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STATE-OF-THE-ART REVIEW OF ECONOMIC EVALUATION OF NON-CONVENTIONAL ENERGY ALTERNATIVES

Meta Systems Inc

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Table of Contents

Economic Evaluation of Non-Conventional Energy Alternative: An Overview..... i

I. Introduction..... 1

II. Social Benefit Cost Analysis..... 7

1. Social Benefit Cost Analysis: An Overview..... 7
2. UNIDO and Little-Mirrlees Approaches to Project Evaluation: A Comparative Analysis..... 28
3. The Limits to Project Level Analysis -- Linkage to Subsector (Industry) and Sector and Intersector Level Analysis..... 33
4. A Brief Review of Recent Contributions..... 40

III. Technological Alternatives and Efficiency in Energy Use..... 41

1. Choice of Technology..... 42
2. Efficiency..... 47

IV. Case Studies in Evaluation of Non-conventional Energy Technologies..... 56

1. Social Benefit Cost Analysis of a Family Biogas Plant..... 62
2. Rural Energy Systems: Sample Analysis of Irrigation Plans. 76

V. Annotated Bibliography on Social Benefit Cost Analysis and Energy Planning..... 135

VI. General Bibliography..... 162

Annexes

A. Economic Evaluation of a Village Level Community Biogas Plant..... A-1
B. Electricity Generation from Biomass..... B-1
C. Appendix to Section IV: Estimation of Calorific Value Parameters..... C-1

Economic Evaluation of Non-Conventional Energy Alternatives: An Overview

1. The economic evaluation of biomass-based renewable energy technologies would consist of the following three steps:*

(a) Financial analysis using market prices for inputs and outputs.

(b) Economic analysis in which market prices are replaced by "shadow prices" (or "accounting prices") which reflect the "real" value of outputs to the society and "real" resource costs of inputs to the society. The objective used in this analysis is the economically efficient allocation of resources.

(c) A comprehensive social benefit cost analysis which includes secondary benefits and indirect costs as well as incorporates the social objectives of employment, income distribution and regional development. This analysis differs from (b) in that policy objectives other than economic efficiency are taken into account.

2. The financial analysis of a renewable energy project would use available market prices and/or projected market prices for valuation of outputs and inputs. However, in developing countries, the markets for

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*The specific details of these steps are detailed in the reports discussed in Section V.A. of the main report, the annotated bibliography.

commodities such as biogas, fuelwood, cow dung, organic manure, etc. may not exist. In such situations, market prices for their substitutes such as kerosene, charcoal, softcoke or commercial fertilizers may be used after making suitable adjustments. The value of direct outputs and inputs during the life of the project can then be discounted to the present by using the market interest rate. The available decision criteria of Net Present Value, Benefit Cost Ratio and Internal Rate of Return can be used to select or rank the project in hand.

3. In many developing countries, market prices do not represent the "real" value (resource cost of an output or input to the society) on account of various distortions as a result of taxes/subsidies, government controls and income distribution. For example, price of kerosene or softcoke used in rural areas may be subsidized for political reasons while gasoline in urban areas may be taxed for the same reasons. Minimum wage regulations may result in market wages being higher than the "real" cost of unskilled labor determined by demand and supply conditions. Similarly, foreign exchange market may be regulated by the government and, hence, the official exchange rate may be lower than the "real" value of foreign exchange to the society. Besides, imperfections in the capital market may result in a multiplicity of distorted interest rates in the market.

4. Due to these and other distortions in factor markets and commodity markets, it has been suggested that in developing countries, benefits and costs of a project should be calculated using "shadow

prices" (or accounting prices) in place of market prices. These "shadow prices" would reflect the "true" value or cost of these outputs and inputs to the society so that a consistent method of comparison and ranking of various projects can be used.

5. Although the need for using "shadow prices" in place of market prices is recognized by many developing countries, as well as international aid agencies, there are only a few countries where consistent estimates of these prices have been made.* The potential sources for shadow prices in different countries include the National Economic Planning Units, the National Central Banks, international lending agencies such as the IBRD, ADB and the Inter-American Development Bank, UN agencies such as FAO and UNDP and international aid agencies such as AID and ODA. Wherever such numbers are obtained it is always advisable to review them with the appropriate ministries in the country concerned.

A review of some of the efforts made at estimating shadow prices in India, Ghana, Colombia, Ivory Coast, and Korea are present in Section 5.B, the annotated bibliography in the main report.

6. In the absence of any available estimates for various "shadow prices", the following approximate values or range of values are suggested below for use in evaluating a renewable energy project. However, it must be kept in mind that sensitivity analysis of the

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*Besides, there are alternative theoretical approaches available for estimation of these shadow prices. Section II, pp. 8-19).

project to these parameters should be performed to determine which parameters need detailed studies.

(a) Shadow wage rate: Shadow wage rates should be used for unskilled labor employed in the project over different seasons. For the sake of convenience, two seasons may be distinguished: a busy season for agricultural/forest related activities and a slack season during which there is relatively very little employment available. Since shadow wage rate would also depend on the extent of unemployment of unskilled labor, it may be useful to divide the country/region on this basis also. As an approximation, the following values for shadow wages may be used: (i) In areas of chronic unemployment during slack season, a shadow wage equal to one-fourth (25%) of market wage may be used (ii) In areas of chronic unemployment, during agricultural peak season, a shadow wage equal to one-half (50%) of market wage may be used (iii) In areas of relatively lower unemployment during slack season, a shadow wage equal to three-fourths (75%) of market wage may be used and (iv) In areas where unemployment levels are relatively low, a shadow wage equal to market wage during the peak season of agricultural or forest related activities may be used.

(b) Shadow Foreign Exchange: It may be correct to assume that shadow exchange rate would be higher than the official exchange rate in most developing countries. However, the extent of premium to be used would vary from country to country and from one period to the other. As an approximation, if the country concerned is not experiencing very serious balance of payments difficulties, it is suggested that a shadow price which is 25% higher than the official rate may be used. In countries which have serious foreign exchange problems (reflected in low exchange reserves), a shadow price which is 50% higher than the official price may be used.

Shadow Price of Land: Using a correct shadow price of land may be very important for renewable energy projects especially those concerned with social forestry scheme or charcoal production. In general, the shadow price of land should be equated to the opportunity cost of land. The opportunity cost of land may be calculated on the basis of benefits foregone in the alternative use of this land. The benefits foregone may relate to the existing or potential uses of land for agricultural, forest, pasture or other industrial uses. As an approximation, one can use the benefit foregone in terms of the value (as shadow prices) of agricultural commodities which could be grown on the piece of land during the life time of the project. The simplest method may be to assume that one rain-fed foodgrain crop could be

potentially grown on this land if not diverted to the project in question. It is recognized that opportunity cost of land can be very project specific and a lot of subjective judgement may be involved. However, it is better to indicate the range of relevant values than to use the convenient value of zero as the opportunity cost of land.

Social Rate of Discount and Opportunity Cost of Capital: There are different viewpoints with regard to use of social rate of discount for projects.* One approach uses a low social rate of discount along with a shadow price of investment. Another approach uses a relatively higher rate of discount (Section II p. 12). For practical purposes, it would be appropriate to use a range of values: 8%, 10% and 12% for discounting without making any adjustments for shadow price of investment. Since estimating opportunity cost of capital is a rather complex matter in developing countries, using a range of values would be appropriate. If a project is found to be sensitive to the rate of discount i.e., the choices switch with higher discount rate, it may be necessary to do a detailed analysis of opportunity cost of capital in that country.

Commodity Prices: The first correction required is for taxes and subsidies -- since these are only transfer payments and do not represent use of real resources. If an input/output is taxed, the tax component should be removed while using the price for valuation of benefits/

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* In this discussion the discount rates refer to an analysis in constant value. The effects of inflation are discounted prior to the calculation of these discount rates.

costs. Similarly, the element of subsidy should be added to the price of input/output concerned.

Even after corrections for taxes/subsidies the input/output prices may not reflect their opportunity costs/values. For tradable commodities, the relevant export/import price adjusted for shadow exchange rate should be used. It is necessary to determine whether a commodity is imported or exported at the margin. For example, if kerosene (or crude oil which yields kerosene) is imported (or importable) at the margin, the shadow price to be used will be c.i.f. price of kerosene multiplied by the premium (25% or 50%) on foreign exchange. However, if steel or cement are exported (or exportable) at the margin, the shadow price would be equal to f.o.b. price multiplied by premium on foreign exchange. In the case of non-tradables (electricity, transport, etc.), an attempt should be made to express the costs of non-tradables in terms of those of tradables. For example, the costs of hydro-electricity may be expressed in terms of the costs of thermal electricity based on tradables such as fuel oil or natural gas.

7. It should be noted that the above corrections would require breakdown of costs and benefits into different categories of labor by season and different materials (steel, cement, oil products, fertilizers, etc.). Besides, it is important to take a view of the future trends in the composition of these costs and the prices of various inputs and outputs. This may require a lot of effort on the part of the analyst. However, if the benefits and costs have to be viewed from the perspective of the society (and not from the perspective of a

consumer/farmer), this type of data collection and adjustment may be necessary.

8. After the corrections for distortions in factor and commodity markets have been used in valuation of benefits and costs, it may be necessary to incorporate indirect benefits/costs and other social objectives of development. For example, in the case of biogas units, health benefits from cleaner fuel, better sanitation, better lighting and the convenience of cooking may have to be evaluated. Similarly, the indirect (or secondary) benefits of social forestry projects may be obtained in terms of control of soil erosion better environmental conditions and more ground water. However, if indirect benefits are added, indirect costs of depriving the poorer sections of free cow dung or free pasture land should also be included on the cost side.

9. Since different projects may have different implications on local employment, income distribution among households and regional development, it may be necessary to incorporate these objectives explicitly into the analysis. One of the ways is to put explicit weights on benefits going to poor households and backward regions. It is suggested that a premium of 10% to 20% may be attached for the ratio of benefits going to poor households/regions. Since shadow wage rate for unskilled labor may have been already used, it may not be necessary to put explicit weightage on employment created by the project. Similarly, the preference for the use of indigenous resources vis-a-vis importable (or exportable) resources would be reflected through shadow exchange rate. However, an explicit premium on the use of local

resources and security and certainty of supplies may be incorporated in the analysis.

10. Even if all the information is available, it may not be easy to estimate the benefits and costs from the society's viewpoint on account of the special problems of quantification and valuation in renewable energy technologies. A variety of such problems are illustrated through the four case studies which are presented in Section IV and Annexes A and B. It should be recognized that in addition to a wide variety of information at project and national/region levels, economic evaluation would require considerable judgement on the part of the analyst. Thus, the quality of economic evaluation of biomass-based renewable energy technologies would depend as much on the analyst as on the data base used for analysis.

Sample Application

It may be useful to recapitulate the above points by providing a sample check-list of parameters on which data may have to be obtained for a village fuelwood plantations project. This checklist is based on a FAO case study of village fuelwood plantations in Korea. As a detailed review of this case study is also available in Section V. B an annotated bibliography.

The main parameters on which data are required are as follows:

Scope and Technical Specifications:

- Planting sites and coverage

- Type of species and planting
- Maintenance and organization

2. Project Costs:

- Shadow Price of Land
- Shadow Wage Rate for Unskilled Labor in Different Seasons
- Shadow Price of Foreign Exchange
- Costs of Materials (Fertilizers, Seedlings)
- Costs of Transport
- Costs of Supervision and Management

3. Project Output and Benefits:

- Quantification of Fuelwood Production/Yield
- Shadow Price of Fuelwood in terms of value of fuels that it would replace (e.g. crop residues, coal or kerosene)
- Reduction in Soil Erosion and Flood Damages
- Improvement of Environment and Weather
- Groundwater Quality and Quality

4. Comparing Costs and Benefits

- Social Rate of Discount
- Decision Criteria: NPV, B/C Ratio and IRR

5. Sensitivity Analysis

- Relevant of Shadow Prices of Land and Labor
- Range of Social Rate of Discount
- Range for Yield of Fuelwood
- Range for Shadow Price of Fuelwood (or substitutes)

Although the Korean case study referred to above provides a good format for carrying out similar studies, one must keep in mind some of its limitations. It should have spent more effort on estimation of shadow prices of land, labor and fuelwood.

The study has assumed that land under the project would have no alternative economic use for the period of the project and therefore land is valued at zero. It is inconceivable that an area of 127,000 hectares can be found which has no potential alternative economic use in the next twenty years. Hence, it may be necessary to estimate the opportunity cost of land in terms of benefits foregone.

The opportunity cost of unskilled labor is calculated on the basis of average earnings of self-employed workers during November-March. This does not seem to be satisfactory since it is not clear as to how many people in the region can earn the amount used as opportunity cost of labor during the entire period. If many workers remain unemployed or earn less than the average earnings, a lower shadow wage rate should be used.

Similarly, the valuation of fuelwood is arbitrary. It is mentioned that since fuelwood is not traded at present, the fuelwood has been valued in terms of the value of fuels that it would replace, handy agricultural residues and coal. Although the methodology used is correct, the prices of alternative fuels used are arbitrary. The entire economics of the project would be very different if prices other than those assumed in the report are used.

