commodities. Also, it was not possible to add up commodities to measure national wealth or production with only exchange ratios. According to Ricardo, this measure must be invariant to changes in relative factor rewards (i.e., capital versus labor) and be a commodity whose capital and labor use did not vary over time (i.e., no technological change). He proposed that both wheat and gold possessed these properties. Although not creating value, they could measure value.

P0050 Although Ricardo had several followers, including J. S. Mill and Marx, labor theories of value and the pursuit of an invariant standard of value waned in the late 19th century. This was partially in response to the logic of the utilitarians, such as Menger, Gossen, Jevons, and Walras, who argued that exchange value was based on both utility and scarcity. Sraffa, a noted Ricardian scholar, sought to resurrect the classical pursuit of a theory of value independent of demand or value in use. In his 1960 book, "Production of Commodities by Means of Commodities: Prelude to a Critique of Economic Theory," Sraffa established conditions under which exchange ratios between commodities can be determined based on their use

in production (i.e., a set of commodity prices that would exhaust the total product). These exchange ratios were not based on any optimality or marginality conditions. Instead, Sraffa divided commodities into basic (goods that entered into all production processes) and nonbasic, and he showed that an invariant standard of value would be a combination of basic commodities reflecting average input proportions in production. This contrived "commodity" would then be usable as a measure of national wealth or income.

P0055 The "marginal" revolution in value theory originated with the confluence of several related streams of economic thought in the 20th century. Menger proposed there were different categories of wants or desires, such as food, shelter, and clothing, that could be ordered in terms of their subjective importance. Within each category, there is an ordered sequence of desires for successive increments of each good. He postulated that the intensity of desire for one additional unit declines with successive units of the good. Replacing the term "desire for one additional unit" with the term "marginal utility," we thus have the economic principle of diminishing marginal utility.

P0060 The idea that people have different, but ordered, categories of wants or desires raises the critical issue of whether trade-offs exist between categories. If individuals weight categories, it implies a trade-off. At one extreme, categories may be lexicographically ordered, like words in a dictionary. One level of want must be satisfied before a lower level becomes relevant in the process of valuation. There are no trade-offs between levels of wants. For example, the need for caloric intake is likely superior to that of recreational pleasure: No number of recreational opportunities will likely substitute for an insufficient diet. In the lexicographic case, individuals would use their monetary resources hierarchically, satisfying higher order wants and needs first. When a higher order want or need is at risk, the individual would take resources away from lower level ones until higher level needs were satisfied. Lexicographic preferences do not mean monetary valuation is impossible because individuals would still be able to state how much of their resources they would be willing to sacrifice for a good or service; however, this may be all their resources if a high-level need is at risk.

P0065 More problematic for valuation are instances in which basic needs cannot be satisfied by the resources at an individual's disposal (i.e., time or money). Similar to Menger, Ekins and Max-Neef suggested the universality of basic human needs, including subsistence, affection, protection, understanding, leisure, identity, and freedom. Although one can imagine needs such as affection being "purchasable" with money, or freedom being purchasable by migration, many of these needs may not be satisfied by money or time because individuals simply may not consider them to be purchasable by money or time. Thus, not only is it possible that trade-offs between needs will not be possible but also some needs may not be reducible to money or time.

P0070 Lancaster introduced the concept of consumption technology, whereby consumers consider characteristics of goods. For example, food may be evaluated on caloric, protein, or vitamin content. Different foods are substitutable depending on the composition of their characteristics. People allocate their budget across characteristics, purchasing goods that are efficient sources of desired characteristics. The technological inability to substitute characteristics may restrict the margins on which environmental goods and services can be valued. For example, although health may be valued, and individuals would be willing to pay for it, the proper mix of calories, protein, and vitamins may make marginal increases or decrements in one of these characteristics either very highly valued or of very low value.

