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Abstract

This paper describes an ecological approach to the assessment of environmental impact and associated costs of all major phases of energy procurement. The approach is based on identification of services performed and benefits offered by natural and man-modified ecosystems and requires that energy procurement activities be analyzed in terms of their impact on these services and benefits. A thorough cost assessment (including quantitative and qualitative factors) of alternate energy plans will aid both the selection of the most desirable alternate and the reduction of unforeseen costs and problems during and after construction.

1. INTRODUCTION

The current rate of energy consumption in this Country is staggering; quantities used to describe it are almost beyond comprehension (see Table 1). Just as the true meaning of these quantities is elusive, so the impact of the vast energy procurement network on natural and man-modified ecosystems is difficult to grasp. Millions of words have been written in the form of environmental impact statements (EIS) for energy procurement activities, and many of them have been useful in planning and decision-making processes. But serious questions remain - Do EISs for energy procurement activities deal adequately with the range of vital, natural, ecosystem processes affected? Do the EIS review procedures encourage thoughtful ecological analysis or merely encyclopedic data gathering? Who really assimilates the large quantities of environmental information normally gathered for energy-related EIS documents? In particular, do those professionals responsible for planning, design, construction and operation understand adequately the environmental impact of the activities?

This paper is written in the belief that ecologically sound yet comprehensible environmental impact assessments can and must be prepared for energy procurement activities. As the already vast energy procurement network expands, the need for adequate environmental assessment becomes ever more pressing. The cost of adequate assessment and planning is high in some cases; the long-term cost of ecologically insensitive planning, on the other hand, can be devastating.

Table 1

U.S. Energy Consumption

Year	Tot.*	Wood (%)	Coal (%)	Pet. N.G. (%)	Hydr. (%)	Nuc. (%)
1860	3.1	83.5	16.4	0.1		
1880	5.0	57.0	41.1	1.9		
1900	9.6	21.1	71.3	5.0	2.6	
1920	21.3	7.5	72.8	16.1	3.6	
1940	25.0	5.3	50.1	40.9	3.7	
1950	34.0	3.3	36.7	55.9	4.1	
1960	44.6		22.8	73.5	3.7	
1970	67.1		18.9	76.8	4.0	0.3
1975	70.6		18.2	74.6	4.6	2.6
1976	74.2		18.6	74.5	4.2	2.7

*Total energy consumption in quads, equivalent to one quadrillion Btu (British thermal units). A quad is equivalent to the amount of energy in 172 million barrels of oil.

Source: Federal Energy Administration, 1977.(1)

2. PHASES OF ENERGY PROCUREMENT

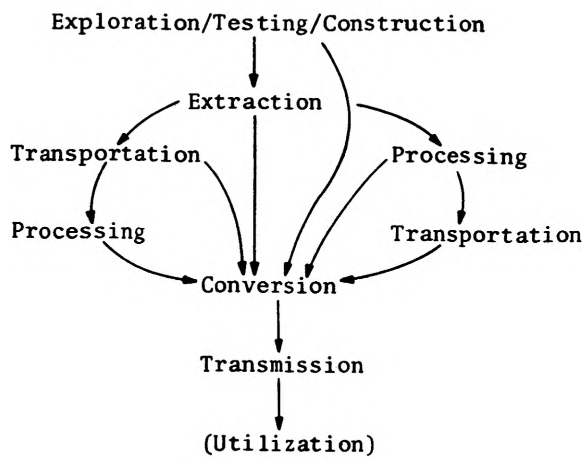
The energy procurement network consists of interconnected phases of activity, each with its separate impacts and costs.(2) There is some variation in the sequence and number of phases, depending on the ultimate source of energy and mode of conversion (see Figure 1). Whereas coal and oil involve extensive extraction, solar and wind require none. In cases where conversion takes place close to the ultimate energy source, transportation becomes a trivial component and transmission may be very extensive.