The Korean case study furthermore does not attempt to quantify and value the indirect (secondary and tertiary) benefits of fuelwood plantation projects which accrue to the society in terms of a reduction in soil erosion and flood damages and an improvement in quantity and quality of groundwater. As some research work on these aspects is underway in India, Nepal and the Philippines, it should be possible to incorporate these benefits in the economic evaluation of similar projects in the future.

Section I

INTRODUCTION

The economic viability and social profitability of a renewable energy technology or a program are necessary conditions for success. A consumer will not invest in an improved stove or a biogas unit if this is not considered a financially viable proposition. Similarly, a project or a program would have to be shown socially profitable before substantial subsidaries may be given to individual users or large scale public investments may be committed. Social Benefit Cost Analysis (SBCA) has traditionally been used as a method of selection and/or ranking of projects.

An overview of the salient features of this methodology is presented here as a background to illustrate the complex problems of economic evaluation of renewable energy technologies. Briefly, an economic evaluation of a project would consist of the following steps:

(i) calculating the financial viability of the project when benefits and costs are valued at market prices and market interest rate is used for the opportunity cost of capital;

(ii) making corrections in financial costs and benefits by eliminating taxes and subsidiaries which are treated as transfer payments and do not reflect real resource costs;

(iii) recognizing the distortions in market prices on account of price and quantity controls, minimum wage regulations, imperfect capital markets and regulations of trade and foreign exchange by the government; and, hence, replacing the market prices by "accounting prices" or "shadow prices" which reflect the real values of inputs and outputs of each project;

(iv) incorporating considerations of income distribution, regional development and employment through explicit weights on these objectives and,

(v) calculating the social profitability of the project by using appropriate values of social rate of discount and shadow price of investment to estimate Net Present Value, Benefit Cost Ratio and the Internal Rate of Return.

Although these components of social benefit cost analysis are known and many governments wish to use these for economic evaluation of projects, it is common to find that not much effort has been made to estimate a consistent set of values for national and regional parameters such as social rate of discount, shadow price of investment, shadow price of foreign exchange, shadow wage rates for various labor categories over various seasons in different regions and shadow prices of many other inputs (e.g. electricity, cement, goods transport). Thus, as a part of (or rather a prelude to) doing an economic evaluation of non-conventional energy sources, one has to "estimate" values of parameters such as social rate of discount as well as various shadow prices listed above. Although this takes the evaluator much beyond the scope of his work, such estimates, acceptable to the planners of the country as well as to others concerned with the project are prerequisite to the evaluation of the project under consideration. Similarly, considerations of income distribution, regional development and employment are rarely included in actual analyses of any projects (not just non-conventional energy projects) on account of difficulties of measurement and/or problems of finding acceptable or desirable weights on these objectives. Hence, such

social considerations have to be explicitly included as an important component of the economic evaluation of non-conventional energy sources.

The economic evaluation becomes particularly complex in the case of non-conventional energy sources in developing countries because of the following reasons:

(i) In many cases, valuation of benefits and costs cannot be done at market prices since markets for major outputs and inputs may not exist. For example, in evaluating the benefits from a biogas plant, "willingness to pay" of the consumers cannot be measured since it has not been expressed in a market place. At the same time, the costs of major input such as cow dung cannot be expressed in monetary terms since cow dung is usually not bought and sold in the market. Hence, the usual methods of evaluation at market prices break down in such cases.

(ii) Not only are there no markets for major outputs and inputs, it is also difficult to estimate the value of substitutes or opportunity costs of resources used in producing inputs. In the same example of biogas plant, the benefit of biogas could be estimated indirectly in terms of the value of commodities for which biogas is used as a substitute. If biogas is used mainly for lighting, or running an engine, the benefits can be estimated in terms of the value of kerosene and diesel oil saved. However, if biogas is used for cooking and replaces fuelwood or dungcakes (not kerosene), valuation of gas becomes rather difficult since neither fuelwood nor dungcakes might have been purchased in the market. The situation becomes further complicated if one tries to estimate the cost of labor input that goes into collection of fuelwood and/or dungcakes. If these fuel sources are collected by men, women and children in their "spare" time, it would not be correct to value their time at the going market wage rate which may be relevant only for the peak agricultural season. This would require estimating the cost of using "leisure" time" for these activities and would become rather subjective. Valuation of other inputs such as land in terms of opportunity costs is equally difficult. For example, it may be very difficult to estimate the opportunity cost of land in growing sugarcane which in turn is used for producing fuel alcohol.

The opportunity cost of land would be equal to zero if it is not being currently used and does not have other potential uses. It would be equal to the value of benefits foregone, if diversion of land to sugarcane reduces agricultural output, milk output and/or draft power. Similar issues become important while evaluating the benefits and costs of fuelwood plantations, improved charcoal production or improved stoves.

(iii) It is important to realize that introduction of an energy technology will alter a multitude of resource flows on account of interdependent use patterns of different resources in the rural setup. More specifically, each technological option has different impacts on various economic groups, such as small farmers or landless laborers, and hence, such income distribution issues would have to be incorporated in the evaluation of each alternative. Besides, various groups in rural areas have differential access to and ownership of resources such as land, labor, trees, cattle and investment funds, as is also the case with political power. Since successful adoption of an energy technology depends on the access to these resources, it is important to consider these issues explicitly.[1]

In the case of non-conventional energy technologies, there are also some special types of uncertainties. In many cases the cost and performance characteristics of many of these technologies are not known to the same degree of accuracy (and confidence) as in the case of conventional technologies. The examples in this category are: gasifiers, gas engines, and Stirling engines of appropriate sizes.

Whenever costs and performance characteristics are known, as in the case of biogas plants, these may be rather site-specific and, hence, cannot be projected for other regions/conditions with the same level of confidence. This gives rise to the problem of estimating the various levels of reliability and availability of these technologies. This introduces an element of subjective judgement when these non-conventional technologies are compared with conventional technologies (such as diesel engines).

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[1]The importance of understanding these interrelations and the significance of analyzing the processes of generation and use of energy in rural areas have been discussed in Briscoe (1979), deLucia and Tabors in deLucia, Jacoby, et al., (1980) and Bhatia (1980).

These complexities and the various means of dealing with them are the principal focus of the remaining sections of this report.

Organization of the Report:

This report is divided into the following sections: Section II presents a brief review of the recent contributions to the methodology of social benefit cost analysis. In Section III a discussion of various issues connected with range of technical alternatives, techno-economic aspects of scale and reliability and measurement of efficiency is presented.

In view of the special problems and issues in economic evaluation of non-conventional energy sources as discussed earlier, major principles involved in quantification and valuation of benefits and costs have been illustrated through a set of case studies. Section IV and the Annexes present the following case studies:

(i) The focus of the first case study on social benefit cost analysis of a biogas plant is on quantification and valuation of benefits.

(ii) The second study is an economic analysis of various irrigation systems which can use alternative energy sources for pumping of water. The emphases in this case study are on defining the range of available technical alternatives, and evaluating their uncertainties via sensitivity analysis of the various parameter values.

(iii) The first Annex is a social cost benefit analysis of a community biogas plant. It focusses on quantification and valuation of benefits and should be considered with the first case study to compare the relative advantages and disadvantages of the two schemes.

(iv) The study in Annex 2 demonstrates the problems of estimating the "economic costs" or "resource costs" of generating electricity from a village-scale biogas plant. Considered are a 2 MW unit fuelwood grown under a social forestry scheme and a 20 MW unit based on fuelwood (from existing forests) and supplying electricity to a large number of village and small-town households and industries.

Finally, Section V provides an annotated bibliography on social benefit cost analysis and energy planning.

Section II

SOCIAL BENEFIT COST ANALYSIS:

This section provides an overview of social benefit cost analysis. The first part focuses upon methodology and the economic principles underlying the methodology (although it does not fully explore the various theoretical issues involved). The second part is a comparative analysis of the UNIDO and the Little-Mirrlees approaches to project evaluation. Part three is a brief literature review which provides the interested reader with a means to become aquainted with some of the more important works in the field.[1]

II.1 Social Benefit Cost Analysis: An Overview

The following is an outline of social benefit cost analysis. As outlined in the Guide to Practical Project Appraisal (1978), the UNIDO method of project appraisal can be broken down into the following five stages, each of which leads toward a measure of the social benefit of the project:

(i) Calculation of financial profitability at market prices;

(ii) Shadow pricing of input-output to obtain the net benefit at economic (efficiency) prices;

(iii) Adjustment for the project's impact on savings and investments;

(iv) Adjustment for the project's impact on income distribution; and,

(v) Adjustment for the project's production of goods whose social values are less than or greater than their economic values.

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[1] These two volumes are also reviewed as a part of the annotated bibliography. It may also be mentioned that the approach used by World Bank Studies and Squire and Van der Tak is similar to that by Little and Mirrlees.

A good technical and financial analysis of a project is required before a meaningful economic evaluation can be made. The analysis should use available market prices and/or projected market prices for valuation of the inputs and outputs. Where markets do not exist (i.e. for commodities such as cow dung or fuel wood) prices of substitute material (perhaps kerosene or charcoal softcoke) should be used. The value of direct outputs and inputs during the life of the project can then be discounted to the present by using the market discount rate. The available decision criteria of Net Present Value, Benefit Cost Ratio and Internal Rate of Return can be used to select or rank the project.

Since market prices in developing countries are "distorted" in the sense that these do not reflect the relative scarcity values of various goods and services,[1] the economic-benefit analysis requires that inputs and outputs are assigned their efficiency shadow prices. Theoretically, all shadow prices should be derived from a comprehensive mathematical model of the economy. However, in practice, simultaneous application of the following two criteria have been suggested for selective shadow pricing: (a) which resources figure most prominently in the benefits and costs of the project at market prices?, and (b) For all resources involved in the project, which market prices are farthest out of line with their respective shadow prices? The most obvious candidates for shadow pricing are (a) main outputs if these are often sold at protected or fixed prices, (b) importable materials which may be domestically

[1] In a perfect market the shadow price for any resource would be its market price. However, in the real world, because market imperfections such as tariffs, quotas, restrictions and monopolies create distortions in demand and supply, there is little chance that the market price will reflect the true economic value and cost of inputs and outputs.

produced under substantial protection or may be imported at high customs duties, (c) major non-imported material inputs which may involve significant tradable material content, and (d) unskilled labour whose market wage often exceeds its shadow wage.

Since goods which are imported or exported, at the margin, may constitute a substantial component of the project, it may become necessary to evaluate the foreign exchange impact of the project so that an adjustment can be made by an appropriate premium, assuming that foreign exchange is more valuable than indicated by the official exchange rate. This adjustment may require estimation of shadow price of foreign exchange in the present as well as over time and the foreign exchange (direct and indirect) content of inputs over time.

In order to measure the impact of a project on savings and consumption, it becomes necessary to determine the distribution of income by different income groups and use their corresponding marginal propensities to save. If the present level of savings is considered less than optimal, the planners may place a premium on the additional savings the project will induce by its impact on income distribution. This could be done by an adjustment factor which may be calculated by the planners on the basis of a subjective valuation of the difficulty the country has in raising the capital required for its investment programme. The net impact on savings and the premium on savings (or shadow price of investment) may be of vital consideration in the choice between a capital intensive and labour-intensive project or between different designs of the same project.

If it is considered that income going to some groups and some regions is more valuable than that going to others from the point of view of income distribution, it becomes necessary to use adjustment factors that reflect these differential values. This may require giving explicit weights that reflect the percentage premium (or penalty) attached by society to income flows to groups below or above some reference level of income. For example, the benefits of a project going to people with income less than $100 per month may be given a premium which would increase the net benefits of the project, thus improving its chances of selection. These distributional adjustment factors may be determined as implicit weights from the projects that have been accepted or rejected by the planners or through an elaborate formula using various values of the elasticity of marginal utility of income. However, the value placed on the income distribution objective through project selection has to be examined carefully and applied uniformly so that a better appreciation of the alternatives in terms of broader social objectives may be obtained.

Where the products of a project are valued at greater or less than their economic value, they are considered to be "merit" or "demerit" goods and can be weighted to reflect their relative social value. For example, goods such as food or energy, that meet basic needs may be adjusted upward in value. Luxury goods such as tobacco or alcohol may be adjusted downward in value. The procedure is quite similar to that of regional or income redistribution weight, in fact one often has a

choice of using merit weights or income weights to accomplish the same adjustment (and must therefore take care to avoid double-counting). Generally, merit weights have a more explicit impact and are accordingly easier to apply and interpret.