P0075 Building on this insight, multiattribute utility theory formalizes the utility-generating technology by proposing that total utility is a function of the characteristics of goods or services. A simple example is the case in which utility, U, from food consumption is a linear function of the caloric, C, protein, P, and vitamin, V, content:

$$U = aC + bP + cV,$$

where the parameters a–c reflect the weighting of three factors in determining utility for food consumption. When utilities are measurable in monetary willingness to pay or willingness to accept compensation, these parameters represent the marginal monetary value of each characteristic. This logic forms the basis for hedonic pricing models of valuation (discussed later) whereby the value of market goods such as a house depends on the characteristics of the house and its location as well as surrounding environmental amenities or disamenities.

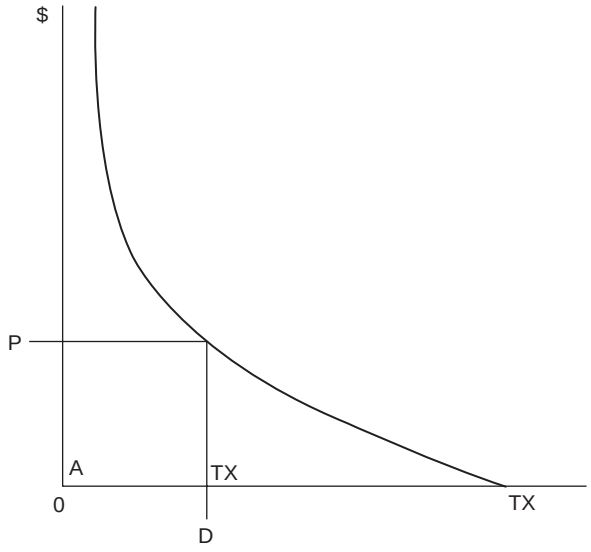
P0080 Gossen proposed that in order to maximize satisfaction from a good, such as labor or money, an individual must allocate that good across different uses to equate its marginal utility in each use. Hence, AU:1 marginal utility would provide a basis for explaining exchange value. If we treat things such as iron, cement, fertilizer, natural agents, and labor as incomplete consumable goods, the marginal utility

of the goods they produce can be used to explain their exchange value. This logic established a theory of value. It also demonstrated that exchange values could be based on marginal use value.

P0085 While the classical theorists sought a standard physical commodity unit for measuring exchange value, neoclassical theorists substituted utility for such a commodity. Because value was assumed to be determined solely by consumption utility on the margin, and consumers were assumed to allocate money optimally across uses (in possession of perfect information, no externalities, fixed preferences, and no interpersonal effects), the marginal utility of money was the same for an individual in all its uses. Money thus became the standard unit of measure.

P0090 The general optimization model of labor/leisure and consumption/saving given time and wealth constraints would yield equivalencies of goods for money, goods for time, and time for money. Time or money can thus be used as a standard of measure of use value; how much time or money will a person willingly sacrifice to obtain commodity X?

P0095 The utility-based values of goods and services are reflected in people's willingness to pay (WTP) to attain them or their willingness to accept compensation to forego them (WTA). WTP and WTA become measures of these values. They may be based on small marginal changes in the availability of these goods and services or on larger changes, including their complete absence or presence. These valuations are reflected in Fig. 1. Let the curve D represent the WTP for each unit of the good or service, T, for an individual or group. This is a marginal WTP. The total WTP for T_0 units of T is the aggregated areas A + B. Area A may be very large for goods or services that have some utility threshold where the good becomes increasingly valuable as it becomes scarcer. This is true for many ecological goods and services, including life-support goods such as oxygen and water; the marginal value is finite but the total value is indeterminate. This is the distinction that lies behind the diamond–water paradox discussed previously.



F0005 AU:4 ***FIGURE 1*** Utility- and exchange-based values of goods and services.

