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ISSUES IN NET ENERGY ANALYSIS

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ABSTRACT

The paper has two major purposes:

- Provide conclusions about problems involved in applying net energy analysis.
- Provide recommendations about the application of net energy analysis which will lead to an evaluation of energy technologies in a less ambiguous, more consistent manner.

In pursuit of these purposes, potential issues in the application of net energy analysis are presented. A number of issue questions are raised which the analyst faces in performing net energy analysis. To observe which issues may influence the results in actual practice, these questions were asked in the review of twelve selected applications of net energy analyses. These observations provide the basis for the conclusions and recommendations presented.

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ISSUES IN NET ENERGY ANALYSIS

INTRODUCTION

Net Energy Analysis is a technique now receiving consideration in the context of establishing criteria to help determine appropriate U. S. energy policy. *The phrase "It takes energy to get energy," describes in simple terms the concern that some energy production systems may require more energy for installation and operation than they will produce in their lifetime.* The utilization of lower quality energy fuel deposits, with their associated higher cost both in dollars and energy, is an example where net energy would be of concern. Another example would be a situation in which the technology required to create an energy system is itself particularly energy intensive, such as the gaseous diffusion process for enriching nuclear fuel.

Since about 1973, net energy analysis, under various methodological guises, has been used to determine the amount of energy involved in delivering useful energy to society. The applications of net energy analysis have included consideration of both traditional systems and alternative energy technologies such as solar, geothermal, synthetic fuels and oil shale. Some studies have indicated that certain new technologies would have net energy yields that are negative; or in other words, the energy invested in the technology itself is greater than the energy obtained from that technology.

Net energy analysis is a controversial analysis technique. Proponents believe that net energy analysis has potential for developing unique information that can be used for evaluating energy policy;(1) on the other hand, opponents have contended that net energy analysis yields no benefits not already provided by economics.(2) This controversy is highlighted by the fact that examples of net energy analysis can be cited where widely varying conclusions have been reached on similar energy systems.

Recent Congressional action has required that net energy be utilized as one of five criteria in evaluating proposed energy technologies. Specifically, the Federal Non-nuclear Energy Research and Development Act of 1974, PL 93-577 5(a)(5) stipulates that "Potential for production of net energy by the proposed technology at the state of commercial application shall be analyzed and considered in evaluating proposals." However, PL 93-577 does not define net energy and, to date, efforts of many analysts to arrive at a unique definition have failed. The continuing debate over the merits of net energy analysis and the ambiguities involved in its application result in an interesting challenge of determining how to adhere to the requirements of Pl 93-577 in a manner that will meet the intent of the Act.

A review of net energy studies indicated that application of the techniques to a specific energy system can indeed yield ambiguous results. A first step in resolving this problem of ambiguity would be to develop a consistent set of procedures and definitions for application of net energy analysis to energy technologies. This paper provides a set of recommendations which represent the first step toward development of consistent procedures.

To support the observations and recommendations made in the paper, the literature was extensively reviewed and twelve studies were selected for comparison.(3-14) Based on these reviews, it was possible to elicit the various issues, factors, and decisions the analyst faces in performing net energy analysis. In addition, it was possible to make observations about which issues influenced results of net energy analyses and which potential issues did not appear to be significant in actual practice.

This paper is divided into three sections. The first section raises the various issues as questions related to the application of net energy analysis. Our observations and conclusions regarding the significance of the issues in actual practice are given in the second section. The third section provides recommendations which will help ameliorate some of the controversy surrounding the use of net energy analysis.

ISSUE QUESTIONS IN NET ENERGY ANALYSIS

The purpose of this section is to review potential issues in the application of net energy analysis. Major considerations in the review were how the various applications:

- addressed energy policy,
- dealt with detail,
- utilized the methods of energy accounting, and
- defined measures of net energy.

A number of questions relative to these considerations were asked as each application study was reviewed.

To simplify the process, the questions were put in the form of a review framework. The review framework is described in the Appendix. The detailed results of the comparison of the twelve studies are also summarized in Tables A-1 and A-2 in the Appendix.

In the remainder of this section, the key factors used in the review framework are discussed. The bases for selection of these factors was the influence they can have on the result of the net energy analysis and the level of controversy that surrounds the selection and utilization of these factors. Comparison of the application studies provides a basis for determining which factors were of significance in actual practice. This comparison of these key factors leads to the observations and conclusions which are discussed in this paper.