Estimation of Key National and Regional Parameters

The above discussion suggests that for a social benefit cost analysis of a non-conventional energy project, one needs the values or reasonable estimates of the following national/regional parameters: (i) Social Rate of Discount, (ii) Shadow Price of Labour, (in some cases, for different categories by season and by region), (iii) Shadow Foreign Exchange Rate, (iv) Shadow Price of Investment (Savings), (v) Income Distribution Weights (which may also take account of regional income differentials). In many cases, the estimates of these parameter values are specified by the national/regional planning agencies and the project authorities have to use these values on a uniform basis. However, in the absence of any officially specified values for the variables mentioned above, efforts may have to be made to estimate these for individual countries. The principles involved in estimation of these national/regional parameters are discussed below:[1]

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[1]It is beyond the scope of this paper to outline the methodology of estimation of these parameters for a given country. A few studies on estimation of these parameters, notably those by Mishra and Beyer (1976 Appendix III) for India, Roemer and Stern (1975) for Ghana, and World Bank (1975) for Ivory Coast, World Bank (1979) for Colombia, and FAO (1979), for Korea, have been reviewed as a part of the annotated bibliography.

(i) Social Rate of Discount: As discussed earlier, benefits and costs occur at different time periods in the life of the project. Benefits received and costs incurred in different years have different values for the society since present consumption would be preferred over future consumption. For a comparison of aggregate benefits of the project with aggregate costs it would be necessary to discount the benefits and costs of different periods to a given year, say the initial year of the project. The present value of a project's benefits and costs will depend very much on the magnitude of the social rate of discount. A higher social rate of discount will reduce the net present value of a project and a lower rate will increase it. Hence, the choice of an appropriate social rate of discount is of vital significance, especially when projects with long gestation periods are being considered.

Conceptually, the social rate of discount can be defined as the marginal rate of substitution between consumption at consecutive points of time. It reflects the weight that the society puts on future consumption vis-a-vis present consumption. The factors which are commonly accepted as determining Social Rate of Discount (SRD) are several: 1) society's present level of consumption, 2) the expected growth of consumption, 3) the expected growth of population, 4) the rate at which marginal utility of consumption diminishes, and 5) society's pure time preference. If per capita consumption is expected to grow, society will be better off in the future compared to present, and hence society will attach less value to additional consumption. The higher the rate of growth of consumption, the lower the value assigned to future consumption, as seen from today's viewpoint.

Although the rate of growth of per capita consumption is important, the society's weights on present and future consumption would crucially depend on the present level of consumption in the country. It is reasonable to assume that many developing countries with low levels of present consumption will place a high premium on present consumption vis-a-vis future consumption. To some extent, a lower level of consumption would also reflect society's impatience for current consumption, i.e., pure time preference.

If a value (or a range of values) of social rate of discounts used at the national level is not available, a range of SRD values can be estimated by using the conceptual framework outlined above. The economic parameters required for such an effort would be: 1) the projected rate of growth of per capital consumption over time, which may be explicitly given in planning documents or may be implicit in development objectives, 2) a probable value of the elasticity of marginal utility with respect to per capita consumption (i.e., the rate at which marginal social significance of extra consumption declines over time) and an idea of the pure time preference which is purely a normative judgment. For example, if estimated rate of growth of per capita consumption is taken at 3 percent and the elasticity of marginal utility with respect to consumption (e) is taken at e = 1.5, the resulting estimate of SRD would be 4.7 or 5 percent ignoring pure time preference. When pure time preference is also to be considered in the value judgment of SRD, the resulting value may range between 8 percent to 10 percent or even higher. It is expected that more than one value of social rate of discount would be used to perform sensitivity analysis in the case of a renewable energy project.

(ii) Shadow Price of Labor: A project increases employment of unskilled, semi-skilled and skilled labour during the period of construction as well as after its completion. One of the ways in which employment objectives can be incorporated in project selection is through the use of shadow wage rate (or accounting price of labour) in place of market wage rate.

It has been pointed out in project evaluation literature that one of the common forms of distrotion is in the labour markets of surplus labour economies, such that the wage rate does not equal the social opportunity cost of labour. The components traditionally identified in the social opportunity cost of labour are: (i) the output foregone elsewhere in the economy, as a result of employing labour on the project,[1] (ii) the costs of migration, training and additional consumption when a worker is moved from a rural area to the project site, (iii) the potential disutility of effort which this worker may incur by moving to a new job and new area and by increasing his level of work i.e. by reducing his leisure, and (iv) the costs in terms of increased aggregate consumption (caused by increasing employment as a result of the project) if savings (or investment) are socially more valuable than current consumption due to non-optimality of savings.[2]

[1]The opportunity cost in terms of output loss would be zero if there were 'surplus labor,' as long as the project was 'marginal.' For large withdrawals of labor, it may be positive. Existence of surplus labor and evaluation of the so-called marginal product in agriculture have been matters of intense debate. See Sen (1975) for an examination of conceptual issues involved, and a summary discussion.

[2]This is based on the assumption that savings out of wages are lower than those out of profit. For a one-sector analysis of this problem of employment-versus-savings dilemma, see Sen (1975) or Marglin (1976). The formula used by Mishra and Beyer (1976) for Shadow Wage Rate (SWR) is AWR or SWR = m + s(I-1)w where w is the market wage paid to a laborer in a new job, m is the marginal product in present

In most traditional analyses the output foregone has been identified with the marginal project of the relevant labour in its previous employment. The estimation of marginal productivity of labour is a difficult task. Traditionally it was assumed that the marginal product of the labourer withdrawn from agriculture would be zero and hence m = 0.[1] The use of agricultural wage rates as a proxy for marginal product (or opportunity cost) has been suggested as the indicator of the shadow wage rate of unskilled labour. However, the important thing to be kept in mind is that the shadow wage rate should reflect the benefit foregone elsewhere in the economy when a particular worker is employed in a project. If the worker is a migrant from a rural area, the opportunity cost of unskilled labour will range from zero in the off-season to the full market wage at harvest/planting time.[2] If most of the construction work related to the non-conventional project can be completed during the agricultural off-season, it may be correct to assume a shadow wage rate of zero for unskilled labour since the output foregone would be very low (or almost equal to zero). Thus, if a project is located in areas where there is large scale unemployment or underemployment and the project uses unskilled labour during the off-season, the shadow wage rate for this category of labour can be taken, notionally, as equal to zero. The shadow wage rates for other categories of workers and during the agricultural season would be site specific and, hence, would require use of location specific values.

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employment, s is the rate of savings from profit and I is the accounting price of investment. The costs of migration and disutility of effort are ignored on account of difficulties of measurement. See Lal (1974).

[1]The marginal product is rarely zero; rather just quite low. For an interesting discussion of the effect of marginal labour inputs in traditional agriculture, see Geertz (1963).

[2]Assuming that the market wage at harvest/planting time equals the marginal product of labor.

(iii) Shadow Foreign Exchange Rate: In most of the developing countries, foreign exchange is always a scarce resource on account of balance-of-payments problems. The usual administrative solution to the balance of payments deficits is to resort to exchange control. However, the official exchange rate under these circumstances does not represent the true value of foreign exchange earned or spent. To evaluate the real foreign exchange impact of policy options involving exports and imports, it is important to make adjustments by using a premium on foreign exchange outflow or inflow. Invariably, this premium to reflect scarcity of foreign exchange is given by using a shadow exchange rate which is higher than the official exchange rate.

If a range of estimates of shadow exchange rate for a country is not available, it may have to be calculated using one or more of the methodologies discussed in literature. Beyer (1975) has reviewed seven different methodologies employed in an attempt to derive a preliminary estimate of the shadow price of foreign exchange in India. The available methodologies include use of economy-wide programming models, determination of the equilibrium rate of exchange and estimation of effective rate of protection (ERP) and domestic resource costs (DRC) per unit of foreign exchange earned or saved. The range of values for India was from Rs. 9.8 to Rs. 12.0 per U.S. dollar compared with an official exchange rate of Rs. 7.5/$1.00. Although this range is modest, it is probably too wide to avoid the switching of project decisions for values within this range, especially projects which are mainly of import-substitution or export-promotion types.

UNIDO (1978) gives a simple formula for calculating an average shadow exchange rate based on a given year's data as follows:

$$SER = OER \left[\frac{(M + T_i) + (X + S_x)}{M + X} \right]$$

Where SER is Shadow Exchange Rate, OER is Official Exchange Rate, M = c.i.f. value of imports; X = f.o.b. value of exports; T_i = import tax revenues and S_x = export subsidies (export taxes treated as negative subsidies).

(iv) Shadow Price of Investment (Savings): In many developing countries, the present level of savings is considered less than optimal and, hence, the planners may place a premium on savings vis-a-vis consumption. The accounting price of investment (savings) is a measure of this premium, defined as the present value of additional consumption generated by a unit of investment. It reflects the social value for the resources a project draws from an alternative investment (a project cost) and for income generated by the project which is reinvested (a project benefit). If savings-investment are optimal, the market value and social value will be the same, with the accounting price of investment equal to 1.0. The divergence between the opportunity cost of capital and the social rate of discount is an indicator of the divergence between the market and social value of investment. Under simplifying assumptions, the shadow price of investment is given by the ratio of opportunity cost of capital (r) and the social rate of discount (i). Thus, if opportunity cost (or marginal productivity) of capital is taken as 15 percent and social rate of

discount is taken as 10 percent, the shadow price of investment, I, is equal to $\frac{0.15}{0.10} = 1.5$. A more realistic formula which incorporates reinvestment or share of saving from incremental income can be given as:

$$I = \frac{(1-\alpha)\ r}{i-\alpha r}$$

Where I is shadow price of investment, i is the social rate of discount, r is the opportunity cost of capital and α is the rate of reinvestment. If the rate of reinvestment, which corresponds to the marginal savings rate for the economy as a whole, is taken as 0.2, r - 0.15, and i - 0.1, the shadow price of investment would be I = 1.7. It should be emphasized that if opportunity cost of capital is higher than social rate of discount and the latter is used for discounting benefits and costs, it would be necessary to adjust both project costs and benefits by using shadow price of investment.

However, some practical difficulties in the use of shadow price of investment are encountered. Although it is easier to revalue (upwards) the capital costs of the project by using the shadow price of investment, it is difficult to estimate that proportion of the income stream generated by the project which is reinvested and should be revalued by the accounting price of investment (the additional value constituting an additional benefit of the project). Estimation of reinvestment benefit requires the knowledge (or estimation) of how a project's benefits will be distributed among various groups and institutions and what their respective rates of saving and investment are expected to be.

In view of these difficulties, shadow price of investment has not been used in many studies[1] which have used the UNIDO or analagous approaches. Instead, a sensitivity analysis of the project to higher values of social rate of discount (up to the level of opportunity cost of capital) have been presented. This is considered as a method of incorporating shadow price of investment in practice although this may lead to some theoretical complications.

(v) Income Distribution Weights: Since income from a project may pass on to groups or regions representing different social priorities, the value of the income to some groups should be weighed differently than the value of the same income to other groups. For example, where income to a poor group has more social value than income to a wealthy group, the income to the poor group should be adjusted upward. Upon adjusting the incomes properly, the net benefits can again be tabulated, this time with appropriate regard to income redistribution objectives.

The prescribed methods for identifying the appropriate weights are to: 1) accept an upper level policy decision, 2) observe and quantify the policy preferences implicit in past projects. Where only two groups are involved it is possible to infer relative weights (or switching values) by examining which projects were accepted and which were rejected and by assuming some consistent decision rules. With multiple groups, it is more appropriate to select a numeraire (commonly, a group or region which is neither taxed nor subsidized) against which all

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[1] See, for example, Mishra and Beyer (1976) and Sinha and Bhatia (1976).

other groups are to be compared. The other groups can then be considered in terms of the elasticity of the marginal utility of income or "the percentage by which the social value placed on additional income falls within a 1 percent rise in income."[1] A more detailed description of these methods is presented in UNIDO (1978).

Development of income or regional distribution weights can be a major undertaking, too costly or time consuming to be considered for the purposes of evaluating a single project. In such a case, and where relevant weights are not readily available, rough estimates may suffice. Generally, a premium of 10 percent to 20 percent on the benefits to poor household and backward regions is appropriate.

Since shadow wage rate for unskilled labor may have already been used, it may not be necessary to put explicit weights on employment created by the project. Likewise, the preference for the use of indigenous resources vis-a-vis importable (or exportable) resources would be reflected through shadow exchange rate, and an explicit premium on the use of local resources and the security and certainty of supplies may be incorporated in the analysis at another stage.

Decision Criteria[1]

Although several decision criteria are available for project choice and ranking, the following three are most commonly used in social

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[1]UNIDO (1978), page 70.

[2]The discussion in this section depends mainly on a similar discussion by Mishra and Beyer (1976, p. 32-35). For a more detailed discussion of decision criteria, see Eckstein (1958) and Dasgupta and Pearce (1972).

benefit cost analyses. These are (i) Net Present Value (NPV) or Net Present Worth (NPW), (ii) Benefit Cost Ratio or B/C ratio, and (iii) Internal Rate of Return (IRR).

