Forty-first North American Wildlife Conference. 1976.

Net Benefits to Society from Alternative Energy Investments[1]

Howard T. Odum
Department of Environmental Engineering and Center for Wetlands, University of Florida, Gainesville

As energy resources for the economy of man begin to be limited and as more and more impacts of man's economy on the environment develop, procedures are needed for evaluating choices as to which energy sources are valuable and which environmental management plans are valuable. Since the economy of man and the economy of nature both run on energy, energy evaluation can be used to determine relative contributions of energy sources and environmental systems. This paper summarizes the way energy evaluation using energy quality factors gives us insight to which are best net benefits to society and to nature.

The interplay of environment and economic systems of man form one system to which many energy sources contribute. Sunlight, winds, waters, waves, tides, etc. come regularly from the renewable flows of the earth. Fossil and nuclear fuels flow through the technological part of the system mainly from unrenewable sources. One way of visualizing the combined actions of the many sources is as a large wheel (Fig. 1). Energies flow in from external sectors, become part of the circulating matter and energy within the economy of man, do work gradually as the energy flows around the economy, are released as used energy, and finally pass out as dispersed heat. In each case some part of the circulating energy of the main economy reaches out to engage the external energy source. Energy is pumped, captured, and processed to the economy with feedback interactions. Although Figure 1 can be thought of as an analogy, the symbols used are those of the energy language, and the same diagram is correct for an economy, for a wheel, or any other system. For more on energy analysis, diagramming and evaluations, see book summaries (Odum 1971, 1976).

To visualize the way energies are combined and gradually released, imagine Figure 1 as a rotating wheel with many people giving it impetus with their hands. Each hand contributes some momentum although the rotating wheel receives and stores the energy letting it go against friction gradually over the whole circle of the wheel.

Money flows as a counter current to energy making a closed circle within the economy. The action of supply and demand on prices helps to even out the distribution of energy around the wheel. Wherever some limiting factor develops in the circle of exchanges, prices rise, and that sector speeds up. In the wheel analogy as in the real economy the value of incoming energy is not recognized locally by money exchange or prices until the energy has been absorbed into the circulation that is shared by the whole system. Money paid for bringing in energy from the outside is not paid according to the energy content of the

[1]Work supported by Contract E-(40-1)-4398 between the Energy Research and Development Administration and the University of Florida.

