BNL 50800

BROOKHAVEN NATIONAL LABORATORY DEVELOPING COUNTRIES ENERGY PROGRAM

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AN ANALYTICAL FRAMEWORK FOR THE ASSESSMENT OF ENERGY RESOURCE AND TECHNOLOGY OPTIONS FOR DEVELOPING COUNTRIES

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BNL 50800
UC-13
(General, Miscellaneous, and
Progress Reports (Nonnuclear)
TID-4500)

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UNDER CONTACT NO. EY-76-C-02-0016

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $4.00; Microfiche $3.00

May 1978 300 copies

ABSTRACT

An analytical framework is described for the assessment of energy resource and technology options for developing countries. The framework, based on the Brookhaven Reference Energy System approach, is designed to provide an overall view of the energy supply-demand system of a country, integrating data from a variety of sources and specialized models. The current version is designed to support the evaluation of resource and technology options for countries which are part of the Department of Energy International Energy Program.

INTRODUCTION

This report presents a brief summary of the analytical approach being used for the initial country assessments in the Department of Energy International Energy Program. One of the goals of that program is to assist developing countries in identifying the major energy resource and technology options available to them. That identification of options can then be used to formulate collaborative energy programs of various kinds. In this paper we do not discuss the goals and strategies of the overall DOE program but concentrate on the energy systems analysis approach used in the program. Nevertheless, the analytical approach has been chosen to satisfy the needs of the overall program.

In addition to supporting the overall program goals, the choice of analytical methods was constrained by a number of other factors: The time available for analysis (2-3 months) and the conditions under which data were to be collected dictated a basically simple analytical approach. At the same time, the approach had to be able to take a comprehensive and long-term view of the energy systems of the countries under consideration. Finally, the methods had to be able to support policy analysis by groups of people over short periods of time.

The analytical approach described in this report satisfies these basic needs. As will be seen it is straightforward, but can incorporate as much technical sophistication and detail as desired. It should be emphasized, however, that the method is designed for normative technology assessment and policy analysis, not national energy planning. As described in this report, for example, the methodology does not include a direct interactive linkage to a national macroeconomic model. The approach is based, however, on methods used at Brookhaven National Laboratory to analyze U. S. energy policy issues. In the U. S. version of the approach, a full set of economic linkages has been developed.(1) Thus, although the approach as described in this report is simplified to satisfy the constraints imposed by the current program, it can be extended quite readily to an economically more complete structure. As discussed below, the framework for analysis is also compatible with linear programming optimization models of the energy system and can use the output of such models if they are available.

Purpose of the Analysis and Overall Approach

The purpose of the analysis is to evaluate the potential of various energy resource and technology options in meeting national economic and social development goals. The kinds of resource options that are of interest are the development of various indigenous conventional resources such as oil, oil shale, natural gas, coal, uranium, hydropower, or geothermal energy. Technology options would include, for example, advanced coal combustion technologies, solar energy for water heating or crop drying, wind-driven irrigation pumps, and energy efficient industrial processes. In general there are two categories of options to be considered: those which correspond to the accelerated implementation of existing elements of the energy system (such as oil-fired electricity generation) and those which correspond to the introduction of a new technology (such as solar electricity). The options that may be of interest are very diverse, ranging from resource extraction to increased end use efficiency; from highly centralized technologies such as large scale nuclear powered electricity production to decentralized household solar water heating; from those relying on commercial fuels such as petroleum to those employing noncommercial fuels[2] such as crop residues. This range of possible options places stringent requirements on the analytical methods used for the analysis.

The various resource and technology options must be analyzed with respect to a number of parameters of concern, or objective functions, or "payoff functions". Among the most prominent of these are the following:

- Total Fuel Demand and Fuel Mix: In most cases a country will want to maximize the efficiency of energy use; that is, solutions which provide the same services at lower fuel use are to be preferred. In some cases where particular resources are underutilized--for example natural gas that is being flared--solutions will be sought to make optimal use of that fuel.

- Oil Imports and Exports: Countries dependent on imported oil will want to reduce oil consumption; those exporting petroleum will want to maximize revenues from exported oil.

- National Social Goals: National social and economic development goals will often include improvements in social welfare--through increased nutrition, housing, rural electrification, rural development, etc. These often have specific energy requirements.[3]

- Total Energy Costs: The cost of energy to all consuming sectors is to be minimized. National policy may emphasize reducing energy cost to particular uses, such as industry or rural areas, but these goals will usually be implemented through pricing policies.

- Balance of Payments: The balance of imports and exports is to be optimized.

- Labor Requirements: The use of local labor is to be maximized, particularly in sectors or regions with unemployment. In general labor-intensive rather than capital-intensive technologies are to be preferred.