The issues and key factors which give rise to controversy can be categorized into two groups:

- <u>Philosophical</u>. Philosophical issues involve choices which are of social value judgment in nature. Discounting and including the energy content of the environment, labor, or institutions are examples.

- <u>Technical</u>. Technical issues result from the wide variance of parameters open to the analyst in his study. The selection of parameters and mode of application can significantly influence results. Technical issues include system boundaries, measures of net energy and accounting. Some agreement among the analysts exist on these issues, although more than one self-consistent approach may be available.

Philosophical Issues of Net Energy Analysis

The factors involved in net energy analysis that are defined to be of a philosophical nature are:

- Return on Investment/Discount Rate. Discounting is a means of allocating resources (money, fuels or other goods) by an assignment of a subjective worth or "value" to that resource. What is done is the setting of a value on early expenditure versus a later one. Through net energy analysis it may be possible to develop some figure of merit expressing the time to pay back the energy investment (breakeven point), a rate of return on investment, or the total net yield on investment over the life cycle of the process considered.

  Such figures can be useful for comparing different energy systems, but there is no developed theory on desired rates of return. There is also no developed basis for discounting the present worth or value of energy generated at a future time as a result of present day investment of energy expenditures.

  Questions regarding discounting in the application of net energy analysis include:

  (1) Does the net energy analysis tell us about anything that economics will not reveal?

  (2) Is the application concerned with the amount of resources available to society? If so, how are the values of future resources in a conservation framework determined?

- Labor. A labor force consumes energy in its everyday affairs, both directly (residential heating, automobiles, etc.), and indirectly (energy content of clothing, homes, purchases, etc.). Inclusion of these energies in net energy analysis has been debated.

  Opponents argue that energy consumption by the labor force is part of the Gross National Product (GNP) and that the purpose of the economic system is to support people. If the population were not building or operating an energy delivery system, they would be doing something else.

  Proponents advocate including not only the energy input of labor building or operating the energy delivery system but the input of labor induced by the system. Induced labor would include that required by development in support of the labor, such as new towns.

  Questions regarding the energy input of labor include:

  (1) How should the impact of labor, however evaluated, be included as an energy input?

  (2) Does labor represent a "hidden subsidy" to the energy system?

  (3) In the application of net energy analysis at a local level, such as a single coal liquefaction plant in Wyoming, is the energy impact of labor of different significance than a general application?

- Institutional/Sociological. The inclusion of interactions between an energy process and society or institutions may be considered. One factor that has been controversial is energy research. Clearly energy research is not directly intended to produce energy.

  Social or institutional questions interact with similar questions regarding labor and include:

  (1) Are speculations about lifestyles or political factors in the analysis?

  (2) What indirect energies such as energy research merit consideration?

- Ecosystem/Environment. Any system will impinge upon the environment in some manner. One method of accounting, eco-energetics, includes indirect energy inputs from the environment. The accounting for the role of the environment has a philosophical basis which forms the controversy. In the discussion of Leach(15) attention is drawn to the extremes of the viewpoints by contrasting two examples. He cites the loss of ecological capital in fuel delivery systems that divert water to new energy facilities in arid areas causing lessened vegetation and soil runoff because less water of poorer quality is supplied to farmers. One sees that the chain can be long and if each step represents an energy impact, some rather large numbers can be generated.

  The other school of thought would consider that almost any of man's activities has some effect on the environment and these effects and their mitigation and control are a normal part of the activities commonly called GNP. Thus, beyond some very direct effects, (adding cooling towers, controlling groundwater pollution in oil field flooding, controlling acid mine drainage, reclaiming strip mines, and other such activities), the effects on the ecosystem are probably adequately captured when the inputs are related to the GNP. This is because some of those activities are included in the GNP through the accounting of industrial and government spending. *In the application of net energy analysis, questions regarding the environment include:*

  (1) Are the energy inputs necessary for mitigation of environmental impacts included in the analysis?

  (2) The environment serves many functions to energy systems, acting as a transformer, heat sink, and material cycler, affecting systems via climate, hydrology, etc. How are these functions accounted?