P0100 Exchange-based values are reflected in the prices, P, at which the goods or services are exchanged. When supply is T_0, and the item is sold competitively, a price P is determined that clears the market. These prices also reflect the marginal valuations placed on available quantities around T_0. Therefore, prices reflect marginal values when there are markets for the goods or services.The total exchange value of T_0 is $P \times T_0$. This is an observable market value when there are markets to observe. However, when there are no such markets, P must be determined indirectly, and $P \times T_0$ would represent a pseudo-market value. This would be the total exchange value of the good if there were a market with an available supply of T_0.

P0105 Measures of economic value are assumed to reflect the difference that something makes to satisfaction of human preferences. If something is attainable only at a cost, then the difference it makes to satisfy preferences is the difference between its utility and the cost of attaining it. Formal concepts of compensating and equivalent variations are used to reflect this difference. For example, suppose in Fig. 1 that T_0 is available at a cost of P. Under these terms of availability, the welfare difference made by T_0 is area A. The marginal value that alterations in availability make to welfare would be reflected by changes in area A. Using timber from trees as an example, suppose timber is harvested at a cost of P per unit of timber. The value of trees, per se, would be represented by area A, which is less than A + B.

P0110 Thus conceived, the basic notion of value that guides neoclassical economic thought is inherently anthropocentric or instrumental. Although value can generally mean the contribution to a goal, objective, desired condition, etc., the mental model used by neoclassical economists is that value is based on want satisfaction, pleasure, or utility goals. Things have value insofar as they propel individuals toward meeting pleasure and need objectives. Values of objects in the environment can be considered on the margin as well as on the whole (i.e., the value of one additional tree versus the value of all trees).

Although value relates to the utility of a thing, the actual measurement of value requires some objective measure of the degree to which the thing improves pleasure, well-being, and happiness.

P0115 In a finite world, the resources people have available to meet their personal objectives are limited. Economists have thus developed an extensive theory of how people behave in the presence of constraints on feasible activities. The working hypothesis is that people make decisions in order to optimize satisfaction, pleasure, or utility. This optimization always takes place in the presence of constraints, such as income, wealth, time, and resource supply. Optimization thus yields a set of possible decisions in most real-world situations—when constraints change, so do the decisions.

P0120 The essence of this perspective is that the economic world works largely deterministically, moving from one equilibrium to another in relatively stable fashion, and responds to changes in constraints in a predictable fashion. The determination of equilibrium is a resultant of conflicting forces, such as supply and demand, or unlimited wants and limited means. Although there are instances of instability, disequilibria, and indeterminism, these are treated as exceptions rather than the rule.

P0125 Since individuals can be observed making choices between objects in the marketplace while operating within the limits of income and time, economists have developed measures of value as imputations from these observed choices. Although monetary measures of value are not the only possible yardstick, they are convenient since many choices involve the use of money. Hence, if you are observed to pay $10 for a bottle of wine, the imputation is that you value wine to be at least $10 and are willing to make a trade-off of $10 worth of other things to obtain that bottle. The money has no intrinsic value but represents other things you could have purchased. Time is often considered another yardstick of value; if you spend 2 h golfing, the imputation is that you value the golf experience to be worth more than 2 h spent in other activities. Value is thus a resultant of the expressed tastes and preferences of persons and the limited means with which objects can be pursued. As a result, the scarcer the object of desire, the greater its value will be on the margin.

P0130 Importantly, the "technologies" of pleasure and production allow for some substitution between things. A variety of goods can induce pleasure and are thus treated conceptually as utility substitutes. A bear may substitute for an elk in consumption, hunting, and a wildlife viewing experience even though bears and elk are not substitutes in terms of ecosystem function. On the production side, inputs are also considered to be substitutable for one another. Machines and technology can substitute for people and natural inputs. Clearly, economists recognize that the relations between goods and services are often more complicated. For malnourished people, sugar is no technological substitute for protein, even though they both provide calories. As discussed previously, preferences may be lexicographic: Some things are more important than others and cannot be substituted for lower level wants or needs. On the production side, no number of lumbermen is a substitute for timber when there is no timber. Production may require certain inputs, but at the same time there may be substitutability between others. As Krutilla suggests, there may be close substitutes for conventional natural resources, such as timber and coal, but not for natural ecological systems.