- Capital Requirements: The requirements of capital resources, particularly imported capital are to be minimized.

- Environmental Quality: The effect on major environmental concerns such as urban air quality, use of arable land, water quality, occupational health, should be identified, if possible, for each option.

In order to accomplish these purposes, the basic approach is as follows: First a view is constructed of the energy implications of current national economic development plans. A consistent description of the future energy system of the country, under the assumption of "current trends and policies" is constructed for certain reference years in the future. The values of the objective functions described above are then calculated for that "reference case". The major resource and technology options are then identified[4] and the rates at which they can be implemented are determined. In doing so the major barriers to that implementation are identified. Finally, one calculates the impact on the various objective functions, of the implementation of each option.

It is this perturbation or impact analysis that is the main purpose of the analysis. The approach to demand analysis, the projections made, the amount of detail included should all be determined on the basis of maximizing the accuracy of this analysis. Thus, once the impacts of a given option have been analyzed, an evaluation should be made of the sensitivity of any conclusions to major assumptions made in the analysis. The conclusions could be tested, for example, with alternative GNP or sectoral growth rates, different price assumptions, or governmental policies regarding rural development or income distribution.

Although the analysis of options is the primary objective, the demand projections which are an integral part of the analysis can be very informative in their own right. Since they are based on detailed sectoral plans, they provide a verification of more aggregate demand projections.

ANALYTICAL FRAMEWORK

General Description

The basic element of the analytical framework is the Reference Energy System.[5]

A Reference Energy System consists of a set of estimated energy demands, energy conversion technologies, fuel mixes, and the resources required to satisfy those demands. Costs, environmental emissions and other factors associated with all elements in the system are part of the supporting data for the RES.

The pictorial format for the Reference Energy System is a network diagram which indicates energy flows and the associated conversion efficiencies of the reference technologies employed in various stages of the energy production/transmission/distribution/end-use system. A simplified RES is shown in Figure 1. For each energy resource, a complete Reference Energy System specifies the technologies employed in the following activities:

1. Extraction
2. Refining and/or conversion
3. Transport of primary energy source
4. Centralized conversion (e.g., electricity generation)
5. Transport or transmission and storage of secondary energy form
6. Decentralized conversion
7. Utilization in an end use device.

Figure 2 shows a more complete RES. As illustrated in that figure each path through the energy system network indicates a possible route for the flow of energy from an energy resource to a given demand category. Alternate paths and branches reflect the substitutability of various resources and technologies for one another. The energy flowing through each step or process is shown above the line representing the activity. The numbers in parentheses are the efficiencies, or relative effectiveness, of the processes. The RES representation permits calculation of the amount of a particular energy resource, for example oil, used to satisfy a particular