Technical Factors of Net Energy Analysis

The key factors or issues involved in net energy analysis that are defined to be of a technical nature are:

- System Boundaries. It is important to have at the initiation of a net energy analysis clear and consistent definitions of the system and process steps to be evaluated and compared. One usually thinks of the energy supply-delivery system as a series of stages leading from a resource at one end to some terminus at the other. This, however, is not a precise definition for the application of net energy analysis.

  The first step in a net energy analysis is to specify the process of consideration. Upon definition of the energy process, the direct and indirect inputs must be determined. There can be little disagreement on direct energy inputs since they are of a physical nature.

  For indirect energy inputs, the problem of boundaries remain a philosophical question for energy inputs from labor, institutions, or ecosystems. Beyond the philosophical questions, boundary definition is the specification of the materials and equipment necessary to create and sustain the energy process.

  To include or exclude a certain material or piece of equipment is a technical question. In effect, the decision is based upon an estimate of the amount of energy embodied in the indirect input. Often it may entail a set of simplifying assumptions. No general criterion is available for basing decisions. It can be assumed that all significant indirect energy inputs are included with the boundary of consideration.

  Questions about boundaries in the application of net energy analysis are:

  (1) What criteria are used for determining processes to be considered?

  (2) How are higher order effects included?

  (3) Is the energy embodied in capital facilities used to produce materials allocated according to production for the technology being analyzed?

- Energy Quality and Weights. In net energy analysis, any standard units may be used to specify energy and physical quantities. The units need only be specified clearly. The problems arise in comparing energies of various qualities. The comparison is usually in terms of the availability of the energy for conversion into work.

  Analysts have recognized this problem and have attempted to deal with it in various ways; for instance, assigning weights,[20] keeping electricity separate,[6] computing quality factors,[21] or simply ignoring the problem. What is at issue is that a Btu contained in, for example, solar radiation, is simply not as useful as a Btu of electricity. *Energy quality questions include:*

  (1) Does the application use common energy units in a consistent manner?

  (2) What assumptions regarding equivalencies or efficiencies are made?

- Measures of Net Energy. Several measures of net energy are often computed in net energy analysis. These are based upon the inputs and outputs of the process that are accounted and are sometimes issue related. In some applications the authors leave the various ratios or sums up to the discretion of the reader.

  A wide variety of computed measures are currently used. Some are based on thermodynamic terms such as changes in enthalpy, others are defined on the basis of the accounts of direct and indirect energy inputs, energy losses, and useful energy output determined for the process.

  Alternate definitions of net energy could yield significant differences in the interpretation of results. There are a number of potential issues regarding the accounting of net energy and the determination of the final "balance sheet" of results.

  Specifically with regard to application of net energy measures:

  (1) Are the accounting methods appropriate for the stated goals or objectives of the study?

- Temporal Effects. A number of questions in net energy analysis relate to intertemporal considerations from accounting for the fact that flows are truly a dynamic phenomenon. Many energy flows do not occur simultaneously; similarly, plant lifetimes affect the actual net energy they may produce.

  In accounting for indirect energy flows, for example, by input-output methods, the data may not be a current description of the system. Likewise, the evaluation of future technologies requires a forecast of the system at times in which it will operate.

  Time-related questions in the application of net energy analysis add another dimension to the boundaries of the study:

  (1) Are life cycles considered in the payback periods for energy investment (related to discounting)?

  (2) Is the economic system in which the process operates described over the same time frame?

Perhaps several other factors in the application of net energy analysis having potential as issues could be identified. Actually, the remaining potential issues relate to policy implications of the results. The question of the role of net energy analysis in policy decision making is a major issue. The general consensus in the field is that such analysis should not be a sole decision criterion. The summary review of the selected applications given in the Appendix provides insight on the potential role of net energy analysis.

OBSERVATIONS AND CONCLUSIONS

This section summarizes the information developed from asking the above questions in the review of several studies. Observations about problems involved in the application of net energy analysis are provided. Then, conclusions about the primary approaches are given regarding their efficacy in the evaluation of energy technologies.

Observations of Net Energy Analysis Applications

In the above section, various issues involved in application of net energy analysis were discussed in detail. The significance of these issues was illuminated by evaluating twelve selected net energy studies described in the appendix. *Some issues, (e.g., discounting and system boundaries), treated similarly in most of the studies reviewed do not seem to be issues in practice. Other issues, such as energy quality factors, environmental energies and measures of net energy were treated differently, causing widely varying results.*

Specific observations about the various issues and their resolution in practice are described below.