P0135 The neoclassical perspective also assumes that tastes and preferences are fixed and given, and that the fundamental economic "problem" consists of optimally satisfying those preferences. Tastes and preferences usually do not change rapidly and, in the short term, this basic assumption is probably not too bad. In the longer term, however, it does not make sense to assume tastes and preferences are fixed. People's preferences do change over longer time frames, as the existence of a robust advertising industry attests. This observation is important because sustainability is an inherently long-term concept and ecosystem services are expected to continue far into the future. This fact is very disturbing for many economists because it takes away the easy definition of what is optimal. If tastes and preferences are fixed and given, then we can adopt a stance of "consumer sovereignty" and just give people what they want. We do not have to know or care why they want it; we just have to satisfy their preferences efficiently.

P0140 However, if preferences change over time and under the influence of education, advertising, changing cultural assumptions, variations in abundance and scarcity, etc., we need a different criterion for what is optimal. Moreover, we have to determine how preferences change, how they relate to this new criterion, and how they can or should be changed to satisfy the new criterion. One alternative for the new criterion is sustainability, or more completely a set of criteria: sustainable scale (size of the economic subsystem), fair distribution, and efficient allocation. This set of criteria implies a two-tiered decision

process of first coming to a social consensus on a sustainable scale and fair distribution and then using the marketplace and other social institutions, such as education and advertising, to implement these decisions. This might be called community sovereignty as opposed to consumer sovereignty. It makes most economists very uncomfortable to stray from consumer sovereignty because it raises the following question: If tastes and preferences can change, then who is going to decide how to change them? There is a real danger that a totalitarian government might be employed to manipulate preferences to conform to the desires of a select elite rather than the individuals in society.

P0145 Here, two points need to be kept in mind: Preferences are already being manipulated every day, and we can just as easily apply open democratic principles to the problem as hidden or totalitarian principles in deciding how to manipulate preferences. Viewed in this light, the aforementioned question is transformed: Do we want preferences to be manipulated unconsciously, either by a dictatorial government or by big business acting through advertising, or do we want to formulate preferences consciously based on social dialogue and consensus with a higher goal in mind? Either way, we believe that this issue that can no longer be avoided and is one that will best be handled using open democratic principles and innovative thinking. This leads us back to the role of individual preferences in determining value. If individual preferences change in response to education, advertising, and peer pressure, then value cannot solely originate with individual preferences. Values ultimately originate from within the constellation of shared goals to which a society aspires—value systems—as well as the availability of "production technologies" that transform things into satisfaction of human needs.

P0150 In addition to income and education, time places constraints on value creation. Constraints of time and intertemporal substitutabilities create temporal implications for value. Neoclassical economists presume that a present time preference exists due to limited time horizons and concerns for uncertainty in the future. This means individuals will discount values of things in the future in comparison to the same things in the present. If I have an equal endowment of apples now and a year from now, I would place a greater value on having an apple now than on having an apple 1 year from now. The ability to convert things to money in the presence of positive financial interest rates will therefore result in the "optimizing individual" discounting things in the future.

P0155 In contrast to economists' traditional assumptions of positive time preferences, or positive discount rates, psychologists suggest time preference is more complicated. For example, Lowenstein and Prelec find that in some circumstances people behave as if they have negative time preference, preferring more in the future to more now. The authors suggest this is due to dread, the anticipation of savoring better conditions in the future, and the aversion to loss. However, this negative time preference may not be operative when the time period is ambiguous. The implications of such experimental results for discounting in environmental policy settings are not clear, but they do raise serious questions about the standard practice of discounting future environmental benefits.