(i) The Net Present Value Criterion: It may be useful to summarize the procedure for finding the net present value or the net contribution of a project. The net present value criterion simply states that any project is economically viable if:

$$PV\ (B) > PV\ (C)$$

or

$$NPV\ (B) > 0,$$

that is, the project's present value of benefits (PV (B)) is greater than its present value of costs (PV (C)), or the net present value of benefits is positive. The net present value of benefits is the difference between the present value of benefits and the present value of costs. The PV (B) and PV (C) here stand for the sum of discounted series of project benefits and costs, the respective formulae for which can be written as follows:

$$PV(B) = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t}$$

and

$$PV(C) = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t},$$

where T is the project life measured in number of years from the date of first investment; B_t and C_t stand for benefits and costs in the t-th year of the project life, and r is the social rate of discount.

The net present value criterion states that the flow of social benefits and costs over the life time of the project should all be discounted to the present at the social rate of discount and the project should be accepted/rejected according to whether its NPV is positive or negative.

However, the NPV criterion gives us an absolute measure of the economic profitability of the project. So long as our attention is confined to a single project, or two or more projects whose costs are the same, this criterion is adequate. Where there are more than one project with different costs, this absolute measure of worthiness fails to produce a correct choice. In the following table, the relevant information is given for two hypothetical projects A and B. On the basis of present value criterion, both projects are worthy of selection. If, however, one is asked to choose between A and B, the choice will be B, which offers a larger net present value of benefits as seen from Column 4. But it is clear from Column 3 that the cost of project B is double the cost of A, while it offers only 10 units more of net benefits than A. Hence the choice B is misleading.[1]

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[1] It may be mentioned that some authors have used "marginal" concept in project selection. For example, see R.J. deLucia and H.D. Jacoby, "Sector-wide Analyses and Investment Program Design," Chapter 10 in deLucia, Jacoby, et al. (1980).

Present Values of Hypothetical Projects

(1)	(2)	(3)	(4)	(5)
Project	PV(B)	PV(C)	Nrv(B)	PB(B)/PV(C)
A	150	100	50	1.5
B	260	200	60	1.3

(ii) Benefit Cost Ratio: Thus, in the case of more than one project (not mutually exclusive) which have different costs, a relative measure of worthiness of projects becomes necessary. The ratio of PV (B) to PV (C), in short, the benefit-cost ratio, provides such a measure. Here it may be necessary to mention that in the presence of constraints on the resources available on investment, C will include only capital costs of the project and benefits (in the numerator will be defined net of annual operating costs). The B/C ratio criterion states: (1) in case of a single project choose the project if its B/C ratio is greater than one, and (2) in case of many projects, rank the projects in descending order of their B/C ratios and choose that number of projects at which the given investment fund is just exhausted. On the basis of this criterion, we can see project A and not B will be

chosen because its B/C ratio (refer to Column 5 of the table) is higher than that of B. There are numerous difficulties with this rule. One fundamental point is that no rule should be sensitive to the classification of a project effect as a cost rather than a benefit, and vice versa. Thus, all costs can be treated as negative benefits and all benefits as negative costs. For the NPV rule it should be obvious that the outcome will be the same however the division is made. But the benefit cost ratio rule will be affected by this division since it will affect the magnitudes which are entered as denominator and as numerator. Thus, if a project has (discounted) benefits of 10, 20 and 30 units, and costs of 10 and 20, the benefit-cost ratio is 2.0. But if the cost of 10 is treated as negative benefits, the ratio becomes 50/20 = 2.5. On the other hand, benefits minus costs (i.e. NPV) remains the same, at 30 units, regardless of the transfer.

Apart from being sensitive to the classification of costs and benefits, the ratio rule is incorrect when applied to mutually exclusive context. Thus, a project costing 100 units, with discounted benefits of 130, has a NPV of 30. This is to be preferred to a project costing 40 with benefits of 60, a NPV of 20. But in ratio terms, B is preferred since B has a ratio of 1.5 compared to A which is 1.8.

(iii) <u>The Internal Rate of Return Criterion</u>: One shortcoming of the net present value and the B/C ratio criteria is that they depend upon an externally given social rate of discount. With the difficulties in finding an appropriate social rate of discount, the internal rate of return criterion has an advantage in that it does not depend, at least

in the initial stages, upon an externally given social rate of discount. The internal rate of return is that rate of discount at which the net present value of benefits of a project becomes equal to zero. Thus if r* is a rate of discount at which

$$NPV\ (B) = 0,$$

then r* is said to be the internal rate of return. More explicitly, the formula for the internal rate of return can be written as follows:

$$NPV(B) = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r^*)^t} = 0,$$

where r* is the internal rate of return.

The internal rate of return is determined through a trial and error procedure. Given the time stream of benefits and costs, the project evaluator arbitrarily chooses a value for r*, discounts the two streams, sums them up respectively and finds the difference between the two sums. If the difference is positive, i.e., the net present value of benefits is positive, he raises the value of r* and repeats the process until the net present value has approached zero. This discount rate r* at which NPV is zero is the IRR. The internal rate of return thus calculated does not on its own provide a decision rule for choosing a project. It requires a standard for comparison -- a predetermined social rate of discount, or a private rate of return which approximates the social rate, or a rate of interest at which the social investment fund is available. If $\bar{r}$ is such a rate of interest, then the decision rule for project choice is formulated as follows:

(i) For a single project, choose the project if

$$r^* \geq \bar{r}.$$

(ii) With many projects, rank the projects in a descending order of values of r^* and choose that set of projects from the top for which $r^* \geq \bar{r}$ until the given investment fund is exhausted.

It is necessary to note that while r^* can be calculated purely from the project data, for the project choice rule, it still requires an externally determined parameter like $\bar{r}$. As with the NPV rule, it remains essential to choose some acceptable discount rate.

The internal rate of return approach suffers from a number of limitations. In the first place, it may not exist, or if it does, it may be non-unique. Only if the net flow of benefits changes sign no more than once is the internal rate of return unique. It is tedious to calculate without the help of the project. It says nothing about the aims of the project; one may prefer a bigger project with greater absolute net benefits to a smaller one with a higher internal rate of return, but lower absolute net benefits. In comparing two mutually exclusive projects, it cannot be applied without further adjustment. On the other hand, it has some advantages also; for example, it appears to be more easily acceptable to administrators.

Thus, it would seem that in the case of an accept/reject case of a single project NPV or IRR may be used. In the case of mutually exclusive projects (e.g., two different ways of achieving the same objective), NPV may be used as the decision criterion. However, in the

case of rationing a given investment fund, B/C ratios of projects may be used for ranking projects. It is useful to calculate all three -- NPV, B/C ratio and IRR -- since each one can provide some useful information for a particular purpose.

II.2. UNIDO and Little-Mirrless Approaches to Project Evaluation: A Comparative Analysis[1]

Although details of the two approaches can be found in the literature cited earlier, it may be useful to summarize their salient features before a comparison is attempted. The UNIDO method[2] discusses various objectives of national planning and suggests that all items involved in a project should be valued in terms of present aggregate consumption. Since valuation of goods and services in terms of market prices is considered inadequate in reflecting societal benefits and costs, these goods and services are valued in terms of "shadow prices" which in fact reflect societal benefits and costs. If the goods and services produced by the project add to the supply of these goods and services available in the economy then they may be regarded as being the net output of the project. However, if these goods and services merely substitute for an alternative source of supply, leaving the total supply constant, then the net output of the project is really reflected by the resources released from the alternative source of supply. In each case the value of benefits is measured by the "willingness to pay" of the purchaser. If the output substitutes for imports or adds to exports, the procedure is to estimate the impact of foreign exchange availability by making explicit assumptions about foreign markets and also about policies of the government. The shadow price of foreign exchange is used to convert the foreign exchange benefits (and costs) into units of aggregate consumption in domestic currency. Costs are equivalent to maximum benefits

[1] Most of the discussion in this section is based on Dasgupta (1977), Sen (1972) and Lal (1974).

[2] Although this method has been discussed in detail in the earlier section, a few concepts are repeated to provide a basis for comparison.

foregone. If the use of input in a project causes a decline in the amount of that input available to the economy by an equal amount, then the value of the input should be measured in terms of benefits foregone in the alternative use(s). If the availability of this input to the rest of the economy does not decline by its use in the project because, say, domestic production of this good increases, then the cost of input is to be measured by the resource cost of the increased production. If an input is imported or is a potential export then cost is measured by the sacrifice in foreign exchange involved converted by shadow price of foreign exchange. The benefits and costs of a project are estimated for the future years and are discounted to the present by using a social rate of discount. Various decision criteria for project selection and ranking are used as discussed in the earlier section.

In the Little-Mirrlees or OECD approach, the components of a project are divided into three broad categories:

1) Traded goods and services, i.e., goods and services which are actually exported or imported and goods that would be exported or imported had the country followed policies that would have resulted in optimum industrial development;

2) Non-traded goods and services; and

3) Unskilled labour.

In the case of traded goods and services, as defined above, the shadow prices are easy to calculate: for an imported product it is its marginal import cost while for an exported good it is its marginal export revenue. Use of world prices in the evaluation of commodities (traded) is a distinguishing feature of this method. In the case of

non-traded goods, the marginal social cost of providing a little more of this good is considered as the shadow price of the commodity. The accounting price of unskilled labour or shadow wage rate depends on (i) labour's opportunity cost, (ii) the industrial wage rate, and (iii) shadow price of investment, a national parameter. In a given year in the life of the project, the algebraic sum of the social value of inputs and outputs in the year yields the social profit (in terms of investment) for that year. The social profit of each year is discounted to the present by using an accounting rate of interest and this sum yields the social value of the project, which is the index by which to judge its profitability.

One common feature of the UNIDO and Little-Mirrlees approaches is that both deal with evaluation of industrial projects. Although the two approaches pursue somewhat different sets of exercises for the evaluation of these projects, they are basically similar.[1] First, both approaches recognize the distortions in market prices and recommend the use of appropriate shadow prices to measure the social value of benefits and costs. Secondly, both recommend the use of present value as the correct criterion in judging industrial projects. Thirdly, it has been shown that the choice of numeraire in the two cases makes no difference to project evaluation. The UNIDO approach recommends measuring benefits and costs in terms of aggregate consumption while the Little-Mirrlees

[1]It has been pointed out in the UNIDO Guide to Practical Project Appraisal (1978), "with the changes in the Little-Mirrlees method embodied in the revised (1974) edition and with the changes in the UNIDO method embodied in this Guide, there is really very little difference between the methods in terms of their fundamental perspectives on economic project evaluation," pp. 3.

approach uses investment (expressed in free foreign exchange) as the unit of measurement. Thus, in the UNIDO approach one revalues investment in terms of consumption using the shadow price of investment. In the OECD approach consumption is revalued in terms of investment using the shadow price of consumption in terms of investment. Fourthly, in both approaches traded goods play an important role in determining the evaluation of the project. In the case of the UNIDO approach, it is considered important to estimate the direct and indirect foreign exchange inflows and outflows as a result of the project and the same are valued using border prices, along with shadow price of foreign exchange. In the OECD case, the shadow prices for traded goods are equated to marginal import cost of an imported good and to marginal export revenue for an exported good.

However, there are some differences in the two approaches and it may be useful to point these out. The differences in the two approaches can be explained in terms of the differences in judgment about the kinds of constraints that are important in the economies and the role that planning organizations can play in influencing economic policies, especially trade and tariff policies in the developing countries. The UNIDO method is more realistic in assuming that in many developing countries there are many restrictions on economic activities and prices reflected as quotas, tariffs, subsidies and administered prices of capital, labour, foreign exchange and many scarce commodities. It further recognizes that the project evaluator may not be in a position to get these restrictions removed or changed and, hence, the control areas of the project evaluator may be rather limited. On the other

hand, the Little-Mirrlees approach assumes that the project evaluator is in a position not merely to suggest changes in trade, tariff and tax policies but also to ensure that these policies are in fact chosen. This would suggest that the agency involved in project evaluation in the country is powerful enough to ensure modifications in various policies of other ministries/departments of the government concerned. The correct assumption may vary from country to country and from case to case and may also alter over time, since the projects sometimes have a long life and political and social influences on tax and trade policies may change during the lifetime of a project.

Thus, the particular method to be used would depend crucially on the nature of the restrictions in the economy in question and the ability of the planner to get these policies adjusted. Since most of the developing countries have imposed price/quantity restrictions, especially in foreign exchange markets, it would be useful to recognize these restrictions as such. The UNIDO method would have a more realistic approach to project evaluation under these circumstances.

II. 3. The Limits to Project Level Analysis -- Linkage to Subsector (Industry) and Sector and Intersectoral Level Analysis

Analysis of the attractiveness of renewable energy alternatives sometimes requires more than project level analysis. This can stem from a variety of factors, most important of which are the scale of the alternative relative to the size of the market, critical interdependencies often associated with the substitutability of fuels or energy sources, other interrelations based on use of limited resources (such as agricultural land) and whether or not the project is an isolated project or conceived as part of a larger program.[1] In these cases the project level analysis should be immersed in broader subsector (industry) or sector level analysis and perhaps even close examination of intersectoral issues.

It is beyond the scope of this document to discuss in detail overall energy sector planning and the role of project analysis in such efforts.[2] However, some discussion of these issues is warranted. The problems associated with the appropriate selection of projects and programs for the energy sector in many developing countries are frequently similar. Many developing countries are in transition from the use of traditional energy (vegetable waste, cattle dung, firewood, etc.)