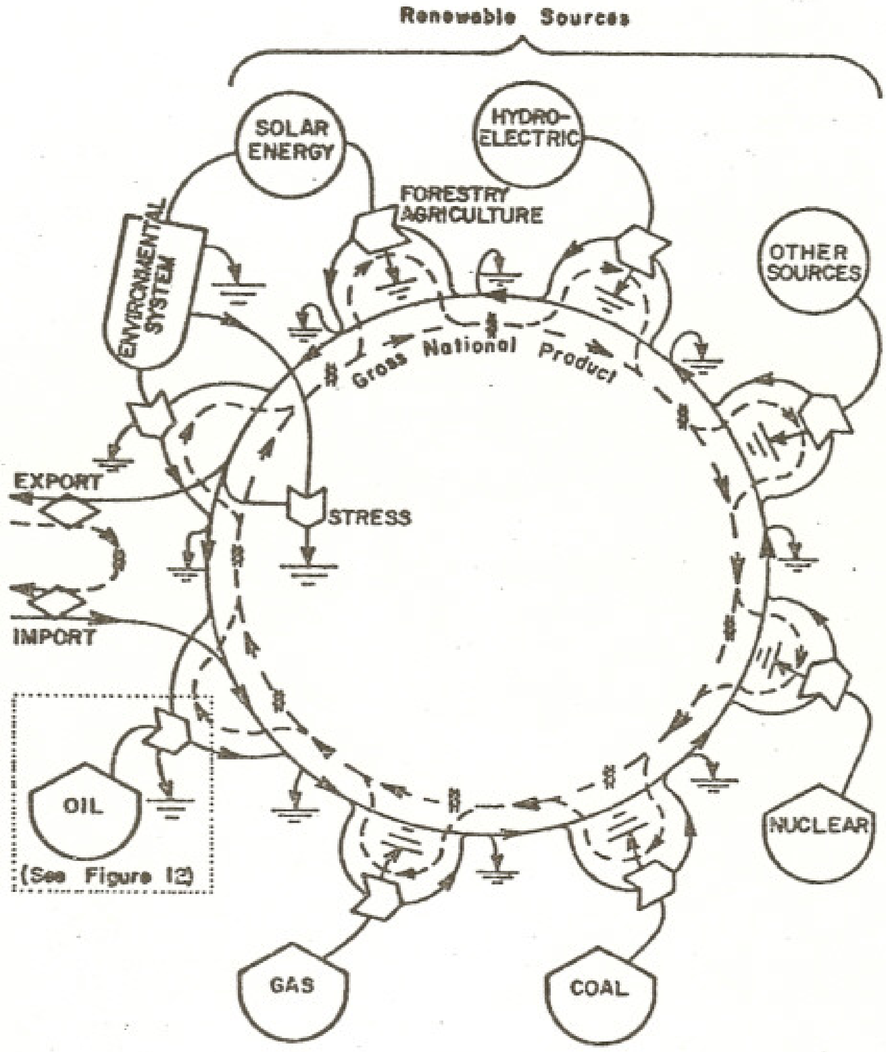


Figure 1. An energy model of the United States for examining the sectors concerned with inflows of external energy. Energy circulates counter clockwise and money clockwise.

inflows, but is paid to and is in proportion to the feedback energy from the main circle of the economy.

In each sector that brings in energy from the outside there are feedbacks of energy from the main circulation to do the work of processing. In some cases much energy is feeding out to interact with the incoming energy; in other cases very little feedback energy is required.

One question facing a country in times of energy shortage is which of the sources impinging on the economy wheel are supplying much energy and which are supplying little or draining energy? Which of those sources impinging on the economy are taking back out of the energy circulation more energy than they deliver? Which of the energy sources have more net energy?

Figure 2 shows three flows in the external sector, like those shown in Figure 1: external energy inflow, feedback of work from the main economy to the point of processing interaction, and yield of energy being pumped from the interaction into the main economy. This diagram may be used to define net energy and identify which energy sources are rich. If the feedback energy that is required is less than that yielded the source is a net energy contributor. Such sources are defined as *primary sources.* If the yield is less than the energy fed back, the source is using more than it contributes. It is partially a consumer. It does contribute some energy. Let us call such sources, that are without net yield of energy, *secondary sources.* To evaluate energy contributions of different types, energy quality is important.