While the local impact of any given phase may be small or readily managed, it is important to consider each phase in relation to connected phases. Coal or oil extraction and processing for energy conversion may have manageable impacts when viewed separately, but their combined impact in a given setting may be much more serious (lowered water table plus increased water pollutant discharges, for example).

The first step in assessing environmental costs of energy-related activities, therefore, is to clearly identify the phase or phases of energy procurement involved and its (their) relationship to in-place facilities for related phases.

Figure 1

Flow Chart of Energy Procurement Activities



3. THE ECOSYSTEM CONCEPT

The second step in assessing environmental costs of energy procurement is to identify the natural or man-modified ecosystem components and processes potentially affected by the proposed activity. This step is invariably more difficult than identifying energy procurement phases, but it is equally important.

An ecosystem is defined as a set of organisms, elements of their abiotic (i.e., non-living) environment and the processes which interconnect them. A lake, a forest, a grassland area are all examples of more or less complete ecosystems. An important fact about ecosystems, however, is that they are connected to each other by the movement of energy, organisms, water and organic and inorganic materials. The boundaries between ecosystems are sometimes very difficult to determine. A lake ecosystem, for example, is connected by varying degrees to the land ecosystems making up its watershed.

The principal components of all ecosystems are mineral elements (including soil and water), solar radiation, and species populations (generally classified as producers, consumers and decomposers). While the relative composition and array of these components vary greatly from one ecosystem to another, all ecosystems have these general components.

The principal functions of ecosystems are photosynthesis (or primary production), trophic transfer of energy, mineralization of organic matter and storage and transmission of "biological information". Each of these ecosystem processes is expanded more fully below.

3.1 PHOTOSYNTHESIS/PRIMARY PRODUCTION

This is perhaps the most vital ecosystem function. It is an energy transduction process, namely one in which energy in the form of solar radiation is converted into the form of chemical potential. It converts energy from a non-storable form (radiation) into one which is not only storable but readily available to biological organisms and useful in meeting all their energy needs. Green plans (including algae) are essentially the only organisms capable of photosynthesis. Photosynthesis (via green plants) is the "biological dynamo" for all ecosystems and ecosystem processes. The input to photosynthesis is water and inorganic compounds; the output is highly diverse organic compounds. The term "primary production" is synonymous with photosynthesis and is often used interchangeably with it.

3.2 TROPHIC TRANSFER

Trophic energy transfer is transfer by "feeding." Photosynthesis by green plants is defined as the first trophic level in ecosystems, meaning that plants are the first level of energy "consumption" in the system. Organisms which consume plants are defined as being at the second trophic level, those which consume consumers are at the third, etc. The number of trophic levels in ecosystems is generally two to four.

The stability and functional dynamics of an ecosystem are strongly influenced by a balanced availability and movement of trophic transfer throughout the organism groups comprising an ecosystem. Significant imbalance may lead to destabilizing "boom" and "bust" cycles of individual species populations.

3.3 MINERALIZATION OF ORGANIC MATTER

Mineralization is the step that closes the loop for re-cycled materials in ecosystems. Decomposer organisms (fungi, bacteria and other lower life forms in soil and water) disassemble organic materials to obtain energy for their own purposes and leave water and inorganic materials as their waste products. It is precisely these "waste products" which are inputs to the process of photosynthesis. The importance of decomposer organisms and the mineralization process as a whole to ecosystem function is quite obvious.

3.4 STORAGE/TRANSMISSION OF "BIOLOGICAL INFORMATION"

The genetic composition of species populations as a group represents a kind of memory in the ecosystem. The memory is in the form of genetically determined capability on the part of each organism to carry out certain functions or fill certain roles in the ecosystem. Collectively the organisms comprising an ecosystem represent a "talent bank" which is transferred from one generation to the next. Removing species or destroying habitats reduces the "talent bank" of the ecosystem directly and indirectly. If habitat conditions in an ecosystem are changed in such a way that a certain tree species cannot become re-established, the affected ecosystem loses the "talent" carried by the population of that tree species for a particular set of functions; it may also lose the "talent" of birds, mammals, insects or other groups which depend strongly on the tree species removed.