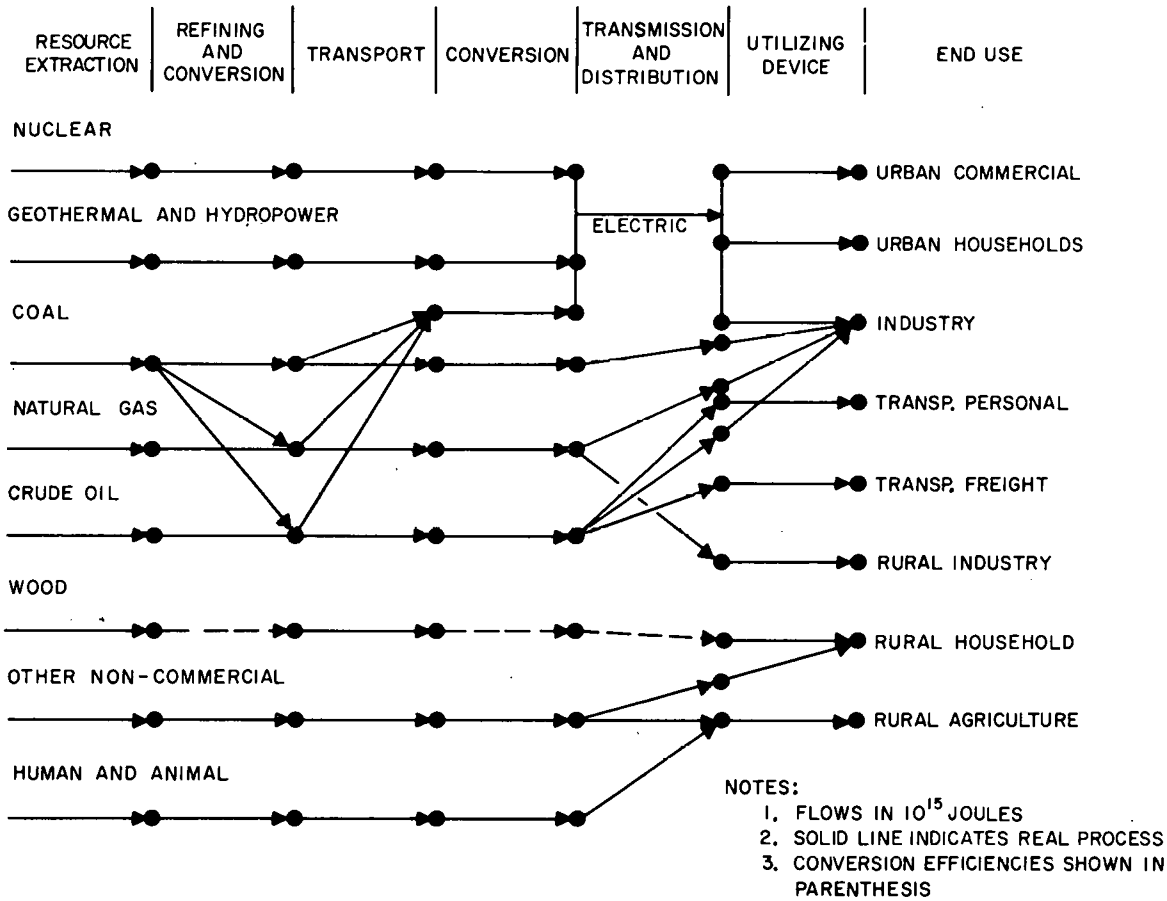


Figure 1. LDC Reference Energy System (Illustrative).