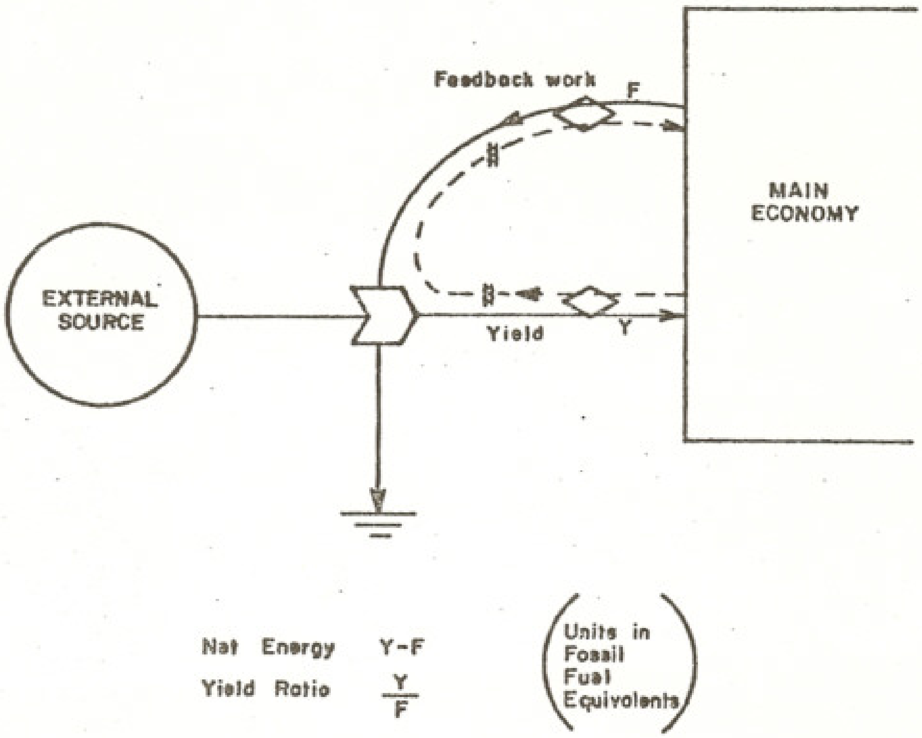


Figure 2. Energy flows where a feedback from the main economy (F) interacts and facilitates an inflow of energy from an external source. The feedback F includes some energy of Y that has made the cycle through the economy and is returned. A good primary source is one that has a relatively small return relative to the yield.

Expressing Energy in Units of Similar Quality

In a chain of energy transformations such as a food chain or a chain of successive steps in manufacturing in a human occupational chain, the final product emerging after successive operations gains quality. With more energy used in developing high quality products comes increased abilities that the product has for feeding back as an amplifier in doing work elsewhere in the system. The increased value of the high quality production in stimulating other work is a justification for the energy spent. It is proposed that the quality of the emerging product down the chain is measured by the energy that must be used to develop the product without waste.

For example, when the energy of the sun passes through the food chain from plants to animals and so on to top carnivores, the calories increase in their cumulative energy cost. The utility of the species to the system is believed to increase also. If value did not increase, it would not pay the surviving systems in their energy economy to provide for such high quality units. The calories of sunlight which produce a calorie of carnivore are a measure of the quality of the carnivore expressed in units of solar equivalents. For example, the ratio might be 20,000 calories of sunlight per calorie of lion.

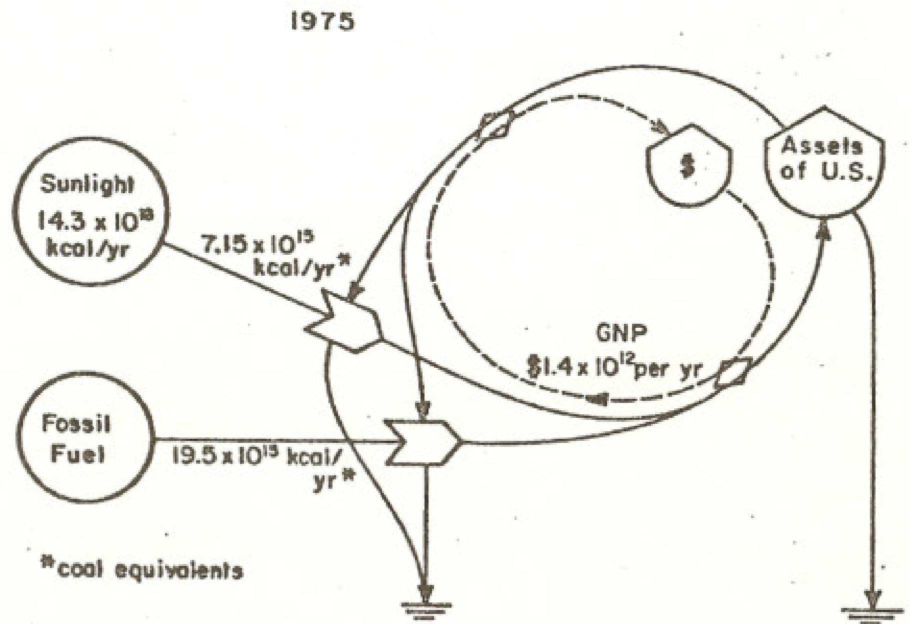
For another example, coal generates electricity through a power plant and the calories of coal required to generate a calorie of electricity is the energy quality factor. The ratio is about 3.6 calories of coal per calorie of electricity (including coal used directly and indirectly in support of goods and services).