- Discounting. Energy flows were never discounted in any of the studies. Some average lifetimes were estimated, determining energy shares from capital equipment. See the discussion under "Temporal Effects" below.

- Labor. Indirect energies consumed in support of labor were accounted indirectly in all of the studies through use of the input-output tables or the energy per dollar ratio. Only one eco-energetic study tried to explicitly account for the energy of supporting labor, resulting in some double counting problems.

- Institutional, Sociological Energies. Only one study, using the eco-energetic accounting, considered institutional energies. No justification is given for considering institutional energies in this particular study.(5) These energies are not considered in any of the other eco-energetic studies.

- Ecosystem/Environment. Most of the studies assumed that the technology being analyzed would be environmentally acceptable, including most of the eco-energetic studies. For the two eco-energetic studies that considered energy flows from the environment, these flows were not consistently calculated.

- System Boundaries. This is not really an issue in practice since all of the studies made similar decisions about system boundaries. The same indirect energy inputs were considered in all studies. Because input-output analysis or the energy per dollar ratio was used to obtain indirect energy inputs for all studies, the higher level energy inputs were consistently considered. Some of the eco-energetic studies include some energy inputs for labor, environment, and institutions. However, there was little consistency between eco-energetic studies.

- Energy Quality and Weights. Electrical input was consistently multiplied by a weighting factor to convert into fossil fuel equivalents. This use of a weighting really shortcuts the analysis; the need to find the energy inputs to produce electricity is bypassed. Quality factors in eco-energetics were used primarily to convert environmental energies into fossil fuel equivalents. These studies did not apply the quality factors consistently.

- Measures of Net Energy. There was no consensus on what measures of net energy should be used. The problem is twofold. First, not all of the studies addressed the same types of policy questions. Second, even when two studies addressed the same policy question, there was disagreement over which measure of net energy would be most useful. In several studies, alternative measures of net energy were presented. Some studies did not calculate measures of net energy, choosing to print tables detailing the energy accounts allowing the user to calculate the ratios that he feels are appropriate.

- Temporal Effects. All of the studies reviewed considered the full life cycle of the system. Construction, startup, operation and retirement energies were considered. Some studies presented graphs of energy flows into and out of the system as a function of time. Graphs such as these are potentially quite useful.

Several observations about possible improvements and synthesis of the methodologies were made as part of the review effort. These observations are provided below.

- *A process analysis was always used to obtain direct energy and material inputs for the process or system. No other method will derive inputs accurately enough for a net energy study.*

- *Input-output analysis is used most often to obtain indirect energy inputs. Such use would increase consistency between studies. There is no methodological reason that input-output cannot be used to obtain indirect energies in the eco-energetics analysis. Such use would be considerably more accurate than the energy per dollar ratio currently used.*

- *One study used process analysis for higher level energy inputs that are large compared to the direct inputs. These large higher level energy inputs were identified through input-output analysis.*

- *Several measures of net energy were usually calculated. Eco-energetic studies did not compare results with and without the energies from environment, labor and institutions.*

- *The eco-energetic studies did not consistently incorporate environmental, labor and institution's energies and quality factors into the analysis.*

- *Eco-energetic studies do not make it clear that the analysis incorporates both environmental impact and energy analysis and in doing so is making social value judgments.*

Conclusions

The characteristics of the primary approaches for net energy analysis are:

Process Analysis is a detailed and very accurate method of energy accounting. However, comprehensive consideration of indirect inputs can cause the analysis to "blow up." To keep the analysis tractable, judgments must be made to determine when energy flows are small enough to ignore. The usual criterion is that energy flows of the magnitude of the total error can be ignored. But if there is no quantified error, when to stop is really a matter of judgment.

Input-Output Analysis, based on economic methods and transactions between industries, provides a comprehensive summary of total indirect energy requirements. The method converts national or regional data on economic transactions (purchases and sales) between industries into energy transactions. Since the data is by economic sector and is national or regional in scope, the method is not accurate enough for level 1 or direct energy inputs. Other problems remain due to obsolete data, averaging effects and difficulty in assessing future technolgies. For indirect inputs, input-output analysis may be of comparable accuracy and is much easier to apply than process analysis.