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[1]While a single small dentro-thermal plant for a particular town may not require broad analysis, a program conceived as a repeat of this model for tens or hundreds of towns should.

[2] For an extensive discussion see R. deLucia and H. Jacoby, "Energy Planning in Bangladesh" Chapter 1 in deLucia, Jacoby, et al., (1980); this section draws on that chapter.

to commercial energy. Rising demand for commercial energy results from increasing energy-intensive production and the substitution of commercial for traditional fuels. The latter substitute is sometimes the result of decreasing (absolute or per capita) traditional fuel (particularly firewood), availability, or income and price effects.

There are numerous choices involved in sectoral investment planning: production versus importation, choice of production process, selection of size (scale), timing and location of investments, and the role of traditional energy sources. The appropriate choices regarding energy supply facilities in developing countries are often dependent on analyzing a number of interdependencies within the energy sector as well as interdenpendencies with other sectors. The interdependencies are relatively more important in developing countries in which both the regional and total energy markets are less developed. In such markets single facilities constructed large enough to capture the economies of scale may not be justified by the existing or projected growth in energy demand. In cases in which the existing or projected market size is limited, although the market size may justify the use of a large facility on a cost basis, the large facility may be too large when technical balance criteria are considered. Given the strong substitutability of alternative fuels, especially when the energy markets (and hence the different mix of energy-consuming technology) are still in flux, potential major supply facilities for one fuel must be analyzed with other fuel supply facilities.

Examples of such important interrelationships will frequently exist when there is an existing refinery system with limited flexibility in the mix of products[1] and a biomass-based program (e.g. ethanol, or charcoal) is aimed at suitability for some but not all products. Partial or full substitution for only some products such as charcoal for fuel oil, may result in significant influence in the system -- perhaps surplus of new oil. If the refining system is not capable of processing the new surplus into other products the options may be unattractive -- selling the surplus at discount in the international market, cutting back overall refining production until it is more in line with demand for heavy products, and importing light products, etc. Major renewable energy programs require more than project level analsis; and there are other strong arguments for sector level analysis.

A sector study analysis should lead to a sector investment plan and to the determination of operational procedures and pricing policies. This is in contrast to a more limited type of effort -- which may be referred to as an "assessment" -- that surveys supplies and demands and identifies investment options but lacks sufficient analysis to support decisions by officials and international lending authorities about specific investments. A sectoral plan requires enough project and sub-sector detail to allow for recommendations regarding timing, size, and location of facilities. Some of the necessary project-level work may have been done separately from the sector exercise and can be integrated

[1] In many developing countries refineries are smaller and do not have catalytic cracking and other high cost processing that allow extensive flexibility in the production of alternative products.

into a plan. If the project level detail is not available from earlier efforts, it must be part of the exercise.[1]

Project- and subsector-level detail is a key aspect of investment analysis. A good sector analysis will integrate alternatives that are based on project-level information, and examine interrelationships among the size, location, and timing of alternatives, and combine the best elements into an overall investment plan. The process includes the consideration of combinations of projects in a subsector of industry (i.e., all the alternatives for the electricity subsector) as well as the integration of oil, gas, electricity, traditional fuels, etc., into an analysis which considers trade-offs between subsectors. As the example above suggests, given the strong substitutability of alternative fuels or energy types, especially when the energy markets are still in flux, potential supply facilities for one fuel or energy type must be analyzed jointly with other fuel systems. (Another example is a new railway system where decisions regarding electrification or diesel clearly require joint consideration of different energy subsectors.)

Often a sector planning exercise builds a catalog of projects that characterize scale and process alternatives, and integrates them into consistent sectoral schemes that reflect a number of different project and energy source mixes, sizes, and locations. Thus there is critical information flow between project-subsector analysis and sector-level

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[1]On the other hand, in an assessment that does not include an investment plan, representative costs and technical descriptions can be used to identify which options warrant further investigation.

planning. Sometimes there will be much to build on -- many of the alternatives will have had prior technical and economic analysis at the project level; others will have had none.

The process of integrating alternatives to the subsector and sectoral level can help prevent undue focus on investments that may seem attractive at a project level but are less so in a broader context. The procedure usually starts by integrating existing information (costs, performance, characteristics, etc.) regarding some alternatives, and making preliminary estimates where this information is not available. The initial integrated analysis indicates which alternatives appear more attractive. If they have not had detailed prior study, additional technical and cost analysis can proceed, but only after this sector-level evaluation has been undertaken.

There are also important linkages to regional planning activities. Here the critical issues are location and scale. Choices among energy supply facilities often involve economies of scale, or indivisibilities of technological alternatives.[1] Moreover, these issues are relatively important in developing countries where regional and total energy demands and markets may not be large. Single facilities large enough to capture economies of scale. However, in such cases it is necessary to analyze transport and production costs simultaneously.

The issue of market-versus-societal demands and the location of both supply and transport facilities touches on one relationship between

[1] These issues are more pertinent to conventional than to renewable resource based technologies.

sectoral and regional planning activities. Another important linkage relates to decisions regarding the location of major energy supply and transportation facilities, which may predetermine regional development possibilities. In many developing countries the composition of existing demand reflects the urban-rural split.

Decisions regarding project and sectoral supply investment alternatives influence future intra-urban and urban-rural divisions of development. The process of energy sector planning must include some concern with regional issues because the location of many energy facilities is going to predetermine development patterns in many sectors, particularly manufacturing.

There also may be important inter-sectoral issues. In many biomass based alternatives the interaction with agricultural and/or forestry sectors is significant. Major programs utilizing significant agricultural and/or forestry land must be evaluated with measures of the real opportunity costs of the resources. This will require analysis of agricultural or forestry-related activities which utilize the resource if such studies have not already been undertaken.

One last linkage between different planning activities is worth mentioning -- that relating to information from operational planning. Operational planning encompasses the analysis of such elements as the operation of refineries and system dispatch for electric power systems. Sectoral investment planning should integrate some characterization of how the system is <u>actually</u> operated and of the possible rate of operating

improvement. Too often studies are based on manufacturers' literature or experience elsewhere. Careful consideration of this issue can help prevent misallocation of capital through decisions that do not reflect the real operating conditions and constraints on the rate at which problems can be overcome.

II.4 A Brief Review of Recent Contributions

In the recent past, there has appeared a considerable volume of literature on social benefit cost analysis as the analytical methodology for project evaluation. There are basic texts which present complete systems of project evaluation, such as the UNIDO Guidelines for Project Evaluation (1972) and Guide to Practical Project Appraisal (1978) and the two volumes by Professors Little and Mirrlees (1968, 1974). Theoretical discussions relating to cost-benefit analysis as well as case studies are available[1] in Roemer and Stern (1975), Dasgupta and Pearce (1972), Marglin (1967), Mishan (1976), Lal (1974) and Harberger (1971). Manuals and guidelines for project appraisal have been issued by the World Bank (L. Squire and H.G. Van der Tak, 1975), Overseas Development Administration, London (1972) and the U.S. Agency for International Development (1974). There have been a number of contributions on various topics by Sen (1968, 1972), Bruno (1972), Lal (1972, 1973), Balassa (1976), Harberger (1968), Bacha and Taylor (1971), Beyer (1975), and World Bank (1977, 1979). Several sectoral case studies are now available, the principal among them being those by Adler (1971), Gittinger (1972), Dattachaudhuri and Sen (1970), Mishra and Beyer (1976), Eckstein (1958), and Lal (1972). However, there are only a few case studies in the field of renewable energy technologies e.g., Bhatia (1977), deLucia and Lesser (1980), French (1979), and Barnett et al. (1978).

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[1]The more important of these contributions are reviewed as a part of the annotated bibliography.

Section III

TECHNOLOGICAL ALTERNATIVES AND EFFICIENCY IN ENERGY USE

It should be clear from the discussion in sections I and II that social cost-benefit analysis is an appropriate means of comparing different energy-related technology alternatives. Economics of scale can be reflected in the capital cost and in the operating and maintenance costs. Uncertain fuel prices can be considered through sensitivity analysis of the operating costs. Equipment reliability can be shown in the maintenance costs and perhaps in the need for additional capacity or back-up systems. Shadow pricing, social discount rates and appropriate decision criteria could be employed as discussed in these earlier sections. The first part of this section is a discussion of the dynamics of this type of technological choice.

The second part of this section deals with mechanical efficiency, a concept which is particularly relevant to selection of the range technology alternatives which are to be compared. Consider, for example, the option of using electrical resistance as a mode of space heating.* The first law efficiency (i.e., the amount of energy delivered divided by the amount of energy supplied) is probably on the order of 90 percent. However the second law efficiency (i.e., the minimum amount of energy needed to perform a function divided by the actual amount of energy used to perform a function) is probably about 5 percent. By definition, the same job could be accomplished with less energy consumed. This argues for consideration of more efficient options.

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*This space heating alternative is used widely in the U.S. due to the extremely low cost of petroleum and other fossil fuels. When one deals with more "realistic" shadow prices, though, this mismatch between energy use and end-use becomes less attractive.

III.1. Choice of Technology

In the August 1902 issue of Country Life In America there were on one page three advertisements for automobiles. The top picture showed an electric automobile, the second picture was for a steam automobile, and the third was for a gasoline engine automobile.

Eighty years later the range of technical choices for automobiles is much more severely constrained then it was in 1902. Why is this? Incidentally, the same issue of Country Life In America also carried advertisements for hydraulic rams and also for Stirling engines, both for use in pumping water at remote locations. It is not possible today to buy these technologies off the shelf for water pumping.

The choice as to which technology to use for which particular end-use activity depends upon the relative prices and availability of fuels and other inputs. In periods of relative stabilisty of prices, a well-working market tends to eliminate the technologies with higher costs and favors those with the lower costs. For example, over the main bulk of this century the ready availability of petroleum fuels at low costs predicated a particular set of technologies relying heavily upon the internal combustion engine as the prime mover. Since 1973, however, the prices of petroleum-based fuels have been rising rapidly relative to other fuels. This implies that some other types of motive power may be more appropriate for use with many engine devices under the current situation.

What then are the things which have a major impact on the choice of technology? It seems that the major parameter is the availability of the energy sources. It does not help, as in many countries, to say that diesel fuel is available at a government-controlled price, when it is only available intermittently at those prices. Hence the persons making a choice of technology cannot have confidence that the fuels will be available when required. The second aspect is the availability of the technology itself. The literature is full of the availability of the technology itself. The literature is full of discussions of a tremendously wide variety of energy-using technologies. But what we find quite often is that these technologies are available only as prototypes or as bench-testing devices and have never been available on any broad scale. It is not possible to pick up a telephone and order many of these devices even in small numbers. Hence the technology that one is choosing must also be available at some reasonable cost and on some reasonable delivery schedule.

One of the most important aspects of technology choices deals with the matching up of the quality of the energy needed at the end-use and the quality and type of energy used by the technologies. It is important to achieve as close as possible thermodynamic matching of the quality of the energy use. For example, it makes little sense to use electricity or petroleum-based fuels directly for process heat in industry, unless that process heat is required at extremely high temperatures. For most process heating and space heating requirements, lower thermodynamic quality energy sources can be used. What this means is that energy is not merely BTU's but BTU's at some particular temperature level. Low cost of high quality petroleum based fuels in the recent past has led in many cases to a severe mismatch between the energy used and the end-use.

Unfortunately there are no easy rules that enable the engineer or economist assessing technology choice under the current conditions that would enable him to move quickly to the match of energy qualities. In order to do this they will have to rely on the scientific assessment of each individual situation.

From the point of view of economic evaluation of technology choice there are a series of parameters which are more directly approached.

1. Initial Costs. The capital cost of the technology is obviously a very important determinant of the technical choice. However, one must remember that the initial cost in many cases is achieved by trading off a variety of other parameters, such as reliability, fuel use, and size. Moreover, in dealing with the initial cost, the capital cost of a particular technology, the economist will also need to assess a breakdown of these initial costs into those dealing with foreign exchange and those with local exchange. The economist also will need to assess whether all of the aspects of this particular technology are required for the end-use. For example, is the pumphouse a necessary component for use in a particular situation?; is the truck chassis an integral part of the required technology for that particular transportation system?; and so on.

2. Life-Cycle Costs. The life cycle costs deal with the costs of fuel and maintenance of the technology over its working life. Obviously, these costs are directly related to some of the components of the initial cost or the captial cost. One can put more materials into a machine and

reduce the amount of maintenance necessary to keep the machine in operation or one can develop a high-technology machine that will require less energy than a less highly developed machine but has a significantly higher initial cost. (The mechanical efficiency aspect of this tradeoff is discussed in some detail in the second part of this section). As with the initial cost, the economist must assess the breakdown of the life-cycle costs into local and foreign costs. The life-cycle costs are quite difficult to estimate with any degree of certainty. Maintenance costs are usually not well documented and even if they were, it is often quite difficult to transfer those into developing country contexts where the availability of skilled mechanics, etc. is unknown. A more difficult problem with the life cycle costs is to make reasonable estimates of the energy input costs over the life of the device. One only has to look at the recent history of petroleum prices to observe that it is a thoroughly hazardous task to estimate future prices for petroleum products.