More on the theory of energy quality is given elsewhere (Odum and Odum 1976), and energy quality factors have been estimated for many transformations. It is an important part of the theory that the process be measured for its quality factors under conditions of the real world in which there is some competition and after some time in which maximum power and minimum waste may have been achieved.

To allow comparison, the energy flows in consideration of net energy (as in Figs. 1 and 2) have to be expressed in energy equivalents of the same quality, such as solar equivalents, lion equivalents or coal equivalents. The idea is to have numbers that truly represent comparative ability to do work. The feedbacks of energy from the main wheel of the economy include high quality flows such as technology, information, human services, and computer work. The energy that generated those flows already went into used heat. These flows carry the value, however, which is that of the energy it would take to replace them.

All energies can be converted 100 percent into heat, but calories of heat equivalents do not measure the energy required to develop a flow or the energy effect of that flow as a multiplier. Instead that flow is multiplied by energy quality factors converting the numbers that are to be compared to energy values of the same quality. In much of our work we use energy quality of coal mined and delivered at a point for use in heat engines as the common type of energy into which other data are converted. These are defined as coal equivalents. Evaluations of net energy, yield ratio, and other comparisons are made in units of coal equivalents.

Work of goods, services, labor and information are often omitted in energy analysis because they are not recognized as energy intensive. They have high values of coal equivalents and are very important. Figure 3 shows the average



$$\frac{\text{Total Energy Flow}}{\text{GNP}} = \frac{26.7 \times 10^{15}\ \text{kcal/yr}}{1.4 \times 10^{12}\ \$/\text{yr}} = 19{,}000\ \text{kcal coal equivalents per } \$$$

Figure 3. Diagram indicating the flow of gross national product and the energy flows from fossil fuels and from natural renewable environmental sources. These flows are used to calculate the ratio of Kilocalories of coal equivalents to the dollar. The ratio is used to estimate the energy flows that are responsible for money flows in the general economy.

relationship of circulating energy and circulating money. Like Figure 1 it gives the reader an aggregated overview of money–energy relationships. Notice that renewable free, solar energies of nature contribute 28 percent of the energy for the economy when expressed as coal equivalents. To evaluate primary energy sources we evaluate in coal equivalents the ratio of energy yielded to energy fed back to get the energy. This is defined as the yield ratio. A synopsis of yield ratios for different energy sources follows.

Solar Energy.

When absorbed and transformed into heat, solar energy develops small gradients of temperature in solar water heaters or in daytime heating of the landscape. About 1 calorie of coal equivalents is generated per 10,000 calories of low temperature heating. If efforts are made to collect this energy by using solar technology such as solar cells, plastic and glass devices, the energy used in developing and maintaining the equipment is far greater than the solar energy collected. There is no net energy.

Net energy is generated by the biosphere from sunlight by developing wind from small temperature gradients, but it does so without energy-expensive installations.

Solar hot water heaters are secondary sources, but not very good ones as discussed below.

Solar energy when absorbed in photochemical processes of plant photosynthesis develops about 1 calorie of coal equivalent per 2000 calories of sunlight. This energy delivers net energy in subsistence agriculture with a yield ratio of 1 to 2 calories yielded for each one fed back by the farmer. Modern industrial agriculture may feed back as much as 10 calories per calorie yielded. In modern technological agriculture, the sun is not a net energy source but is a secondary source. Agriculture is a consumer with some energy contribution.

Coal

Coal requires energy to mine and energy to restore lands, and energy flows of nature interrupted by the mining have to be included as an inherent cost. Ballentine (1976) found yield ratios 4 to 36 depending on the distance of transportation and the type of distribution. If coal is transported two-thirds as coal for heating and one-third as electricity for use as electricity as in our current economy, the ratio of yield to feedback (both in coal equivalents) is about 6 to 1.