It is readily apparent to the interested observer that natural systems usually have considerable redundancy in their "talent bank" or set of "biological information". Systems adjust to changes of even the most extreme kind. However, the interested and thoughtful observer must also conclude that there is a limit to the flexibility of natural systems. Taking the resiliency of natural systems for granted may have disastrous consequences, as witnessed by the "dust bowl" era of our Country.

4. ECOSYSTEM GOODS/SERVICES/BENEFITS

The ecosystem processes just described have a large number of by-products and consequences which are extremely beneficial for the human species, which is the dominant component of many ecosystems. Some of the benefits are immediate and direct; others are of secondary or indirect benefit, but significant nonetheless.

4.1 MARKETABLE GOODS

This class of benefits is the most direct. It includes all food materials, even though much of those materials are taken from highly modified ecosystems. It also includes timber and natural fiber plants as well as a large number of non-renewable minerals.

4.2 GENETIC POTENTIAL FOR CULTIVATED CROPS AND DOMESTICATED ANIMALS

This is a less direct benefit than marketable goods, but it is vitally important. All plants and animals used for food production are evolutionary products of ecosystems from throughout the world. While the genetic stock of cultivated plants and domesticated animals is large, it would be fool-hardy to believe that no new, naturally produced strains are needed to satisfy world needs or to cope with potentially significant climatic changes in years to come. If climates do change, the need for new stocks may be large indeed.

4.3 BUILDING OF SOILS

The rate of erosion of productive soils in this Country is very high in many areas. Since soils are the by-product of natural and man-modified ecosystem events such as weathering, organic matters accumulation and mineralization, it is vitally important that we not only protect existing soil reserves but that we protect those processes which build new soils as well.

4.4 BREAKDOWN/MINERALIZATION OF ORGANIC RESIDUES

This process was discussed earlier as one which is common and vital to all ecosystems and provides the important benefits of decomposing vast quantities of organic waste material in land and water ecosystems and of re-supplying photosynthetic organisms with raw materials.

4.5 NATURAL PURIFICATION OF SURFACE WATER AND GROUND WATER RESOURCES

While a small minority of streams and waterways look (and smell) like wastewater treatment facilities, all natural and semi-natural surface waters perform the same water purification processes which take place in a more concentrated fashion in treatment facilities. Sedimentation, decomposition of organic residues and re-aeration of water to replace the oxygen consumed by micro-organisms in breaking down organic wastes are common to both "natural" and "designed" treatment. Natural purification proceeds constantly and quietly in most streams and waterways, and its benefits are sometimes not realized until disturbance slows the process or vastly increases the need for purification. Natural purification also takes place in marshes, local depressions and groundwater recharge areas, thereby protecting groundwater quality.

4.6 ATTENUATION OF AIR POLLUTANTS

Vegetation in natural and man-modified ecosystems traps large quantities of air pollutants on leaves, stems, trunks and branches. Local meteorological conditions together with type and density of vegetation determine the effectiveness of this natural filtering function.

4.7 MODULATION OF HYDROLOGIC CYCLE

Well vegetated ecosystems have a strong modulating influence on components of the hydrologic cycle. The kinetic energy of rainfall itself is attenuated, robbing it of force capable of loosening near-surface soil particles and initiating erosion. Roots penetrating the soil enhance groundwater infiltration during and after storms, thereby reducing runoff and enhancing natural stream recharge between rainfall events.

4.8 AMELIORATION OF NEAR-SURFACE CLIMATE EXTREMES

As everyone knows through experience, the climate near the ground in wooded areas is protected from hot and dry extremes during summer and from cold, desiccating extremes during winter. This amelioration of micro-climate enhances conditions for seed germination and seedling establishment as well as burrowing, feeding and reproduction for insects, birds, mammals, amphibians and reptiles.

4.9 NATURAL CONTROL OF PEST POPULATIONS

Ecosystems with a large variety of animal groups are often less likely to have serious outbreaks of pest populations (particularly insects) than less diverse ecosystems. This is thought to be the result of increased number and kind of potential predators whose populations can grow as their food source grows.