3. Reliability. The reliability of a technology is a very important parameter from the point of view of the user and is unfortunately quite difficult to assess. Are diesel engines reliable? The answer to that question would be to take a look at the widespread use of diesel engines throughout the developing world; even though diesel engines do require heavy maintenance and a substantial cost in keeping them going, they probably are a thoroughly reliable technology. From the user's point of view, however, reliability is the one parameter which utlimately clinches the decision to choose or not choose a particular technology. It is interesting to note, however, that the concept of reliability is not just based

upon the technology itself but upon the context in which it is being used. For example, in parts of northern India, many farmers consider eletric pumpsets as being very unreliable. The unreliability of the pumpsets in this particular case stems from the unreliability of the electricity supply and from any technical defects in the pumpsets themselves. Electric pumpsets in other contexts would be considered very reliable. Should one accept a lower level of reliability for devices that have either lower first costs or lower first life cycle costs? This type of question needs to be addressed in any assessment of the choice of technology.

4. Scale. This is possibly the most important parameter in the choice of technology. Unfortunately this is one parameter which is in many cases quite difficult to define, particularly at the ends of the scale. For example, many large heat engine systems are available over a wide range of prices starting from 50 kilowatts up to 60,000 kilowatts. These can often be ordered directly from catalogs in that range of sizes. As one might expect, there are economies of scale associated with these types of devices and that, over the typical ranges available, the larger tend to be the more fuel-efficient than the smaller. However, when one gets down to the lower end of the scale, one finds the tremendous shortage of information about the size and performance of different heat engines. The effects of scale also have important economic and social consequences. Not only do larger devices cost more in terms of initial costs they also typically require much larger tasks to be performed. If there is a mismatch betwen the scale of the device and the end-use, then the devices typically run at much lower efficiencies and hence their life-cycle

costs increase rapidly. Hence there is little sense in using a 15 HP motor for a job that requires only 3 HP. Moreover, a small user may not be able to meet the initial costs for such large technology. Therefore, the choice of a larger technology than is absolutely needed implies a need for some form of social organization to take advantage of the excess capacity. In many countries this has been the rationale for the formation of pump groups and tubewell cooperatives. However, the analyst must be aware of the social problems in making such organizations work effectively. The costs in such cases for the actual usage of the technology may be considerably lower than if the technology were commanded by a single individual who needed it at that scale. Other questions arise as to where the economies of scale decline to insignificance. Is there some level of device where the transportation costs balance out the advantages of increasing size? For example, one might expect that with biomass-fueled electric generators, there is some upper limit on the size of the generating plant beyond which the transportation of the biomass to the plant will predominate over the scale efficiencies of a larger plant. Indeed this tradeoff between transportation and increased scale is an important feature of many types of purchasing and manufacturing technology.

III.2. Efficiency

In considering the economic attractiveness of renewable energy alternatives, the ultimate criteron should be one of economic efficiency as incorporated in a measure such as the benefit cost ratio discussed earlier in this report. When appropriately calculated, this measure includes appropriate weighting of both costs and benefits that have different impacts or importance. But considering the attractiveness of

energy alternatives there is also a role for incorporating into the analysis efficiency concepts based on a technical focus. The importance of including such considerations is an integral part of the choice of technologies. Consideration of technical energy efficiency concepts aids both in the selection between alternatives and in determining whether one is considering an appropriate and/or wide enough set of alternatives.

There are two energy efficiency concepts that should be considered. These are frequently referred to as the first and second law (of thermodynamics) efficiencies.[1]

The first law efficiency is defined as follows:

$$\eta = \text{efficiency} = \frac{\text{amount of energy delivered in form required (output)}}{\text{amount of energy that must be supplied to achieve the desired effect (input)}}$$

This concept can incorporate energy in all forms (heat, work, fuel, potential or kinetic energy, etc.). It does not explicitly account for the thermodynamic quality or special characteristics of the energy being utilized. The first law is only concerned with the quantity of energy being used.

But the quality of energy is very important. Some tasks such as those requiring very high temperatures, can only be done by certain energy types. While task requirements that require lower quality energy (such as low

1. A thorough discussion of these concepts is presented in American Physical Society (1975).

temperature task, e.g. cooking) can be met with high quality sources (e.g. liquid fuels), tasks requiring higher quality (e.g. high temperature) often cannot be met with lower quality sources (e.g., wood) except without some conversion, as the conversion usually entails considerable losses quantities of energy. In selecting the energy alternatives it is useful to include alternatives which match (in quality) the task needs. While these alternatives may not in the end be selected due to other economic (used in the broad sense) factors they hould be considered.

The second law efficiency is a useful concept in examining the degree to which the alternatives match the requirements of the task. It is defined as follows:

$$\varepsilon = \frac{\text{minimum amount of energy (work) required to perform the desired function}}{\text{actual amount of energy (available work) used to perform the function}}$$

But the concept of the second law is applicable to an examination of the preference of any device, process or system and the degree to which these attain that which is theoretically achievable. This requires not just the measurement of the energy per se but the availability of the energy type to do work (and the measurement of the exhaustion of this availability in the course of performing the function. The term "available work" used in the second law definitions above represents the availability of an energy type to do useful work.[1]

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1. The concept of available work is discussed in detail in APS, ibid. For fuels this is approximately equal to the fuel's heat of combustion.

The measure of efficiency is very much dependent on the boundaries of the system being analyzed. First and second law efficiencies are calculated either for devices or systems with prescribed boundaries but in actual operation devices are usually components in a larger system. The house furnace example often used to demonstrate marked differences between first and second law efficiencies (see below) is only one part of an entire heating system which in turn is part of a house.

The difference between the first and second law efficiencies can be demonstrated by example. Consider the ordinary house furnace operating under non-extreme conditions (desired indoor temperature the "new standard" 68°F., outdoor temperature just at freezing, 0°C., 32°F.). An ordinary furnace could deliver to the rooms about one unit of energy for every 1.25 - 1.5 units of energy used. Thus the first law efficiency is:

$$\eta = \frac{1}{1.25 \text{ to } 1.50} = 67 \text{ to } 80\%$$

Consider the second law efficiency. To do this we must first calculate the mean theoretical work energy needed. The minimum amount of energy/work to determine a unit of heat to the room can be calculated from extending Carnot's theory of heat engines considering the house as one resevoir and the outside air the other. The minimum work to deliver q units of heat from 0°C. (273°K.) to 20°C. (293°K.) is 0.07 q.*

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* Using Carnot's Law $w = q_2 \frac{293° - 273°}{293°} = 0.07\ q_2$

This is the amount of work that an "ideal" heat pump would require. The furnace therefore has the following second law efficiency:

$$\varepsilon = \frac{\text{minimum energy}}{\text{actual energy}} = \frac{.01 \times 1}{1.25 \text{ to } 1.5} = 4.7 \text{ to } 5.6\% \text{ efficiency}$$

While the ideal heat pump would have a first law efficiency of 1400%,[1] actual heat pumps have first law efficiencies of 100 to 300% depending on various factors.[2] Heat pumps work best when the temperature difference is small. Assume for the above condition that the heat pump has a first law efficiency of 225%, i.e., to deliver one unit of heat (output) it requires 0.444 units of energy. The second law efficiency would then be:

$$\varepsilon = \frac{.07}{.444} \approx 16\%$$

The concept of these efficiencies when applied to systems of devices is not immediately straightforward. Consider the following example for pumping which build an analysis presented in a companion report. In this case a series of biomass based alternatives for water pumping are considered.

The concept of second law efficiency can also be applied to other cases. However, the results are not as satisfactory as that for space heating as the following application to heat engines demonstrates.

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[1] $\eta = \frac{q}{0.07q}$

[2] For a detailed discussion see APS <u>ibid</u>., p. 13.

As stated previously, the second law efficiency is defined as:

$$\varepsilon = \frac{\text{minimum amount of energy required to perform the desired task}}{\text{actual amount of energy required to perform the desired task}}$$

The problem in using this equation with heat engines comes in specifying the minimum amount of energy required. There are three alternatives that seem equally valid and these are discussed below:

(i) One justifiable choice of the minimum energy required (equivalent to the engine system with maximum efficiency) could be to use the most efficient engine that exists now. This would be the diesel engine (marginally superior to the Stirling engine) with a typical efficiency of 40 percent. In this case, the second law efficiency for a gasoline engine (efficiency $\sim$ 25 percent) would be 25/40 = 62.5 percent.[1]

(ii) An alternative choice would be to assume the maximum efficiency of any engine is the maximum ideal efficiency (i.e., ignoring frictional and other losses) of all engines existing now. The ideal efficiency is limited by the temperatures of heat absorption and rejection of the engine and the maximum is that for the Stirling engine (70 percent). Now, the denominator in the second law efficiency expression is 70, and ε for a gasoline engine would be 25/70 = 36 percent.

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[1] $\varepsilon = \dfrac{\text{minimum amount of energy required}}{\text{actual energy used}} = \dfrac{\text{efficiency of actual process}}{\text{maximum efficiency obtainable}}$

(iii) A final alternative is to suggest that neither of the above are appropriate. The problem with the first is that presumably research and development will reduce the frictional and other losses in an engine, and some years from now it is conceivable that a Stirling engine with an efficiency of 50 percent will be available. It can therefore hardly be appropriate to speak in absolute terms of a maximum available efficiency of 40 percent. A similar argument applies to the second alternative above. The ideal efficiency is directly related to the operating temperature of heat input to the system (i.e., fuel burning). At present the maximum temperatures obtainable are limited by the temperature resistant properties of the materials used. It is again conceivable that in the future, ceramic Stirling engines will be available with ideal efficiencies of 90 percent. The logical extension of this is that the maximum efficiency that can be obtained is in fact 100 percent for an ideal engine operating from an extremely high temperature (to a low of atmospheric or less).[1]

The APS defines the minimum amount of energy required as the "work available" in the fuel. Since the "work available" is actually almost the same as the heat of combustion (or energy input) of the fuel burnt, this approach is 100 percent (as in (iii) above).

Efficiencies of a biomass-engine-pumping system are shown in Table III. 1. As discussed, the first and second law efficiencies are identical.

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1. With this assumption, first and second law efficiencies will be the same (e.g., for a gasoline engine, $\varepsilon = 25/100 = 25$ percent).

TABLE III.1

EFFICIENCIES OF COMBUSTION ENGINE SYSTEMS

System	Biomass Conversion Efficiency	Engine Efficiency	Pumping Efficiency	Overall System Efficiency (1st & 2nd law)
Diesel	40-70	25-40	80	8% - 22%
Otto				
Gasoline	40-70	15-25	80	5% - 14%
Gas	40-70	20-40	80	6% - 22%
Stirling	40-65	30-40	70	8% - 18%
Steam turbine (<50 kw)	40-65	5-10	80	1.5% - 5%

Source: Adapted from Meta Systems Inc, State-of-the-Art Review of Biomass Fueled Heat Engines, August, 1980.

The concept of a second law efficiency is particularly appropriate for space heating, where the operating temperature ranges for a heat pump are specified (atmospheric, and room temperature) and where the heat pump has a seemingly unreasonable efficiency of 1400 percent. However, when the concept is transferred to heat engines some subjectiveness enters. The conclusion that the minimum energy required for a given task is equivalent to the "work available" (approximately the heat of combustion) in the fuel effectively implies that the first and second law efficiencies are the same, and supplies no new information.

SECTION IV
CASE STUDIES IN EVALUATION OF NON-CONVENTIONAL ENERGY TECHNOLOGIES

The previous two sections have presented a discussion of the methodology of economic evaluation of projects, of the choice of technologies, and technical issues involved in the efficient use of different energy sources. In this section, two case studies in economic evaluation of some of the non-conventional energy technologies are presented. (Two additional case studies are provided as Annexes A and B.)

The first case study is concerned with economic evaluation of a family-sized biogas plant in Indian context. It is explicitly concerned with conceptual and practical problems arising in social cost benefit analysis, and in evaluating different procedures for the estimation of or assumptions regarding shadow prices for inputs and outputs. The analysis recognizes that quantification of several major indirect costs and benefits is a major problem limiting the overall validity of the analysis; however, it does throw considerable light on the ranking of alternative designs for biogas plants. Comparison with Annex A (a similar study concerned with community-sized plants) shows the relative social advantages and disadvantages of family-size and community-size plants.

The second study is an economic analysis of various irrigation systems using different energy sources for the pumping of water; it is based on work in a "representative" village in Northeast Thailand. The

emphasis here is on examining technical alternatives, on the evaluation of uncertainty, and on a sensitivity analysis for various parameter values. Four technological options -- diesel engine and diesel pump, dual fuel/diesel engine and diesel/biogas pump, gas engine and pyrolysis gas pump, and free piston Stirling engine using biogas -- are considered, and their appropriateness to the needs and resources of different farm classes is examined. This study neglects the issues of social cost benefit analysis in that economic accounting using "shadow prices" and appropriate discount rates is not performed; the only component of social cost benefit analysis attended to here refers to the savings in foreign exchange. Two different values of foreign exchange premium have been used, in a hypothetical import-component proportion, for these calculations.