Oil

At the present price of oil, our economic exchange sends back to oil-supplying countries about 1 calorie coal equivalent of energy for 6 calories of oil yielded and refined. Whereas a rich deposit of oil near the surface yields oil with a yield ratio of 50 to 1 or more, deposits like this are mainly gone from the U.S. One field in Hendry County Florida for example is yielding 10 to 1 (DeBellevue 1976). The U.S. oil that has been price regulated at $6 per barrel has to yield 13 to 1 to be economic. The rapid rise of percentage of foreign oil shows that the quantity of such high yield ratio oil left in the U.S. is apparently not large. One estimate of oil from the North Sea showed almost no net energy. If oil prices by oil supplying nations are adjusted upward at the rate of inflation, the yield to the U.S. will tend to reamin at 6:1, the present ratio that is the basis for much of the U.S. economy. If refining is included the yield is 10 percent less.

Gas

Because it has been obtainable with so little cost, natural gas has been a very rich source with a high yield ratio and it is a high quality of energy. However, it has been used as a low quality energy in many uses. As the United States is now running out of gas, it is losing its richest net energy. As the country falls back on energies with a lower yield ratio, the activities outisde of energy procurement will have to decrease.

Nuclear Energy

When all the energy used cumulatively by the Atomic Energy Commission and all other inputs to nuclear energy are calculated, one finds there has not yet been any net energy from nuclear energy. It was mainly running on fossil fuels in its early years. When one power plant was considered through its full lifetime and fuel traced through the whole energy transformation chain, Kylstra and Han (1975) found a 2.7 yield for one fed back, much less than the fossil fuels of oil and coal now being used. If a major accident occurs and the energy losses of the disturbed area are subtracted, a lower yield ratio results. If these estimates are correct, nuclear energy may not be the preferred energy source; less economic vitality is possible with nuclear energy than with current fossil fuels.

Fusion and Breeder

Until actual operations are functioning (if they become practical), yield ratios cannot be calculated. The difficulties and costs of reprocessing byproducts of the breeder process back into fuel rods may make the yield ratio of the breeder low. Fusion may be too hot to yield net energy since so much energy must go back into controlling and reducing the temperature for coupling to the world of humanity. We don't know the outcome, but one suspects there may be no net energy.

Geothermal Energy

Where high temperature gradients exist as around volcanoes, geothermal steam power plants may yield 50 units to 1 unit that is fed back (Gilliland 1975), but the number of such areas is too small to be important for the United States as a whole.

Tide

Tidal energy as harnessed at La Rance, France yields 14 to 1, but the tide there is 20 feet on the average. Tidal energies are already important in our estuaries in maintaining fishery production, water cleansing, and transportation. Subtracting the energy of the tide would lower these values, and the net energy calculated overall would be less.

Oil Shale

The energy spent on the U.S. government test plant at Anvil Points, Colorado, was 80 times larger than the yield. There was no net energy. Whether test operations tried since are any better is not known, since the data are not available for public examination.

Wind

In most areas of the United States, wind speeds are low and erratic. Wind energy is dilute energy in these areas. If cheap materials are used and devices are simple, the wind may be used to pump water. However, electric wind mills have so much energy cost concentrated in them that they do not yield net energy when the wind is 10 miles per hour.

There is much yet to do in evaluating energy alternatives, but the work so far suggests that the sources available to the U.S. are mainly those of about 6 to 1 yield ratio. In a recent report to Congress (Odum et al. 1976), external inflows of Figure 1 were evaluated with net energy calculations of representative examples. A general summary was given in a new book (Odum and Odum 1976).