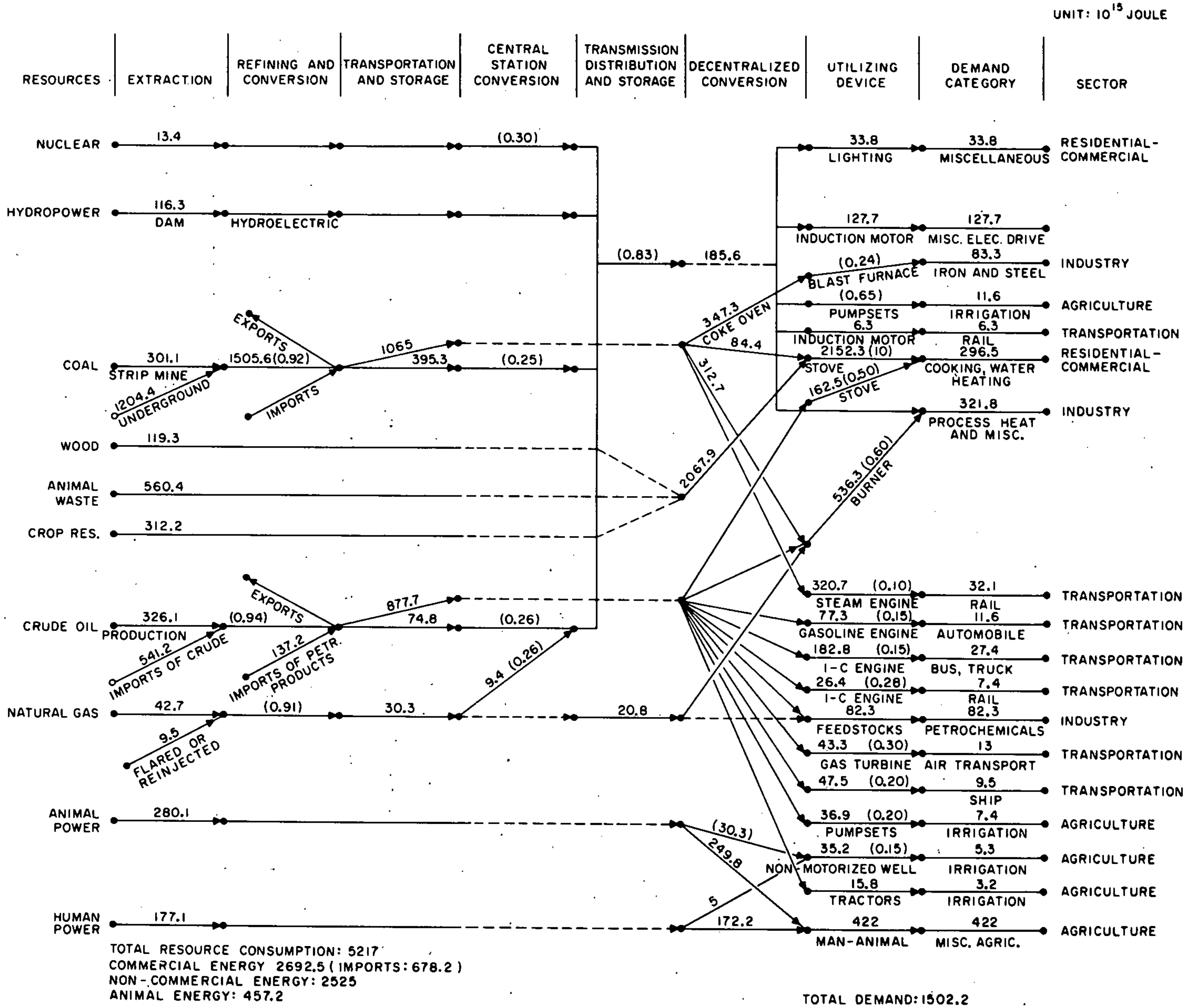


Figure 2. Reference Energy System - Commercial and Non-Commercial Energy - India 1972

demand, for example space heating, either through a particular intermediate fuel form, such as electricity, or directly. Energy demands are assumed for each reference year from historical data and projections. Both commercial and non-commercial fuel forms can be dealt with and centralized energy systems (such as large scale electricity generation) are distinguished from decentralized systems (such as small scale solar electricity production).

The values on the left side of the RES under the heading "extraction" represent the raw energy input needed to satisfy the basic energy demands. The values on the right side of the RES under the heading "Demand Category" represent the basic energy demands in terms of a specific set of end-use categories. These are discussed below. Fuel demands are shown under the heading "Utilizing Device."

Demand Analysis

The analytical approach is "driven" by a detailed consideration of energy demand. In this section we describe the approach to demand analysis in some detail in order to provide guidance to data collection.

Three important points must be stressed at the outset. First, data requirements can not be specified in the abstract. They depend strongly upon (1) the otpions to be analyzed and (2) the availability of information. If stress is to be laid on increased energy efficiency in industry, for example, more detail is required in industrial energy demand than would be the case if only increased supply options were being examined. Similarly, since the current program precludes the collection of new primary data, one cannot disaggregate demand more than permitted by existing information.

The second general point to be stressed is that the demand analysis must be flexible, and will probably require some imagination. Where "necessary" data on demands or efficiencies do not exist, some reasonable surrogates or approximations based on experiences in other countries, if necessary, should be invoked. This leads to a final point: that every number in the analysis be documented with respect to its source or the assumptions made in deriving it. In this way the more uncertain parts of the analysis can be identified or alternative assumptions can be made.

The specification of an energy demand for the RES entails three pieces of information:

1. Measure of Demand Activity: the demand level specified in units of activity, or other determinant of demand, e.g., passenger car kilometers, tons of steel produced, number of rural households (for cooking), number of irrigation pumps in operation, etc.[6]

2. Direct Fuel Consumption: the amount of fuel (in joules) of various kinds ("fuel" includes electricity) delivered to a particular end use category.

3. Relative Effectiveness: the relative efficiency with which various fuels provide energy to satisfy a specific activity. Relative effectiveness is distinguished from efficiency in that it reflects differences in utilization practice as well as device efficiency.[7]

In addition to these basic quantities it is useful to define a quantity known as Basic Energy Demand. Basic Energy Demand is the amount of energy (in joules) which represents the useful energy required by a particular demand category. This is a derived quantity, independent of fuel type.

Let D_i = amount of fuel i used for a given activity

e_i = relative effectiveness with which fuel i is used for the activity

E = Basic Energy Demand for the activity

Then

$$E = \sum_i e_i D_i$$

Basic Energy Demands are represented on the rightmost column of the Reference Energy System under "Demand Category." Under "Utilizing Device" are shown the Fuel Consumption and Relative Effectiveness. An example, for cooking in rural households, is shown in Figure 3. Some more detailes on demand analysis and a useful form of worksheet are shown in Appendix A. A typical list of demand categories and projection variables are shown in Table 1.

The utility of this formalism is twofold: First, it provides an explicit representation of the efficiency of energy end use that is necessary for analyses