Eco-Energetics is a philosophical methodology which includes value judgments about the worth of environmental quality in terms of energy. The use of the average energy per dollar ratio to calculate indirect inputs may lead to large errors. The methodology has not been consistently applied. That is, institutional, environmental, and labor energies are sometimes included and sometimes ignored. In addition, when these energies are included their value is not always calculated in the same manner.

The purpose of net energy analysis is to account for all of the energy required to create and sustain a process. It is not appropriate to use net energy analysis to analyze the labor requirements, the environmental impacts or the economics of a process. Separate techniques exist for labor, environmental and economic analysis; none of them provide an adequate accounting of energy requirements. Incorporation of any factor other than energy into net energy analysis requires value judgments, which can bias results for or against any given technology.

Results from net energy studies are directly comparable only under limited conditions. These conditions are:

a) The technologies being compared are all commercially viable;

b) The same boundaries (e.g., resource base and end products) are used for analysis of the technologies;

c) The same energy accounting methods and measures of net energy are used.

The implications of each of these conditions is discussed further below.

Commercial Viability. A commercially nonviable technology will require some technological innovation to become economical. The innovation may be an increase in efficiency, change in material requirements, a new method of fabrication, lower maintenance requirements, etc. Any one of these innovations may reduce the

cost and the energy requirements of the technology. Therefore, any energy accounting of a non-commercial technology will tend to underestimate the net energy of the technology. For example, an estimated ten-fold reduction in costs is needed for photovoltaics to be economical. Whatever innovations occur to cause a ten-fold cost reduction will also significantly increase the net energy of photovoltaics.

Comparable Boundaries. Two boundary problems can cause results of net energy studies to be noncomparable. The first is consideration of different products. For example, one study might consider electricity at the generating plant boundary while another considers electricity delivered to the consumer. Another aspect of this is evaluation of technologies that do not supply energy as an output. For example, a solar collector which produces hot water for use as a commodity rather than an energy source should not necessarily be expected to produce net energy. The question for analysis in this example should be: What is the energy subsidy per unit of hot water for the solar system compared to alternative methods for generating hot water for domestic consumption?

The second boundary problem is not considering the energy inputs in the same detail. Thus, some studies consider the energy costs of gathering, extracting, and transporting the input energy while others do not. If a solar heater is to be compared to a natural gas heater, for example, the energy needs for extracting and transporting the natural gas should be included. The solar collector system is the equivalent of the wells and the pipeline for the natural gas.

Energy Accounting Measures. Several methods of energy analysis and measures of net energy are available. Some methods and measures are more appropriate for certain policy questions than others. Some methods of energy analysis try to include factors other than energy, as discussed previously. Such inclusion is inappropriate. However, different measures of net energy can be used for responding to different policy questions just as different measures of corporate performance are used depending on whether one is the president, a stock holder, the banker, or a tax agent.

The above discussion outlines reasons why good net energy studies may still produce noncomparable results. Comparing solar energy technologies to commercially developed energy technologies can be very misleading; solar energy generally is marginally economic tody. Therefore, it should not be expected to be as energy efficient as other commercially viable technologies. As the economics of solar energy improve, so will its energy efficiency. A second cause of lower efficiencies for solar devices is that the solar collector system is part of the system. To be comparable to other energy sources, the exploration, extraction, collection, processing, and delivery to the site must be included. That is, the solar collector for solar energy is equivalent to the oil fields, refineries, pipelines and delivery trucks for oil-supplied energy.

RECOMMENDATIONS

If net energy analysis is to be meaningful in evaluating energy technologies, a consistent and unbiased set of procedures must be developed. A starting point is to recognize the role and limitations of net energy analysis as only one of many analyses used in evaluating energy technologies. Net energy analysis, as it has been practiced, embraces a variety of methods, assumptions, and perspectives. As discussed in the previous section, net energy analysis studies may produce widely varying results for many reasons.

Without established objectives and procedures, results from net energy studies will continue to be inconsistent and of limited use. The following recommendations do not solve the problems of net energy analysis, but they provide guidance for the development of a set of procedures.