3. ECOLOGICAL CONCEPTS OF VALUE

S0015

P0160 Value is a term that most ecologists and other natural scientists would prefer not to use at all, except perhaps in its common usage as a reference to the magnitude of a number (e.g., "the value of parameter *b* is 9.32"). Using the definitions provided earlier, ecosystems and nonhuman species are presumed not to be pursuing any conscious goals, and therefore they do not have a value system. Likewise, one cannot talk about value as the degree to which an item contributes to achieving a goal in this context since there is no conscious goal being pursued. Nevertheless, some concepts of value are important in the natural sciences and are in fact quite commonly used.

P0165 If one limits the concept of value to the degree to which an item contributes to an objective or condition in a system, then we can see how natural scientists use the concept of value to talk about causal relationships between different parts of a system. For example, one could talk about the value of particular tree species in controlling soil erosion in a high slope area or the value of fires in recycling nutrients in a forest.

P0170 There are other ways in which the concept of value is used in the natural sciences. For example, a core organizing principle of biology is evolution by natural selection. Evolution in natural systems has three components: generation of genetic variation by random mutations or sexual recombination, natural selection by relative reproductive success, and transmission via information stored in the genes.

Although this process does not require conscious, goal-directed behavior on the part of any of its participants, one can still think of the overall process as being "goal-directed." The goal of survival is embedded in the objective function of natural selection. Although the process occurs without consciousness of this goal, individuals and species as a whole can be observed to behave as if they were pursuing the goal of survival. Thus, one often hears evolutionary biologists talk about the survival value of particular traits in organisms. Natural selection models, which maximize the fitness of individuals, are not only testable but also bear close similarities to economic utility maximization models.

P0175 In addition, the idea of coevolution among a whole group of interacting species raises the possibility that one species is valuable to the survival of another species. Extending this logic to the coevolution of humans and other species, we can talk of the value of natural ecosystems and their components in terms of their contribution to human survival.

P0180 Ecologists and physical scientists have also proposed an energy theory of value to either complement or replace the standard neoclassical theory of subjective utility-based value. It is based on thermodynamic principles in which solar energy is recognized to be the only primary input to the global ecosystem.

P0185 This theory of value represents a return to the classical ideas of Ricardo and Sraffa but with some important distinctions. The classical economists recognized that if they could identify a primary input to the production process then they could explain exchange values based on production relationships. The problem was that neither labor nor any other single commodity was really primary since they all require each other for their production. The traditional primary factors are really intermediate factors of production.

P0190 The classical economists were writing before the science of thermodynamics had been fully developed. Energy—or, more correctly, free or available energy defined as the ability to do work—has special characteristics that satisfy the criteria for a primary input described previously:

1. Energy is ubiquitous.
2. It is a property of all the commodities produced in economic and ecological systems.
3. It is an essential input to all production processes.
4. Although other commodities can provide alternative sources for the energy required to drive systems, the essential property of energy (the ability to do work) cannot be substituted.
5. At the global scale, the earth is essentially a closed system in thermodynamic terms (only energy crosses the boundary), so at this scale it is the only primary input.
6. Smith's three sources of exchange value (wages, profits, and rent) are intermediate inputs in this global scheme and interconvertable using the primary energy input.

Available energy is thus the only basic commodity and is ultimately the only scarce factor of production, thereby satisfying the criteria for a production-based theory that can explain exchange values.