If the economy has been level since 1973 with this kind of energy availability, we should expect a fairly level economy for the immediate future since the net energy of sources is not expected to increase beyond a yield ratio of 6 to 1. In the long run, barring some new source or a better yield from fusion than expected, the net energy of the world and sources available to the United States will decline, and the economy will have to do less. The yield ratio provides a clear measure for choices about energy source alternatives.

Secondary Sources and Energy Investment Ratio

Evaluating secondary sources is done by comparing the feedback energy (F) with the inflow energy flow (I) being used (See Figure 4). The following theory is proposed. Natural energy that is free attracts investments of money or direct effort that bring in energy directly and indirectly from the main economy into interaction with local sources. For example machinery and fertilizer interact with sunlight in agriculture. For another example, tourists and their economy interact with natural areas to which they are attracted. The ratio of F to I is defined as the *Investment Ratio* where both are given in coal equivalents.

A secondary source is believed to be economic when the ratio of energy fed back is no more than competitors are using. Where both flows are expressed in coal equivalents, the typical ratio of purchased, fossil-fuel-based energy is about 2.5 to 1 of natural free energy.

When much more energy is used than 2.5 to 1 as in solar technology, the process is regarded as uneconomic. In contrast successful economic investments are those where purchased energy flows are brought into interaction with large natural subsidies of energy of sunlight, wind, and rain, and the investment ratio is small. Some evidence that low ratios stimulate growth are the counties of

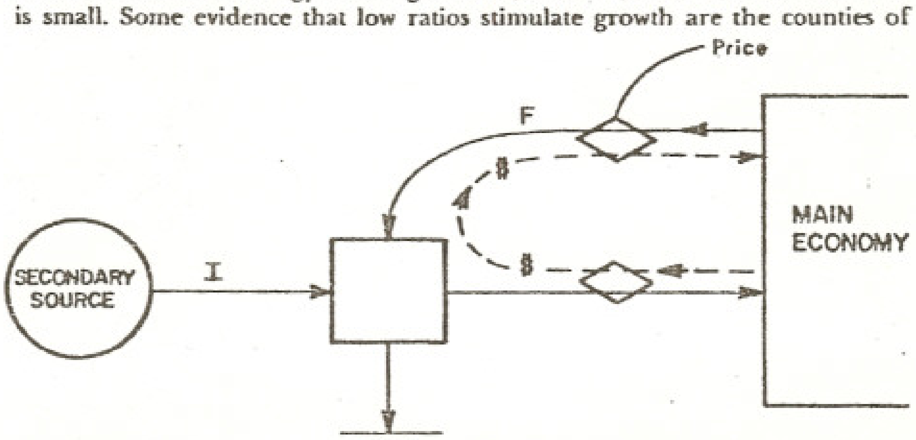


Figure 4. Money flows that are assoicated with energy investment in a secondary source. A secondary souce is economic when the contribution of the free external secondary energy I is larger than for competitors, when F/I is less than 2.5. F/I is defined as the investment ratio where F and I are expressed in units of equivalent quality.

southwest Florida which are undeveloped ones with lower investment ratios than Miami, for example.

Theories of low investment ratios favoring relative growth are believed to apply only to periods when the overall economy is not growing. When growth is rapid on rich energy sources, the areas that are ahead in growth can grow faster and out compete other areas even if they have lower investment ratios. As soon as growth levels, the advantage goes to those of lesser density and there follows a redistribution of invested energy flowing in from outside.

Evaluating Environmental Technology with Energy Analysis

Interactions between the main economy and the environment are part of the means for harnessing the secondary sources. Projects to develop environmental interactions need not yield net energy, but they must have a low investment ratio insuring a good return in conservation per unit energy brought from outside. Investing energy helps the economy when as much environmental energy is enlisted as would be the case in alternative investments.

In recent years laws for protecting the environment have not provided examination of the energy involvements. Some propositions such as tertiary treatment of sewage and cooling towers have very high energy investments relative to the area of natural energy being utilized or being protected from loss. Like solar technology, these solutions are poor energy uses. For conservation to be effective, the energy involved could protect or utilize as much as other investments of energy.