The second Annex focuses on electricity generation using a village-scale biogas plant, comparing the costs of central electricity generation and transmission for this technology with other conventional technologies, on the one hand, and those for units of two different sizes -- 3 MW and 20 MW -- using biogas plant, on the other. (The 3 MW unit is assumed to be using fuelwood under a social forestry scheme and the 20 MW unit is assumed to be based on fuelwood from existing forests.)

As discussed earlier in Section II, the estimation of opportunity costs of land and biogas inputs in the non-conventional energy technologies present a far more difficult conceptual and practical problem than, say,

in the case of foreign exchange or unskilled labor, where some simplifying assumptions and approximations may be made. For traditional agriculture, it is not just that markets for land does not exist or is very weak, for in that case it may be possible to assign an imputed value to land in terms of output price. The problem is that markets in labor may not exist either, and labor allocation in traditional, self-farming agriculture does not take place according to economic rules. Thus, while imputing value to inputs in traditional agricultures, it is impossible to separate the values that may be imputed to land and labor separately.[1]

Further, even if this problem could be resolved, estimation of the "shadow price" of land in terms of opportunity costs of foregone alternatives is difficult if such alternatives are not clearly defined. For example, consider a biomass-fueled energy project where non-crop vegetable residues (tree twigs, lakri, etc.) are used as fuel. It is possible that the land in question lies fallow at particular periods when it is practically impossible to put it to other use. In this case the opportunity cost is zero since no social product is loct. However, consider an irrigation project along with this energy project which can put this land to agricultural use. There the opportunity cost would be positive, and the opportunity costs to the private user and to the society as a whole may well differ. More, this opportunity cost shall be dependent on the particular crop that may be produced; ideally, the most profitable crop will be produced, and opportunity costs should be considered in terms of the value added of the produced crop. But when in actuality the land is being put to another use, it is difficult to choose between the hypothetical alternatives. One has to consider alternative technologies

1. See Lloyd G. Reynolds, "Introduction", in Reynolds, ed. (1975) for further discussion.

(and hence, costs) of production for each crop, alternative methods of production and use, and the estimated opportunity costs, in addition to being non-unique, would be both locationally and temporally specific.

Consider another example where the fuel in biomass energy project is crop residues. (For simplicity, neglect the question of alternative crops, and/or their material value for residue weights and quality.) These residues may otherwise be lying waste, in which case the opportunity costs for using them as fuel is zero; if there were substantial labor effort in collecting and disposing of them, this opportunity cost would even be negative. But suppose they were used as animal feed in varying proportion. It is not just that these residues are not marketed and hence do not have a price; we often do not know what substitutes may be used as feed, at what price, and what their availability is.

Now suppose some of the residues for one crop were to be used as fuel. It is clear that the losses in animal feed use can be met either by using another crop's residues, if available, or by substituting a commercial feed. At a given level and composition of livestock, the kcal as well as nutrient requirements, are approximately determined. Using data on kcal and nutrient composition of initial feeds, one can in principle construct a feed balance and then estimate the shortfalls in kcal and nutrients for a given type of animal. Depending upon the level of aggregation, one can also examine the distributive impacts of such shortfalls.

It needs to be pointed out that calculations of such feed balances based upon nutritional values of different feeds and feed requirements of different animals does not by itself answer the question of economic opportunity costs; it simply gives us a physical measure of shortfalls in availability. However, given such calculations, one can in principle identify the proper substitute feeds for a particular crop residue, and estimate its cost.

There are practical problems with these procedures, too. Data on nutritional values of particular crop residue may not always be available. Only recently were nutritional data on some of the tropical feeds published by FAO.[1] Feed requirement data for animals in U.S. or Western Europe are not necessarily applicable to animals in the Third World agriculture.[2] However, either of the two principle systems - the Swedish one, used more extensively in Europe and Northern Africa, and the U.S. one, used in Northern America - for calculation of feed balances may in principle be used to create similar systems in the Third World as well.

The discussion so far has assumed a static scenario in the sense that feedback and second-round effects are not considered. And these considerations usually are the important motivation in planning for non-conventional energy technologies. For example, while diversion of crop residues to fuel use may result in a shortfall in the present availability of animal feed, one must consider that such fuel use in an irrigation technology actually leads to increases in crop production and hence in availability of residues in the next period. In fact, not

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1. FAO (1975)

2. Cullison (1975), for example.

only should we consider these additions to crop and residues in physical balances and in cost benefit analysis, but also that they make possible additions to livestock, increases in quality of livestock, and so on. For a large enough project, a systematic study of such interrelationships should be made; crop studies, feed nutritive studies, feed balance studies, etc. need to be conducted. At a sufficient level of disaggregation, combined with detailed information on social structure and relations, one can also use such studies to forecast distributive impacts of technological change.

It should be noted that neither the case studies presented here, nor the additional case studies in Annexes 1 and 2 are supposed to be complete: each one has different focus, highlighting one aspect at a time. For reasons discussed above, it has not been possible to include the analysis of opportunity costs, estimation of shadow prices, or to incorporate explicit value judgements in assigning parameter values to distributional or other social, non-efficiency criteria. As should also be obvious, the cases are not readily comparable in their contexts, costs, benefits, appropriateness of selection criteria, or technological design. And yet, the case studies present different aspects of applicable methodologies for the economic valuation of non-conventional energy technologies. Whereas the results cannot be transferable in toto to other contexts and problems, it is hoped that at the present level of knowledge and data availability, these methods can be used in more general fashion.

IV.1 Social Benefit Cost Analysis of a Family Biogas Plant[1]

In this case study of a family biogas plant in Indian conditions we attempt to present the principles which could be used for similar case studies elsewhere. The example below shows that the most difficult aspect of social cost analysis in the renewable energy field is the quantification and valuation of direct and indirect benefits and costs. However, for any appraisal of appropriateness of a mix of technological alternatives, it is absolutely necessary to trace through its impact on the rest of the economic and social system. Since resources going to a given technology, say biogas plants, have alternative uses, one should be able to demonstrate that not only are the aggregate benefits to the society in this particular use higher than aggregate costs, but that benefits per unit of capital costs in this case are higher than those obtained in other activities. Thus, efficient use of resources would require benefits to be higher than costs in such a way that a reallocation of resources away from this particular use does not increase the total welfare of the society. (Figure IV-1).

An economic appraisal (from the point of view of society) of investment in a biogas unit would require quantification and valuation of primary benefits, as well as of the direct and indirect costs associated with the installation of the plant.

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[1]For details see Bhatia (1977) and Bhatia (1980). This section draws heavily on the latter.

These benefits and costs may be enumerated as follows:

A. Primary Benefits:

1. Biogas as a source of fuel
2. Digested manure or slurry as fertilizer.

B. Secondary Benefits:

1. Convenience of cooking with a clean fuel.
2. Reduction in uncertainty of energy supply.
3. Renewable source of energy.
4. Self-sufficiency in terms of reduction of imports.
5. Employment to the local people.
6. Possibility of using vegetable wastes and human wastes.
7. Reduction in health costs due to anaerobic digestion.

C. Direct Costs:

1. Capital costs

   a. cost of land
   b. civil construction
   c. gas holder
   d. pipes and appliances

2. Operating Costs

   a. cow dung used as major input
   b. labor for dung collection
   c. labor for operating the unit
   d. cost of painting and hosepipe, etc.
   e. cost of water.

D. Indirect Costs:

1. Depriving poor classes of cow dung

2. Management problems

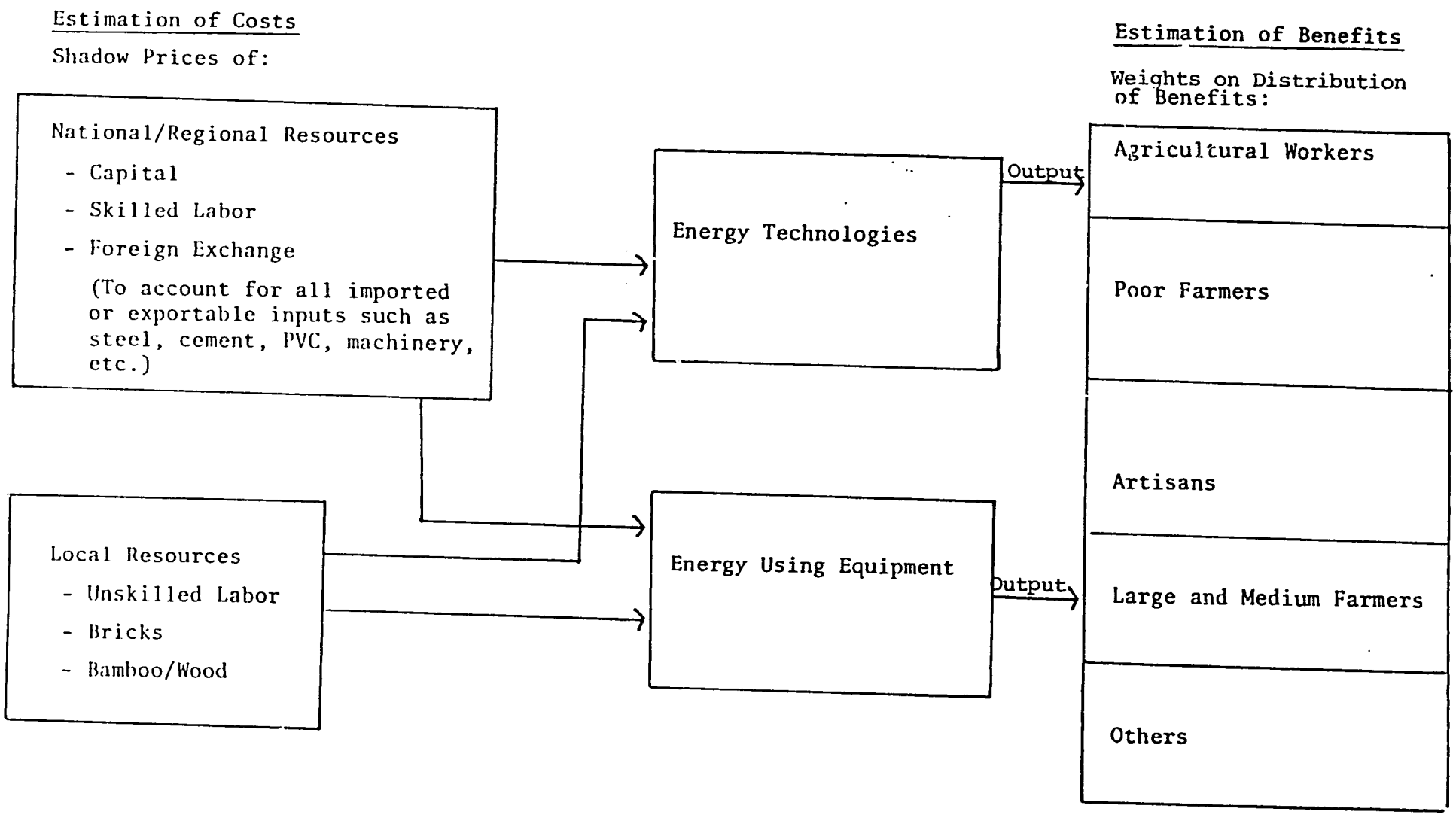
3. Inconvenience of mixing cow dung with water and feeding the slurry.

Valuation of Primary Benefits

Biogas units are available in various sizes, ranging from capacities of 2 cubic meters (70 cubic feet) of gas per day to 140 cubic meters (4,948 cubic feet) per day. The smallest sized unit, of 2 cubic meters

Figure IV-1

FRAMEWORK FOR ESTIMATION OF COSTS AND BENEFITS



(cu m), requires about four to five animals and can produce enough gas to meet the cooking requirements of seven persons. We present here a detailed social benefit cost analysis of investment in a family size biogas unit of 2 cu m per day.[1]

Two major benefits from a family-size biogas unit are: (1) gas to be used for cooking and lighting, and (2) digested slurry to be used as fertilizer manure. The valuation of these benefits involves estimation of the quantity of gas obtained, quantity as well as quality of digested manure obtained, and the monetary values which can be assigned to gas and fertilizer nutrients to reflect the benefits to society. The details of estimation of benefits are described below as well as given in Table 14.

A 2 cu m per day (70 cft/day) plant can produce enough gas to light 2 lamps of 100 candle power (each for two hours) and to provide for the cooking needs of 5 persons, assuming the requirements 5 cft/hour for each lamp and 10 cft/person/day for cooking. The value of this gas to society can be measured in terms of the "economic cost" of providing alternative sources of energy for lighting and cooking if investment in biogas is not made.[2] The source of energy for lighting would be kerosene in villages without electrification, while it would be electricity or kerosene in electrified villages. Now, 20 cft of gas used in lighting can be replaced by either 3.2 kwh of electricity or 0.37 litres of kerosene. The cost of electricity is taken to be $0.04 per day taking

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[1]For details, see Bhatia (1977).