4.10 RECREATION AND AESTHETIC ENJOYMENT

Many natural and near-natural ecosystems have particular recreational potential - for hiking, fishing, canoeing, sailing, photography, solitary enjoyment of open space, etc. Benefits vary greatly with vegetation type, terrain, land use history, proximity of suitable land and water areas and local demand for recreation.

4.11 STUDY AND RESEARCH

Almost any ecosystem offers some potential for ecological study and research, but systems in greatest demand for this purpose are those which have suffered the least disturbance from the natural condition.

5. LEVELS OF COST ASSESSMENT

There are numerous levels at which costs are incurred when energy procurement affects ecosystem processes. Each level is amplified briefly below.

5.1 MARKET VALUE OF LAND AND GOODS

The most obvious level at which cost is incurred is in the value of saleable land and goods in the ecosystem at the time changes are brought about. Saleable goods include harvestable crops, fish, timber, and ores.

5.2 PROJECTED LOSS/REDUCTION IN PRODUCTIVITY

Each ecosystem has a rate of productivity for useable or desirable goods. They include productivity in the form of crops, pasture, timber, fish, birds, fur-bearing animals, etc. Their value is set by market conditions as well as access, land/water quality and other site factors affecting productivity.

5.3 PROJECTED COST OF SERVICES ON A REPLACEMENT BASIS

Having identified the range of useful services performed by natural or man-modified ecosystems earlier in this paper, it is necessary to determine the cost of replacing these services in the event of ecosystem disruption. For example, if a swamp of marshland purifies polluted urban stormwater or agricultural runoff before it enters a water-quality sensitive stream, draining or altering the swamp for energy procurement incurs a substantial cost in the form of lost, needed service.

5.4 LOSS OF "NATURAL INSURANCE"

The capacity of natural and certain man-modified ecosystems to perform the services described above is often greater than the demand placed on them. This excess capacity, however, is a very important feature of stable ecosystems in that it offers a "natural insurance" against catastrophe-severe drought, flooding, outbreak of disease, extensive fire, etc.

Changing ecosystems in such a way that this "natural insurance" is reduced represents a cost to those depending on services the ecosystems provide; it increases their risk to natural or man-induced catastrophe.

5.5 LOSS OF UNIQUE SPECIES, COMMUNITIES, OR ECOSYSTEMS

The cost of eliminating or severely threatening rare and/or endangered species, natural communities or ecosystems is very difficult to evaluate because it is almost impossible to assess the real, long-range significance of the threatened entities to the ongoing function of the natural systems of which they are a part. In the face of this ignorance, it is not illogical to assume the worst, namely, that the role of the unique entity is highly significant until clearly proven otherwise. While extinction has been taking place naturally for thousands of years, the capacity we possess for causing unnatural extinction in just ten years is very great indeed. The cost of loss in this area, therefore, must be reckoned as being extremely high and avoided if at all possible.

5.6 LOSS OF AESTHETIC VALUE OR OTHER SOCIAL/CULTURAL VALUE

Aesthetic values in relation to natural systems are very real but require subjective evaluation. Replacement cost for the land or water area affected must be viewed as the minimum cost of disturbance, with additional cost increments assigned in relation to the perceived subjective value - whether for reasons of scenic quality, historic or archaeologic interest, social value to local communities, etc.

6. BRIEF EVALUATION OF SAMPLE CASE

We have outlined the basic considerations required in assessing environmental cost of energy procurement activities. Each case is unique and requires the good judgement of professionals in the fields of ecology, engineering, geology, economics and others in order to arrive at the most fair and reasonable cost of impact on natural systems.

The sample case described below illustrates how some of the basic considerations are applied.