The economy of man and nature is a combined one, and poor uses of the energy of the main economy detract from the energy that might go into other conservation endeavors. Conservation like other activities serves and competes when its energy investment is effective. Where energy of the environment is well utilized in symbiosis with the energy fed back from the economy, the ratio may be closer to the average (2.5) or less.

It is proposed that the investment ratio is usable for estimating carrying capacity of an area for economic development, for evaluating projects that are supposed to stimulate the economy, and for evaluating environmental protection projects that are supposed to protect the environment.

Examples of Environmental Technology Which Are Poor Conservation Measures and Uneconomic

Many environmental protection measures propose very expensive technology that directly and indirectly draws energy in large ratio from the main economy. At Crystal River, Florida, Odum, Kemp, Smith, McKellar, and others (1975) found that a proposed cooling tower would have an investment of 100 coal equivalents from the main economy for each one coal equivalent of estuarine value saved. The investment ratio (100 to 1) was far above the 2.5 to 1 which we suggested was usual and economic.

As Figure 3 shows, any flow of money causes energy to use 72 percent from fuels and 28 percent somewhere from the environment that supports the economy with life support work. At Crystal River, with investment of 100 units, 28 units of environmental value are being drained elsewhere to protect one at the site. If this theory is correct, the environmental technology is hurting the environment and is in violation of the laws that cause environmental technology to be constructed in the first place.

Another example of environmental technology with very high investment of energy without much value for the environment is tertiary treatment by technological means. A value of 1800 to 1 was obtained by dividing the energy flow that goes with money flow by the energy flow of the land displaced. Since nutrients and water are usable as positive resources by most ecosystems, release of such wastes can be a resource. Little environmental protection is gained from eliminating these wastes technologically. There is a preferable way—developing domestic ecosystems as interfaces between economic activity and the environment.

Ecological Engineering of Interface Ecosystems

Self designing ecosystems can be allowed to adapt to wastes that are released in some dilution. Examples are the cypress swamps into which secondary sewage wastes are being added at 1 inch (2.54 cm) per week in Florida (Odum, Ewel, Mitsch, and Ordway 1975). The ratio of purchased energy to energy flow of the environment is not far from 2.5 and thus may be in the economic range for the investment ratio. The ecosystems that develop in adaptation to the special waste outflows develop species that can use the wastes with less stress and more as a resource than those that may have been replaced.

Energy Evaluation of Wildlife

In many decisions, direct evaluations are needed of wildlife. The energy value of a wildlife species may be estimated by diagramming the position of the species in a network diagram using energy language and showing the energy of nature and of humanity that impinge on its food chains and contribute to its protection. By estimating the solar equivalents required for the steady maintenance of a calorie of that species and using an energy quality factor for calories of sun to coal of 2000, one may estimate the coal equivalents required to maintain the species. The higher up the food chain, the more valuable is a species and the higher the cumulative energy used in its development. Theory suggests that the energy values indicate the importance of the species work to the ecosystem in generating value as an amplifier. Some higher animals have higher quality factors than electricity.

Endangered Species

When a species is endangered and the ones being evaluated are the last ones existing, the energy value may be estimated as the energy used for redeveloping the species by repeating the evolution or repeating genetic breeding artificially. One is evaluating the gene pool and the means for using the population later. This approach involves multiplying times like 10,000 years times the energy flows of larger areas. The energy value can be very large.

An alternative approach to evaluating endangered species with energy is to estimate the area of suitable habitat which might be prevalent if the world returns to a lower energy based more on renewable energies. Then the higher animals that were important in the ecosystem's own self management may cause it to produce more with its adapted animals than if they were extinct. For example, in Florida, Carolina parakeets and ivory billed woodpeckers were managers of seeds and insects respectively in the heavy cypress forests that were cut early in the century. These forests are partly grown back now and the acreages are large. If the birds caused higher productivity (gross production), then the amplifier value of the last ones would be the energy value of the increased productivity of the habitat over its whole range, a very large figure.