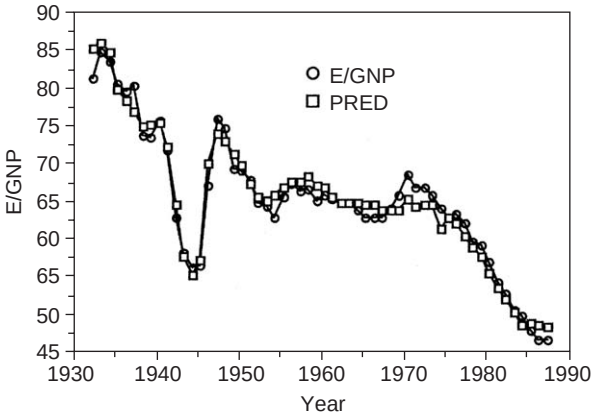
P0195 Energy-based concepts of value must follow the basic principles of energy conversion. The first law of thermodynamics states that energy and matter are conserved. However, this law essentially refers to heat energy and mechanical work (raw energy or the bomb calorimeter energy). The ability to do work is related to the degree of organization or order of a thing relative to its environment, not its raw heat content. Heat must be organized as a temperature gradient between a high-temperature source and a low-temperature sink in order for useful work to be done. Similarly, complex manufactured goods such as cars have an ability to do work that is not related to their raw energy content but may be related to their degree of organization relative to their environment. The second law of thermodynamics states that useful energy (organization) always dissipates (entropy or disorder always increases) within an isolated system. In order to maintain organized structures (e.g., an economy) one must constantly add organized, low-entropy energy from outside the system. The earth as a whole is just such a system. In thermodynamic terms, it is essentially closed (i.e., energy, but not matter, crosses the boundaries). Of course, some matter does cross the boundaries (i.e., meteorites and spacecraft) so the earth system is at least slightly open, but these flows of matter are very small compared to the flow of solar energy in and heat energy out.

P0200 Estimating total energy consumption for an economy is not a straightforward matter because not all fuels are of the same quality; that is, they vary in their available energy, degree of organization, or ability to do work. Electricity, for example, is more versatile and cleaner in end use than petroleum, and it also requires more energy to produce. In a oil-fired power plant it takes 3–5 kcal of oil to produce 1 kcal of electricity. Thus, adding up the raw heat equivalents

of the various forms of fuel consumed by an economy without accounting for fuel quality can radically distort the picture, especially if the mix of fuel types is changing over time.

P0205 An energy theory of value thus posits that, at least at the global scale, free or available energy from the sun (plus past solar energy stored as fossil fuels and residual heat from the earth's core) are the only primary inputs to the system. Labor, manufactured capital, and natural capital are intermediate inputs. Thus, one could base a theory of value on the use in production of available energy that avoids the problems that the classical economists encountered when trying to explain exchange values in economic systems.

P0210 There have been a few attempts to empirically test this theory using both time series data and cross-sectional data. Studies that have tried to adjust for fuel quality have shown a very close relationship between available energy consumption and economic output. Cleveland *et al.* and Kaufmann have shown that almost all the changes in energy:gross national product (E:GNP) (or energy:gross domestic product) ratios in the United States and Organization for Economic Cooperation and Development countries can be explained by changes in fuel quality and the percentage of personal consumption expenditures (PCE) spent directly on fuel. The latter effect is due to the fact that PCE is a component of GNP and spending more on fuel directly will raise GNP without changing real economic output. Figure 2 is an example of the explanatory power of this relationship for the U.S. economy from 1932 to 1987. Much of the apparent gain in energy efficiency (decreasing E:GNP ratio) is due to shifts to higher quality fuels (e.g., natural gas and primary electricity) from lower quality ones (e.g., coal). Renewable energy sources are generally lower quality and shifts to them may cause significant increases in the E:GNP ratio.



F0010 ***FIGURE 2*** The energy:GNP ratio for the U.S. economy from 1932 to 1987. The predicted ratio (PRED) is based on a regression model with percentage of primary energy from petroleum and from electricity and percentage of personal consumption expenditures spent on fuel as independent variables ($R^2 = 0.96$). From Cleveland *et al.* (1984) and Kaufmann (1992).