- Net Energy Analysis should be used only to evaluate energy requirements and outputs of a process. Labor, economics and environmental impacts should be evaluated in separate analyses using the appropriate methodologies.

- Process Analysis should be used to obtain direct inputs to the process or system. No other method measures inputs accurately enough.

- Input-Output Analysis should be used to obtain indirect energy inputs. Such use would provide for increased consistency between studies.

- Eco-Energetics should use input-output analysis to obtain indirect energy inputs instead of the energy per dollar ratio. This change improves the accuracy of the methodology.

- Eco-Energetics Studies should present results with and without quality factors and flows from the environment, labor and institutions, making explicit the types of policy and social value decisions that the methodology makes.

- Measures. Several measures, summarizing the study results, should be calculated. The "balance sheet" of results from a net energy analysis should provide alternative accounting. In addition, the study should state the policy issues which the accounts are supposed to address.

- Data are not of consistent quality, particularly for developing technologies. Sensitivity studies should be part of the results showing the magnitude and possible effects of uncertainty.

- Level of Analysis for indirect inputs should include materials, energy required to produce the materials, and energy embodied in the equipment required by the process.

- Energy Quality should be presented in net energy analysis in two contexts:

  (1) the thermodynamics-based availability for conversion into work,

  (2) a factor expressing substitutibility of one energy source for another energy source in a particular end-use application (e.g., the substitutibility of natural gas for electricity in air conditioning).

  End-use applications for both work and heating vary in the nature of their demands for "quality" of energy, thus no single measure of quality suffices. This is an area where some progress can be made toward adoption of conventions for presentation of results, but this will require discussion and resolution of issues among practitioners and decision-makers.

- Discounting of energy flows does not appear to add any useful insight to the decision-making process.

- Environmental, Institutional, and Labor effects should be treated within the purview of conventional environmental and economic analyses. It does not seem to be appropriate to consider these factors as part of net energy analysis.

- The Life Cycle of the energy systems being evaluated should be used as the minimum time period for evaluation. This approach parallels economic investment analysis and is the most compatible for use with it in the total evaluation process.

- Similar Systems should be analyzed within the same net energy study. This would help solve problems using quality factors and boundary problems.

- Comparison of Results between studies is meaningful only when the same end products or end uses are being considered.

- Energy Content of Capital Goods used in the process should be accounted in all net energy studies. The recommended use of input-output analysis will assure that these higher order energy inputs are included.

- Dismantling and Disposal of the facilities at the end of their useful lifetime should be considered. For some energy technologies, substantial future energy commitments are necessary for safe dismantling and disposal.

- Variations in the Results can be reduced by:

  (1) using input-output analysis for indirect energy inputs;

  (2) analyzing comparable systems within one study; and

  (3) presenting results with and without quality factors and unconventional energy flows.

  The variations would be less confusing if the study clearly states its assumptions.

- Evaluation of Developing Technologies remains an issue in the application of net energy analysis. Technological breakthrough must sometimes occur before a given system becomes economic. There is no satisfactory method for assessing the effects of unknown technological advances.

- A Data Base detailing energy flows and energy contents should be established. Then studies would be founded on a common basis and efforts would be reduced in their performance.

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APPENDIX

SUMMARY OF REVIEW OF APPLICATIONS STUDIES

The observations and conclusions given in the paper resulted from the review of twelve net energy studies within an issue oriented framework. The framework used for reviewing these studies is given below. The framework uses issues as key headings and questions relating to the issue were developed. Each of the twelve studies were reviewed with an emphasis on developing answers to the issue related questions. A summary of the results for each study is presented in Tables A-1 and A-2. Table A-1 summarizes methodological issues, that is, factors which define the approach and comprehensiveness of the analysis. The analytical features describe the specific techniques and methods employed in each of the studies and are summarized in Table A-2. Observations from the comparison of these studies were stated above. The components of the comparison framework are:

- Methodological Approach. Which of the basic net energy analysis methodologies are employed? Candidates include process analysis; input-output analysis; eco-energetics; and combination of these methodologies.

- Structural Hierarchy. Does the study deal with the effects of several levels of aggregation or is the analysis confined to a single level? Some studies deal only with the effects at the local level and ignore national or global implications. Many global or national approaches may be useless to local decision makers. Thus, the components of structural hierarchy include: national, regional, and local, which constitutes single level studies, and multilevel studies.