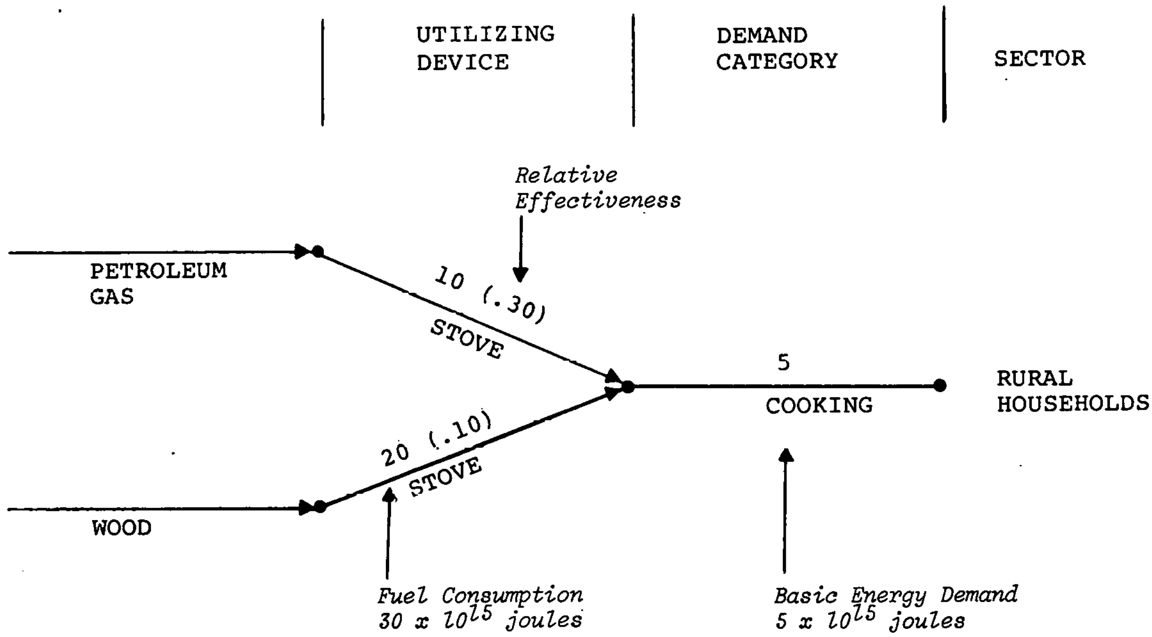
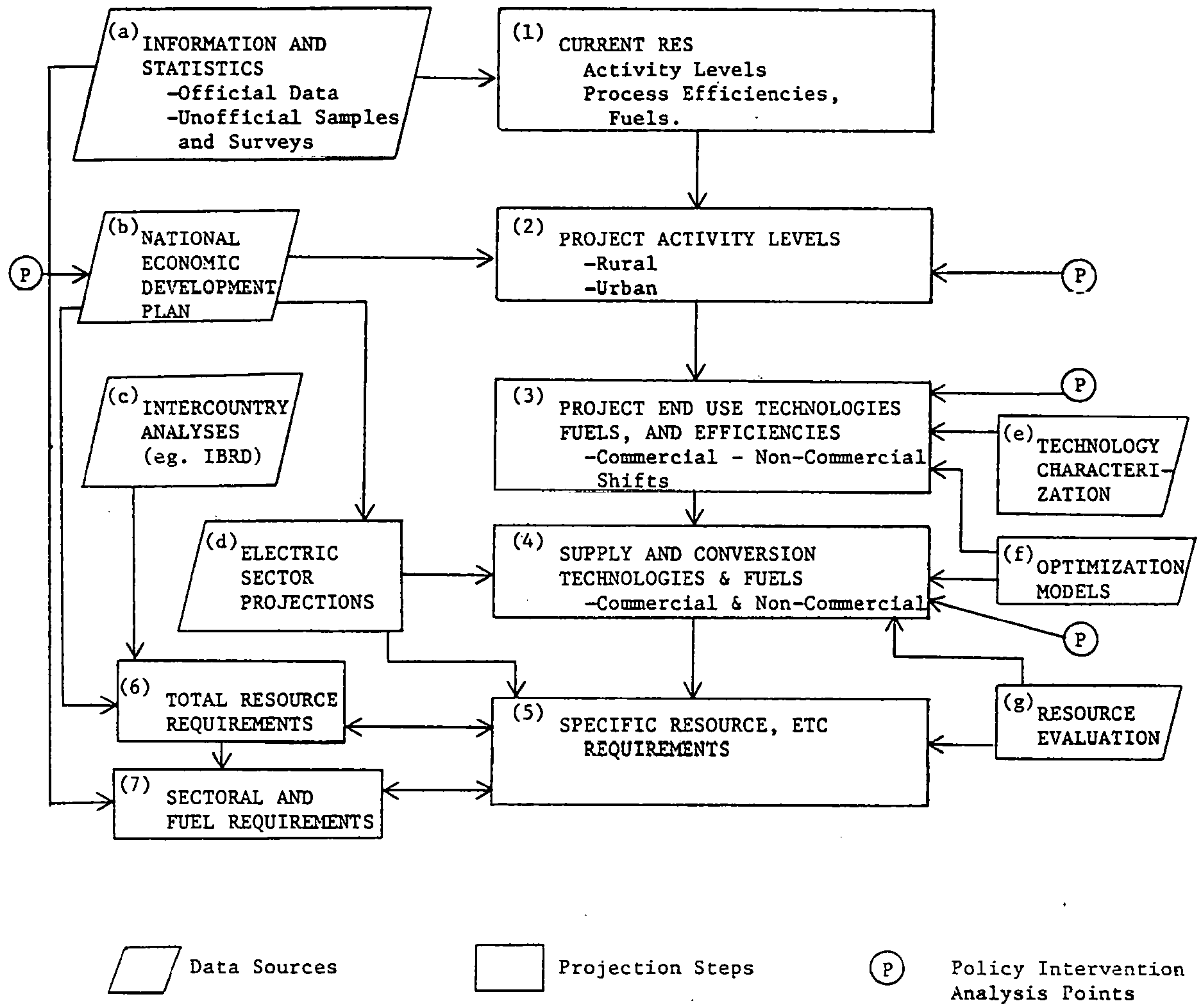