P0215 Another way of looking at the relationship between available energy and economic output uses cross-sectional rather than time-series data. This avoids some of the problems associated with changes in fuel mix and distortions in GNP. For example, Costanza and Costanza and Herendeen used an 87-sector input–output model of the U.S. economy for 1963, 1967, and 1973, modified to include households and government as endogenous sectors (to include labor and government energy costs), to investigate the relationship between direct and indirect energy consumption (embodied energy) and dollar value of output. They found that dollar value of sector output was highly correlated ($R^2 = 0.85$–0.98) with embodied energy when this was calculated including the energy costs of labor, government, and environmental inputs (although not with direct energy consumption or embodied energy calculated excluding labor and government energy costs). Thus, if one makes some necessary adjustments to estimates of energy consumption in order to better assess available energy, it appears that the empirical link between available energy cost and economic value is rather strong.

P0220 Some neoclassical economists have criticized the energy theory of value as an attempt to define value independent of consumer preferences. This criticism is, on the one hand, axiomatic since a major purpose of an energy theory of value was to establish a theory of value not completely determined by individual preferences. On the other hand, techniques for calculating embodied energy utilize economic input–output tables. These tables summarize production interdependencies but they are not completely independent of consumer preferences, which helped to structure the production interdependencies over time.

P0225 In summary, the energy theory of value overcomes some of the problems of earlier production-based theories of value encountered by the classical economists and does a fairly good job of explaining exchange values empirically in the few cases in which it has been tested. Despite the controversy and ongoing debate about the validity of an energy theory of value, it seems to be the only reasonably successful attempt to operationalize a general biophysical theory of value.

S0020 ## 4. COST AND PRICE

P0230 Energy (and earlier labor) theories of value are inherently based on relative production costs. Thus, it is more accurate to speak of energy cost or labor cost and not energy value or labor value. However, in economic systems it is well-known that cost and price will, in general, come to equilibrium. This is the essence of the basic ideas of supply and demand. If a commodity has a much higher value than its cost of production, profits will be high and more of the commodity will be produced (with increasing marginal cost) until cost just equals price and profits are 0 for the last unit of production. Likewise, if cost is much higher than price, less will be produced until they are again equal. Therefore, a method that estimates costs, although not technically estimating price or value, should in fact be a fairly good approximation to price and value in cases in which markets have reached an approximate equilibrium. Since markets are never really in equilibrium and there are many types of market failure to complicate things, we would expect there to be some divergence between cost and price in real systems. The question then becomes the following: Are the commodities overpriced or underpriced? Should the energy costs be taken as the standard and market exchange values be adjusted, or should the energy costs be ignored and the market prices taken as the standard? Given, on the one hand, the enormous data requirements to calculate energy costs accurately and, on the other hand, the pervasive market imperfections complicating market prices, there is no unambiguous correct answer. However, one can learn much by examining energy costs and market prices and comparing their degree of correspondence. Costanza did just that at the aggregate level of an 87-sector input–output model and found a fairly high degree of correspondence for those sectors in which markets were fairly functional and lacking severe externalities and a low correspondence for those sectors in which they were not (basically, the extractive sectors at this level of aggregation).

P0235 As discussed previously, embodied labor costs alone would give a much poorer approximation to exchange value than embodied energy costs since embodied labor is a less comprehensive measure of total cost than embodied energy, especially in industrial economies in which capital, direct energy, and government expenditures are significant components of total cost relative to labor.

S0025 ## 5. CONCLUSION

P0240 A modern approach to value and valuation needs to be pluralistic, including a broad range of both subjective and objective methods. Embodied energy cost has proven to be an important element in this spectrum of approaches, and it makes the link with the classical economists' production-based theories of value. Embodied energy should more accurately be called a theory of cost rather than value, although the two are obviously related in well-functioning markets. The most productive approach is to keep these distinctions in mind while applying a range of subjective and objective methods in order to obtain a clearer picture of the complex nature of value and, ultimately, to do a better job of valuation against a much broader range of social goals.

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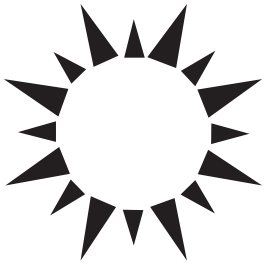

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