- System Boundaries. This factor deals with the comprehensiveness of the system and its components. Specifying system boundaries will determine the extent to which the net energy analysis is taken. This can be clarified by breaking down into further detail the candidate system boundaries, e. g.,

  (1) Primary fuels. Are the primary fuels of coal, oil, gas, uranium, geothermal, solar or other forms considered?

  (2) Secondary fuels. Are fuels such as electricity, waste heat, distillates, and biomass considered?

  (3) Supply trajectory. Are all phases of the fuel cycle included such as exploration, extraction, processing, transportation, generation, conversion, distribution, and consumption?

  (4) Demand. Which end use economic sectors are included, such as residential, commercial, industrial, transportation, and agriculture?

- Energy Inputs. This factor deals with the various kinds of energy inputs normally associated with net energy studies. Inputs should be quantified for both the construction or capital formation stage

of the energy technology and the operational phase of the technology, including coverage of goods and services utilized. Subfactors involved in energy inputs include:

  (1) Resource base. Are the issues of sequestered resources, resource losses and renewability of resources considered?

  (2) Direct energy. Which input quantities are used to characterize major energy flows, such as energy amount, direct resource use, process energy losses, and thermodynamic efficiencies?

  (3) Indirect inputs. What indirect energy inputs were considered? Was the energy content of capital and materials, labor, institutional and environmental inputs considered?

- Indirect Energy. How are the indirect energies measured? Different techniques may be used to measure the indirect energies associated with capital, materials, labor, institutions and environment.

- Economic. A number of economic factors are included in net energy analysis. The economic factors are directly related to the accounting function of net energy analysis. Examples of economic factors include:

  (1) Discounting. Are energy expenditures that occur at different times comparable? Are economic discount rates or energy per dollar ratios used? What rates or ratios are used?

  (2) Interfuel competition. Are interactions between competing fuels considered and, if so, how? Is the treatment explicit of implicit?

  (3) Demand specification. Does the study involve a supply-only analysis with an assumed consumption level to meet, or are common ratios used? How are uses determined?

- By-products. Is the energy content of any useful by-products measured? The twelve studies that have been reviewed in Tables A-1 and A-2 are given as References 3 through 14.

TABLE A-1. Methodological Features

	Type of Analysis	Structural Hierarchy	System Boundaries: Primary Fuels	Secondary Fuels	Supply Trajectory	Demand	Energy Inputs: Resource Base Issues	Direct Inputs	Indirect Inputs
Energy Costs Bullard	Explanation of I/O Methodology	U.S. Economy 357 Sectors	Coal Crude Oil Natural Gas	Hydro Nuclear	None	Implicit In Balance	Some	Monetary Flows & Energy	None
Mitchiner	Development Dynamic Methodology	Site Specific for Solar	Solar Nuclear	None	Causal relation	None	Resource Base Included	Efficiencies & Fuel Fractions	None
DSI Estimates of Merit	Process - I/O Combination	U.S. Generic	Oil Gas Coal Oil Shale	Electricity Seven Types	Comprehensive Set of Alternatives	None	Resource Oriented	Resource Base Process Energies	Capital & Material
DSI Consumer Technologies	Process - I/O with End Use	Northeast U. S.	Oil Gas Coal Shale	Electricity from all fuels & solar, geothermal	Comprehensive for region	End-Use Technologies	Not a Major Factor but Region Specific	Resource Base, Process Energies Efficient	Capital & Materials
DSI Energy Planning	Process - I/O Combination	Northeast U. S,	Oil Gas Coal Oil Shale	Electricity from various options	Trajectories Combined for Set of Options	End-Use Sectors in Options	Not a Major Factor	Technologies in Energy Flows	Capital & Materials
CERI	Process - I/O Combination	Oriented for Western U.S.	Coal Oil Shale Gas Crude Oil	Electricity from Fossil Fuels	Fossil Fuel Delivery	None	Resource Oriented	Energy Flows, Technologies	Capital & Materials
IEA Rotty	Process Analysis with I/O for High Order	National with Possible Regional Applications	Uranium Coal Oil	Electricity	Mining through the generating of electricity	None	None	Actual Energy Purchases	Capital, Materials & Construction

TABLE A-1. Methodological Features (cont'd)