Figure 3. RES Demand Element - Rural Cooking.

REPRESENTATIVE DEMAND PROJECTION VARIABLES

SECTOR/CATEGORY	MEASURE OF ACTIVITY	UTILIZING DEVICE/ACTIVITY	OTHER VARIABLES
Industrial			
Iron and steel	Output (Tonnes)	Blast Furnace (coke) Process Heat	Capacity Projections
Petrochemicals	Output (Tonnes)	Feedstocks Process Heat	Capacity Projections
Cement	Output (Tonnes)	Burners	Construction Projections
Other Large	Output (Tonnes)	Process Heat Electric Drive	Industrial Value Added
Rural Small	Output (Tonnes)	All	Rural Population
Transportation			
Passenger-Auto	Passenger-km	Int. Comb. Engine	Population, disposable income, Road km
Ship	Vessel-km	Diesel	
Air	Passenger-km	ICE; Jet	
Truck	Tonne-km	Diesel, ICE	Passenger vs Freight Travel
Railway	Tonne-Passenger-km	Diesel, Electric Drive	
Pipeline	Thruput, Barrels/day	Pump; diesel, electric	Capacity Projections
Agriculture			
Soil Preparation	Tractor-km	Int. Comb. Engine	Number of Tractors
Irrigation	Pump-hours	Diesel Pump	Agricultural Production
		Electric Pump	Number of Pumps
Urban Households			
Cooking	No. of Households	Stoves; gas, oil, electric	
Lighting	No. of Households	Electric Lights	Disposable income
Misc. Electric	No. of Households; appliance ownership	Moters, electric devices	Disposable income
Rural Households			
Cooking	No. of Households	Stoves; kerosene & non commercial	
Lighting	No. of Households	Electric & gas lamps	Rural Electrification
Commercial			
Lighting & Appliances	No. of Establishments and/or Floorspace	Vapor Compression	Value Added in Sector
Air Conditioning	No. of Establishments and/or Floorspace & Saturation	Vapor Compression	Value Added in Sector (Including Tourism)
Cooking	No. of Restaurants	Stoves; gas and electric	Value Added in Sector (Including Tourism)
Municipal Services			
Lighting	Urban Population; Saturation	Lamps; florescent & incandescent	Municipal Budgets
Other	Urban Population; Saturation	Pumps, etc.	Municipal Budgets



Note: Feedback Loops Not Shown.

Assumes no existing National Energy Plan.

Figure 4. LDC Country Technology Assessment Reference Case Projection Methodology

In most countries there exists a projection of electricity demand and capacity mix. The methodology provides an independent projection of electricity demand, based on total energy demand, that can be compared with national projections. Aggregate demand for energy fuels is a quantity derived from the projection and RES process. Aggregate demand can also be derived from projections of national economic growth and a specification of income elasticity of energy demand. Such aggregate projections can be compared to the RES projection and, if considered appropriate, can be used to adjust the sectoral demands.

Specification of Conversion Technologies

In order to complete the Reference Energy System the characteristics of each process element or technology must be specified. This applies to the technologies used for final consumption (such as air conditioners and stoves) and those used "back" in the system, the supply technologies (such as electricity generating technologies or pipelines). The following information should be provided for each technology:

1. Primary Efficiency: the ratio of useful energy out of the process to primary energy delivered to it (for example, electricity out to fuel in for electricity production). If significant amounts of ancillary energy of some other form is used it should also be specified. For end use technologies "relative effectiveness" is used rather than primary efficiency (see above).