Trends for the Future

As energy sources decrease, the investment ratio that will be competitive will decrease also. The world ratio is only 0.3 to 1. Purchased energies will be used less and less and more and more scrutiny should go into getting a low ratio. Since there is net energy in subsistence agriculture—perhaps as much as in nuclear power, we need not fear the future of lower energy, but many propositions for development with public funds need to be scrutinized for their yield ratios and investment ratios. Private projects can be evaluated to determine if they are economic also. The energy analysis ratios (yield ratio and investment ratio) can be used to protect many resources that have high indirect energy contributions to the system of man and nature but are not evaluated in money cost-benefit procedures.

References Cited

Ballentine, T. 1976. A net energy analysis of surface mined coal from the Northern Great Plains. Thesis, Master of Engineering. Department of Environmental Engineering Sciences, University of Florida. Gainesville. 161 pp.

DeBellevue, E. 1976. Energy basis for an agricultural region: Hendry County, Florida. M.S. Thesis. University of Florida, Gainesville. 215 pp.

Gilliland, M. 1975. Energy analysis and public policy. Science 189: 1051-1056.

Kylstra, C. and Ki Han. 1975. Energy analysis of the U.S. nuclear power system. Pages 138-200 *In* H.T. Odum, ed. Energy models for environment, power and society. Contract E-(40-1)-4398. Energy Res. and Devel. Admin.

Odum, H.T. 1971. Environment, power and society. John Wiley, N.Y. 336 pp.

Odum, H.T., K.C. Ewel, W.J. Mitsch and J.W. Ordway. 1975. Recycling treated sewage through cypress wetlands in Florida. Occasional Publ. No. 1, Center for Wetlands. University of Florida, Gainesville. 14 pp.

Odum, H.T., W.M. Kemp, W.H.B. Smith, H.N. McKellar, D.L. Young, M.E. Lehman, M.L. Homer, L.H. Gunderson, F. Ramsey, and A.D. Merriam. 1975. Power plants and estuaries at Crystal River, Florida. Report to Florida Power Corporation. Contract GEC-159-918-200-188.19 with University of Florida, Gainesville. 540 pp.

Odum, H.T., C. Kylstra, J. Alexander, N. Sipe, and others. 1976. Net energy analysis of alternatives for the United States. Pages 253-302 *in* U.S. energy policy trends and goals, Part V. Congressional Record, 94th Congress, 2nd Session, Subcommittee on Energy and Power of Committee on Interstate and Foreign Commerce.

Odum, H.T. and E.C. Odum. 1976. Energy basis for man and nature. McGraw Hill. 297 pp.

Discussion

MR. JOHN CLARK [Conservation Foundation]: I have two questions which are somewhat related.

In relation to the Ganges River anecdote, first there is the problem that the cooling tower, for example, is there to protect the natural amenities and is not an energy source. I wonder how you figure that in?

Secondly, you are transforming energy from one source to another when you produce that heated water. It may be, for example, as dilute as the sun and it may be much more dilute than the other energy operations going on in the plant. It seems to me that there is a tremendous energy resource available which we are throwing away.

How do you relate those two?

PROFESSOR ODUM: Energy is never not used. It is a question of who uses it and how. For example, if you divert the Ganges River water, you shift energy from one source to another and you may then realize, after you have done this, that it was doing a lot of work for you.

Environmental impact should be measured after the system is redesigned and as to what it is going to do to match it. Survival of nature, and man is a part of nature and custodian of the biosphere, whether he realizes it or not, is dependent on the economies of man making sense with nature or otherwise there will be political circumstances in which conservation takes a beating.

Therefore, in totality here, you have to maximize the total energy of the combined pattern of man and nature for it to survive, meaning, of course, that in order for man to survive, his economic system must be in tune with that of nature.

If you were to set up something that isn't economic but political, then nature loses out in the long run because it gets defeated in the decision process. Therefore, we have to combine and maximize the combined power of the two in harmony so that both survive.