	Type of Analysis	Structural Hierarchy	System Boundaries: Primary Fuels	Secondary Fuels	Supply Trajectory	Demand	Energy Inputs: Resource Base Issues	Direct Inputs	Indirect Inputs
Gardner Oil Shale	Eco-energetics	Regional Analysis for National Policy	Solar Fossil Fuels	Electricity Internal Heat Use, Shale, Liquified Oil	Mining through refining the resulting oil	None	None	Solar losses calculated directly, all others are implicitly included by energy/dollar ratio	Capital, Materials, Labor, Land and Water
Ballentine Coal	Eco-energetics	Regional Analysis for National Policy	Coal Oil Solar	Electricity Internal Energy Use	Mining through delivery of electricity to the consumer	None	None	Purchases of fossil fuels & electricity calculated solar losses	Capital, Materials, Labor, Land and Water
Kylstra Nuclear	Eco-energetics	National	Uranium Solar Fossil Fuels	Electricity Plutonium Waste Heat	Mining through delivery of electricity to the consumer	Projections for electric & non-electric based on 1960-1970 data	None	Uraniun input is calculated, all others from energy/dollar ratio	Capital, Materials, Labor, Institutions
Zucchetto Transportation Modes	Eco-energetics	National	Fossil Fuels Solar	None	None	None	None	Obtained implicitly by the energy per dollar ratio	Capital and Materials
Alternative Water Heaters	Eco-energetics	Site Specific Analysis for National Policy	Solar Fossil Fuels	Electricity	None	None	None	Obtained implicitly by the energy per dollar ratio	Capital and Materials

TABLE A-2. Analytical Features

	Indirect Energy Costs				Economic				
	Capital and Materials	Labor	Institutional Sociological	Environmental	Discounting	Payback	Interfuel Competition	Demand	Byproducts B.
Energy Costs Bullard	I/O Coefficients	Embodied In I/O Tables	None	None	None	None	None	Implicit In Balance	Embodied In I/O Tables
Mitchiner	Energy Reinvested For New Capacity	None	None	None	None	None	Electricty Assumed Suitable	None; Only Available Energy	None
DSI Estimates of Merit	Estimated From I/O Coefficients	Embodied In I/o Tables	None	Technology Assumed Acceptable	Static Average	Averaged Over Life-Time (Static)	None	None	Accounted For Useful Byproducts
DSI Consumer Technologies	Estimated from I/O Coefficients	Embodied in I/O Tables	None	Technology Assumed Acceptable	Static Average	Averaged Over Life-time (Static)	None	Based on History and Esti-mates	Accounted For Useful Byproducts
DSI Energy Planning	Estimated from I/O Coefficients	Embodied in I/O Tables	None	Technology Assumed Acceptable	Static Average	Averaged Over Life-time (Static)	None	Based on History and Estimates for Options	Accounted For Useful Byproducts
CERI	Estimated from I/O Coefficients	Embodied in I/O Tables	None	Technology Assumed Acceptable	Static Average	Averaged Over Life-time (Static)	None	None	Accounted For Useful Byproducts
IEA Rotty	Process Analysis for Major Materials I/O for all others	I/O	None	None	Static Average	Can be deduced from graph of energy balance of reactor over time	None	None	None

TABLE A-2. Analytical Features (cont'd)

Gardner Oil Shale	Energy Per Dollar Ratio	Energy Per Dollar Ratio Plus Water, Land Use	None	Water, and land by loss of Photosyn-thesis	Static Average	None	None	None	None
Ballantine Coal	Energy Per Dollar Ratio	Energy Per Dollar Ratio	None	Water, land and Ecosys-tem Dis-tion	Static Average	None	None	None	None
Klystra Nuclear	Energy Per Dollar Ratio	Energy Per Dollar Ratio	Energy Per Dollar Ratio In AEC Budget	None	Static Average	Calculated By Dynamics Simu-lation of U.S.	None	1960-1970 Growth Rates For Electric And Fossil Energy	Plutonium
Zucchetto Transportation Modes	Energy Per Dollar Ratio	Energy Per Dollar Ratio	None	None	None	None	None	None	None
Alternative Water Heaters	Energy Per Dollar Ratio	Energy Per Dollar Ratio	None	None	None	None	None	None	None