2. Costs: Capital and operating, expressed in constant dollars for a given reference year.

3. Environmental Impact Parameters. These are often expressed in terms of residuals produced (emissions of CO_2, CO, SO_x, particulates to air and acids, bases, BOD, disolved and suspended solids to water) per 10^9 joule or other factors of concern, such as land use.

In addition, for those technologies which are involved in the option analyses, the following information is important:

Unit plant size

Construction period

Lifetime

Date of first availability

Feasible rate of introduction

For all technologies their characteristics should be specified for each reference year. A complete data set for current and future technologies, as they apply in the U.S. is available at Brookhaven National Laboratory.[8]

The resource requirements derived in the analysis can then be compared with projected estimates of resource production to arrive at import requirements or export potential. Other characteristics of the system such as capital requirements, sectoral cost of energy, and environmental impacts can also be calculated for the entire Reference Energy System.

Option Analysis

Once the Reference Energy System is established for the future years of interest, and the aggregate characteristics of the system are determined, one is ready to perform impact analyses of future options. In some cases this will involve a simple technology substitution, such as substituting solar cookers for wood burning stoves. In other cases it may involve a complex set of resource and technology substitutions, such as increased natural gas production and use in electricity generation, domestic cooking, and industry. In all cases the basic procedure is to:

1. Identify the processes or sectors in which the new resource or technology will substitute,

2. Establish feasible rates of introduction of the resource/technology and levels of introduction in the future reference years

3. Produce a new system description, a Perturbed Energy System, for the appropriate years, and

4. Calculate the change in resource consumption, cost, and other objective functions identified above.

In order to facilitate option analysis a computer model corresponding to the Reference Energy System for developing countries has been developed.[9]

A Final Note

In constructing this analytical system we are very much aware that many of the principal concerns of energy policy can not be quantified and inserted into a model. The process of energy policy analysis is necessarily a judgemental one and the methods described in this report have been designed to assist, rather than replace, that process.

NOTES AND REFERENCES

1. K. C. Hoffman and D. W. Jorgenson, "Economic and Technological Models for Evaluation of Energy Policy," Bell Journal of Economics, Autumn, 1977, also BNL-22895, Brookhaven National Laboratory, Upton, New York.

2. The term "commercial" energy generally refers to energy forms normally actively traded in developed country markets such as oil, gas, coal and electricity. The primary categories of "noncommercial" energy are wood, agricultural wastes, and animal dung. The term "noncommercial" is in fact a misnomer, since there are monetary markets for these fuels. In some contexts, the term must be extended to include human and animal power. Other terms sometimes used for "noncommercial" are "traditional," "primitive" (vs. "modern") or "nonconventional" (vs. "conventional").

3. P. F. Palmedo, et al., "Energy Needs, Uses and Resources in Developing Countries," BNL-50784 (Feb. 1978), Brookhaven National Laboratory, Chapter C, Energy for Basic Human Needs.

4. In reality these options must be identified earlier in the analysis so that greater attention can be given in developing the reference case in areas or sections which will be the subject of policy analysis.

5. The Reference Energy System approach was developed at Brookhaven National Laboratory in 1971 for energy R&D assessment and has been extended for various analyses since that time. See M. Beller, Ed., "Sourcebook for Energy Assessment," BNL-50493 (December 1975), Brookhaven National Laboratory.

6. Saturation effects can be dealt with directly as follows: Take the energy demand for refrigerators. If the measure of demand activity is the number of households, one needs to specify the "saturation" of refrigerators, that is the fraction of households with refrigerators. See Appendix A.

7. The relative effectiveness of electric space heating, for example, includes the effect of different use patterns, and insulation levels with electric vs. oil fired heating.

8. Brookhaven National Laboratory, "Energy Model Data Base - Users Manual" BNL-19200 (1974).

9. A. Reisman and R. Malone, "Less Developed Countries Energy System Network Simulator LDC-ESNS - A Brief Description," Feb. 1978, Brookhaven National Laboratory, Upton, New York.

APPENDIX A

ENERGY DEMAND AND FUEL MIX ANALYSIS*

For the purpose of energy resource and technology assessment it is necessary to develop projections of energy demands in a detailed, or disaggregated, manner. This approach is required in order to evaluate technologies that may apply to very specific end uses. To evaluate the use of solar energy for water heating, for example, the projected growth of this end-use must be exhibited in the reference system.

It is recognized that projections made in this disaggregated manner may well underestimate the total energy demand in the future because of unanticipated new uses of energy. Since the technologies employed for such uses obviously cannot be defined, it is not, in general, necessary to reflect these uses in the reference systems. It is felt, however, that such demands are more likely to involve electrical energy than other energy forms. To reflect this impact on the supply systems, several undefined electrical demands can be included in the residential and commercial miscellaneous electric categories (by postulating phantom appliances and demands), and in the demand category for industrial miscellaneous process heat.