6.1 SAMPLE SITE CONDITIONS

The site is a 1000-acre land tract on which severe surface disruption is required in order to meet a particular need in energy procurement, such as strip-mining for coal. The land has 600 acres in forest (secondary growth, of which 300 acres is in pine and 300 acres in pine and mixed hardwood). There are 200 acres of cropland (corn, small grains, soybeans) and 100 acres of pasture. Streams, ponds and marshes cover 75 acres and building lots, roadways and vacant land cover 25 acres.

6.2 ECOSYSTEM GOODS/SERVICES/BENEFITS AFFECTED

6.2.1 Goods

The marketable goods on the site consist of timber, coal and grain, each with respective market value per board-foot or ton, depending to some degree on quality. The value of the coal may be the prime economic factor of the activity, with the timber value a significant secondary factor.

6.2.2 Productivity

The site has productive capacity for timber, (harvestable stand per 20-50 years, depending on species type and management practices); grain (60 bushels per acre per year of corn and small grain; 25 bushels per acre per year of soybeans); grazing (50 cattle per year on pasture); and a certain productive capacity for wildlife.

6.2.3 Services

The forest land, pasture and cropland all have a significant potential for soil building, with the level of yield strongly dependent on management practices in all three areas. The forest and pasture offer significant erosion and runoff control year-round; the cropland is subject to erosion and runoff during a number of months of each year, depending on management practices. Low-lying areas on the site serve as groundwater recharge areas; the recharge is highly significant to the flow conditions and year-round water quality of the streams and ponds. The marshes also serve as significant recharge areas and are capable of removing a large fraction of the pollutants carried in cropland and pasture runoff. The large wooded area and interface areas between wooded and open areas offer suitable habitat space for a variety of birds which serve to control many potential insect pest populations. The vegetation cover over most of the site protects the near-surface soil environment from summer and winter climatic extremes and prevents near-surface desiccation. The large wooded tracts serve as effective traps for fugitive dust from unpaved roads and other dust-generating activities.

6.2.4 Recreation/Aesthetic Enjoyment

Recreation potential is offered in the forms of hiking, swimming, riding, canoeing, fishing, photography, solitary enjoyment of open space and community and regional aesthetic enjoyment of the forested areas. The value of this benefit may be determined on the basis of present and future visitors to the site and the uniqueness of the site in the region.

6.2.5 Study/Research

The site offers abundant opportunity for investigating forest and wildlife management practices, hydrology, micro-meterology, field observation of forest and stream habitat types for non-research students and for study of natural control of pest populations. Again, the value of this benefit may be determined on the basis of present and projected use by students and research workers and by the uniqueness of the site in the region.

This case, like so many others, has important parameters which are readily quantifiable (marketable goods, productivity estimates), important parameters which are only roughly quantifiable (soil building, erosion and runoff control, water and air purification, recreational use) and many equally important parameters which are either unquantifiable or quantifiable only with an excessive amount of time and effort (the number and kind of species likely to be significant in pest control, aesthetic value, long-term value for study and research). A common danger in mixed analyses of this sort is that they tend to place greater weight on those parameters which are or appear to be quantifiable. As mentioned earlier in this paper, the only protection against this danger is the good judgement of multi-disciplinary professionals responsible for the decision-making process and the close coordination of the process with local citizens who can and should be called upon to evaluate many of the subjective choices affecting their environment (time and space do not allow discussion of this critical role of citizens).

7. SUMMARY

Adequate assessment of environmental impact and associated cost of energy procurement activities requires a careful analysis of the goods, services and benefits which natural and man-modified ecosystems provide. We have described the kinds of benefits ecosystems provide, the various levels at which costs may be incurred in the event of significant disturbance and a hypothetical case which illustrates how the general approach can be applied.

REFERENCES

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BIOGRAPHY

Ronald G. Alderfer, Ph.D., is Chief Ecologist and Associate Partner with the firm of Harland Bartholomew and Associates. His experience includes environmental and ecological analyses in a wide range of planning and engineering projects. From 1969 to 1975 he was Assistant Professor of Biology at the University of Chicago, where he developed and carried out research on environmental regulation of photosynthesis and growth of plants and taught at both the graduate and undergraduate levels.