The projections of energy demands and the fuel mix for the reference years can be developed on worksheets of the form shown in Figure A1. It is useful to define several parameters. These are:

1. Fuel Demand, D_i = The quantity of a fuel,** i, actually consumed in a specific demand category, such as space heating, automotive transport, or aluminum production.

2. Total Fuel Demand, D = the total fuel required to satisfy the requirements of a specific demand category. Electricity is considered as a fuel in this sense and $D = \sum_i D_i$.

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* Taken with modification from M. Beller, Ed. "Sourcebook for Energy Assessment", BNL-50483, Dec. 1975.

** Fuel as used in this sense includes electricity.

Sector: RESIDENTIAL
Category: WATER HEAT

	1972			1980			1985			1990			2000			2020		
	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i	f_i	e_i	D_i
DIRECT FUEL USE																		
Methane	.51	.57	1.178	.53	.57	1.357	.53	.57	1.448	.50	.57	1.467	.44	.57	1.486	.44	.57	1.847
Jet fuel																		
Gasoline																		
Distillate oil	.10	.63	.183	.10	.63	.232	.10	.63	.247	.10	.63	.266	.10	.63	.306	.10	.63	.380
LPG	.05	.57	.117															
Residual oil																		
Coal																		
Other																		
ELECTRICITY	.30	1.00	.393	.37	1.00	.540	.37	1.00	.576	.40	1.00	.669	.46	1.00	.886	.46	1.00	1.101
TOTAL FUEL DEMAND, D, 10^{15} Btu			1.871			2.129			2.271			2.402			2.678			3.328
BASIS 10^6 households			66.7			75.			80.			86.			99.			123.
SATURATION, S,	.96			1.00			1.00			1.00			1.00			1.00		
BASIC ENERGY DEMAND, E, 10^{15} Btu			1.246			1.459			1.557			1.673			1.926			2.393
UNIT BASIC DEMAND, E_u, 10^6 Btu/household			19.459			19.459			19.459			19.459			19.459			19.459

REFERENCE TECHNOLOGIES: Gas and oil burners, electric resistance heat.

DATA SOURCES: (from BNL 50483)

D_i for 1972: Btu/household requirements, by housing type, from Ref. (10) for gas and electric; Btu/household consumption for oil water heated homes taken from Ref. (16), Region II Fuel Mix tables.

f_i for 1972: Ref. (7).

e_i : Ref. (4) for gas and electric, Ref. (16) for oil. The e_i are held constant over all reference years.

BASIS OF PROJECTIONS: The basic demand derived for 1972 is escalated in proportion to the saturation and to the number of households as projected in Ref. (14) for 1985 and 2000 and interpolated for the other reference years.

Figure A1. Sample Demand Worksheet

3. Relative Effectiveness, e_i = the relative effectiveness with which fuel, i. is used in a demand category. This parameter depends on the utilization technology employed. See discussion in Section II.

4. Basic Energy Demand, E = the amount of energy that would be required in a specific demand category, assuming a relative effectiveness, e_i of 100% for each fuel employed. Thus, for a given demand category where quantities of fuels, D_i, are consumed with actual Relative Effectiveness, e_i, $E = \sum_i e_i D_i$.

5. Degree of Saturation, S = the fraction of the potential demand for a particular energy use actually being fulfilled at a given time. For example, if 95% of all households have refrigerators, and potentially all houses can have one refrigerator, S = 0.95.

6. Saturated Basic Energy Demand = the Basic Energy Demand that would exist in a category if there was 100% saturation, = E/S.

7. Unit Basic Energy Demand, E_u = the Basic Energy Demand per unit, e.g., per household, per lb of Al produced, etc.

8. Fuel Fraction, f_i = fraction of the Saturated Basic Energy Demand that is satisfied by using the i'th fuel.

$$f_i = \frac{e_i D_i}{E/S} \text{ and } \sum_i f_i = S$$

The procedure for developing the fuel mix projection in a given demand category begins with the definition of the base year mix. The methodology has been described above and leads to estimates of the Basic Energy Demand for each demand category in the reference year of interest.

The Basic Energy Demand derived in this manner is independent of the fuels employed to satisfy the demand and is projected into the future on the basis outlined above, including any increased saturation that may be postulated. In categories where a unit basic demand is defined, it is used as the basis for the projection and, in most cases, is held constant over all reference years. By specifying the Fuel Fractions, f_i, and Relative Effectiveness, e_i, the Fuel Demands, D_i are derived from the basic energy demands for each future reference year. Thus the fuel mix is defined.