[2]This assumes that cow dung, fuelwood and kerosene currently being used have to be replaced by other fuels on account of considerations of social productivity of cow dung as manure, deforestation problems caused by fuelwood, and high foreign exchange costs of imported kerosene. Valuation of benefits becomes more complex if these assumptions are not valid as shown later in the case of community plant.

the "economic costs" of electricity at $0.022 kwh, to account for the variable costs of generation, assuming that the costs of generation, transmission, and distribution, are fully allocated to energize wells. The equivalent cost of kerosene, at $0.4 per litre, is $0.15 per day. Thus, if biogas is available for lighting, society would not have to incur $0.15 per day in terms of equivalent quantity of kerosene. Hence the benefit to society from using 20 cft gas for lighting can be taken to $0.15 per day or $53 per year.

On the same lines, it would be economic for the society if soft coke instead of kerosene is used for cooking. Assuming a delivered price of soft coke at $8 per ton, the "resource cost" of 1.25 tons of soft coke for cooking (equivalent to the use of gas for cooking @ 50 cft/day) would be $10 per year. Thus, in the absence of gas from a biogas unit, the costs to the society of providing alternative fuels would be $63 per annum. This can be used as a measure of the benefit that the society derives from gas from the unit. This analysis, so far, assumes that there is no additional benefit from additional quantity or better quality of slurry from the unit. If it is assumed that there is an improvement in the form of nitrogen available, the annual benefits will be higher by $55 per year. (See Table IV-1.

Valuation of direct costs is relatively straight forward. Both the capital costs and operating costs can be broken down in trhee components: steel, cement and unskilled labor. For each of these items, one can use appropriate shadow prices to obtain the estimates of cost form the viewpoint of the society. It may be noted that use of shadow prices of steel and cement requires use of shadow price of foreign exchange which is used to

reflect the premium that the society attaches to foreign exchange on account of its scarcity. Use of shadow prices, thus, takes explicitly into account the self-reliance objective of development planning. Similarly, the objective of providing additional employment of unskilled workers has been taken into account by the use of shadow wage rate for unskilled labor which is lower than the market wage rate. This gives the estimated capital cost of a biogas unit (conventional KVIC design) at $290 and annual operating costs (excluding cow dung) as $9 per year. The corresponding costs for a Chinese-design unit are $175 and $9 respectively. (See Table IV-2).

In accordance with the earlier discussion on decision criteria, we utilize an appropriate social rate of discount to calculate net present value (NPV) and benefit cost (B/C) ratio.

The results of the benefit cost analysis of a family biogas unit are presented in Table IV-3. It may be noted that NPVs are positive in all the cases and B/C ratios are much above unity. As was expected, B/C ratios are higher in the case of shadow prices (due to zero shadow wage rate and 25 percent premium on imported kerosene and area on the benefit side) than under the market price assumptions. Since the capital costs of a Chinese-type design are considerably lower and benefits are assumed to be the same as in the case of conventional design, the B/C ratios with the Chinese-design units are relatively higher. If, however, it is assumed that there would not be appreciable increase in the nitrogen content of biogas slurry due to handling practices of farmers and hence manure benefit is ignored, the B/C ratio would drop to 1.24 in the case

of conventional design. The IRR in this case is 13 percent indicating that the project would be socially unprofitable if social rate of discount is higher than 13 percent or shadow price of investment is used along with a lower discount rate.

It may also be useful to perform sensitivity analysis of the results with respect to: (a) national/regional parameters such as social rate of disount, shadow price of foreign exchange or shadow wage rates (b) commodity prices such as the price of kerosene, soft coke, urea etc. (c) technical parameters such as methane content of gas, calorific values of kerosene/soft coke, NPK content of slurry, etc. These sensitivity analysis results would show how robust the earlier results are and which are the parameters which are important in determining the social profitability of the technology.

Care should be taken to incorporate the secondary benefits as well as indirect costs of biogas units in social benefit cost analysis. Even if these cannot be quantified, it would be useful to list all such benefits/costs along with the B/C ratios such that the policy maker can compare and evaluate different technologiecal or policy options. For example, it is said that availability of pollution free, clean fuel is expected to improve the quality of rural life. Besides, instant availability of gas makes cooking more convenient and faster. Since these benefits are important considerations in persuading a prospective user to opt for a biogas unit, these would significantely affect the private benefit cost analysis, it would not be appropriate to put a specific premium on these benefits as these family biogas units are to

be installed by relatively richer farmers. In fact, a smokeless fuel such as LTC (low temperature carbonization) coke is available in the market which can provide the equivalent benefits. Similarly, it is not considered necessary to attach special premium to the fact that the biogas unit reduces the uncertainty of energy supply since adequate stocks of alternative fuels (e.g., soft coke and kerosene) can be maintained by the prospective owners of biogas units.

Another benefit of these units, generally mentioned, is that reliance on the use of biogas as fuel involves neither dependence on import of foreign energy resources nor dependence on a diminishing supply of domestic energy resources. The first point is already taken into account by giving a premium on foreign exchange for the import of kerosene. The second consideration would require a special premium on soft coke, if the reserves of non-coking coal were relatively small. Since India has more than 12,000 million tonnes of proved reserves and over 48,000 million tonnes of indicated and inferred reserves of non-coking coal (enough to last 150-200 years), it does not seem appropriate to put a special premium on the cost of soft coke.

The decentralized technology of biogas production would provide employment to the skilled and unskilled laborers in construction of these units, in maintaining the units as well as in the collection of dung. These employment benefits have already been quantified and incorporated in the social cost benefit analysis, in terms of zero "shadow wage rate" of unskilled labor.

Possibilities of using vegetable waste and human excreta would be additional benefits of biogas units if these wastes cannot be utilized

either in compost manure or direct in the field. Given the inhibition regarding use of human excreta for producing gas for cooking, it is too early to quantify and attribute these benefits to biogas technology. The other vegetable wastes can be used both in scientific composting and in biogas units.

The only significant indirect benefit of biogas technology seems to be in terms of health benefits. The smokeless flame of the gas contributes to eliminating eye troubles and environmental pollution. It has been indicated that other health costs are also probably diminished since the process of anaerobic digestion is known to kill many of the pathogens transmitted in cattle dung. Besides, the manure pit which is often the cause of flies and mosquitoes becomes free as the outlet slurry (digested manure) does not attract these insects. Rather, they run away from the pit due to some repelling odor that comes from the slurry.

The health benefits of biogas technology are confined to those units where latrines are attached to the gas plants. It has been found that only a small percentage of the individual family gas plants were connected with latrines. It is also observed in a study[1] that "almost the whole sample, irrespective of the socio-economic status was prejudiced against laterine connections and had experienced problems in this connection." With this bias against the use of night soil in a gas plant, most of the plants are not in a position to get the associated health benefits. Besides, even in plants with attached latrines, it has not been shown that the health benefits of anaerobic digestion are better than those of aerobic digestion. However, there is a need for a detailed analysis and

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[1] T.K. Moulik and U.K. Srivastava, (1978).

quantification of health benefits of biogas technology as compared with the scientific compost technology. In the absence of such knowledge it would be inappropriate to give credit to biogas technology for indirect health benefits associated with the installation of these plants.[1]

The main element in indirect costs may be that the installation of biogas units by rich farmers would result in an increasing tendancy to have stable-bound cattle in order to augment the collection of dung and urine. This would deprive the poorer sections in rural society (landless laborers and marginal and small farmers) of a cheap source of fuel for their energy needs. The effect of installation of biogas units on the availability of fuels to other sections of the society has not yet been studied in detail. This would require a comprehensive survey of villages where these plants have been installed. There would also be regional variations in the practices followed regarding collection and disposal of cow dung. Hence, these effects would have to be quantified and incorporated in the context of some specific investiment in biogas units.

On aspect of social benefit cost analysis which has to be kept in mind is that even though many objectives such as employment generation, regional development, income distribution, self-sufficiency and use of local resources etc. can be taken into account by using shadow prices instead of market prices, there may still be intangible benefits and indirect costs (arising on account of externalities) which cannot be quantified. Such benefits may deal with convenience, ease of operation, flexibility, mobility, versatility which though difficult to quantify can be expressed in terms of preference scales of the users. If social benefit

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[1] It has been reported in studies on Chinese biogas programs that one of the important motivations of the Chinese program was the health benefits from disposal of human excreta and pig manure.

cost analysis is modified to incorporate these preference scales along with use of benefit cost ratios, it can still be used to evaluate technological and other alternatives. The strategy suggested here is to broaden the methodology of social benefit cost anslysis by incorporating these considerations.

It may also be useful to consider some special resource requirements or special adaptability problems of some technologies. In the case of family biogas plants, availability of land and water in adequate quantities near the kitchen may be a serious constraint for many villages and may well be an important reason for its non-adoption. In the case of the photovoltaic system, it may be the difficulties of leaving these in the open spaces in the field under heavy monsoon conditions resulting in damage or theft.

TABLE IV-1. ESTIMATION OF BENEFITS OF A 70 CFT (2 CUBIC METER) PER DAY FAMILY BIOGAS PLANT

	Market Prices	Shadow Prices
Annual Benefits		
1. Lighting		
Gas used at 20 cft/day and valued at equivalent kerosene prices.	$40	$53
2. Cooking		
Gas used at 50 cft/day and valued at equivalent soft coke prices.	$31	$10
3. Manure (Additional)		
Additional N content of 0.6% in 13.36 tons of biogas slurry valued at urea prices.	$35	$55
4. Total	$106	$118
Present Value over 10 years		
At 8% interest rate or discount rate	$671	$798

Notes: 1. The following conversion factors have been used:

Lighting Conversion Factors:

.37 liter kerosene = 3.2 kwh of light
20 cft gas = 3.2 kwh of light
1 liter kerosene = 54.05 cft gas

Cooking Conversion Factors:

1 cft gas = 70 kcal (125 kcal at 56% efficiency)
1 liter kerosene = 1720 kcal at 21.7% efficiency)
1 kg soft coke = 5772 kcal (.177) = 1021.6 kcal (5772 kcal at 17.7% efficiency)
1 cft gas = $\frac{70}{1021.6}$ kg sfot coke

2. Kerosene Prices: $0.25 per liter market price, $0.40 per liter shadow price.
Soft Coke Prices: $25 per ton market price; $8 per ton shadow price assuming that two-third of coal costs are unskilled labor valued at zero.
Urea Prices: $0.2 per kg at market price, $0.30 per kg shadow price. Assuming N content of 1.6% in biogas slurry or agains 1% N in cow dung (dried basin).

TABLE IV-2. CAPITAL COSTS OF CONVENTIONAL AND CHINESE-TYPE BIOGAS PLANTS IN INDIA: 70 cft/day

	Market Prices	Shadow Prices
A. Conventional Design		
1. Digester Well		
Skilled Labor	71.4	71.4
Unskilled Labor	35.7	0.0
Materials (cement & steel)	35.7	44.6
Sub-total	142.8	116.0
2. Gas Holder (steel)	116.6	145.8
3. Appliances	32.0	40.0
Total	290.4	301.8
B. Chinese Design		
1. Digester Well	143.0	116.0
2. Appliances	32.0	40.0
Total	175.0	156.0

Notes: 1. Unskilled labor is shadow priced at zero. A premium of 25 percent is used for cement and steel.

2. There is no steel gas holder in the Chinese-type design and, hence, the capital costs are lower.

TABLE IV-3. RESULTS OF BENEFIT COST ANALYSIS OF A FAMILY BIOGAS PLANT

	Market Prices	Shadow Prices
A. Conventional Plant		
1. Present value of Benefits (@ 0%) P(B)	$671	$798
2. Present Value of Operating Costs P(C)	$ 57	$ 57
3. Present Value of Capital Costs P(K)	$290	$302
4. Net Present Value NPV = P(B) - P(C) - P(K)	$324	$439
5. B/C Ratio $= \frac{P(B) - P(C)}{P(K)}$	2·12	2·45
6. Internal Rate of Return: (IRR)		35%
B. Chinese Design		
1. NPV	$439	$585
2. B/C Ratio	3·50	4·75
3. IRR		71%

IV-2 Rural Energy Systems: Sample Analysis of Irrigation Plans

The complexity of the rural energy system arises from the variety of energy sources often available and used as well as of the many different uses to which these resources are put for both energy and nonenergy purposes. Thus attempting to intervene in this system in an optimal manner requires understanding of the system and how its equilibrium will be changed. This understanding should be based on a detailed picture of resource endowment of the areas and the resource flows between and within the different village sectors which take into account variations by season and by economic class. It is thus necessary to identify current energy use levels and patterns, the magnitude of potential energy resources and to collect important socio-economic information.

The purpose of this analysis is to identify the most attractive or beneficial new energy technologies for introduction to the system. First, the technical and socio-economic feasibility of the different candidate technologies must be assessed. Then, a more precise analysis should be performed to determine the most attractive yet feasible technologies. The first step here relies on resource assessment information for the aggregate village or locale. For wind and solar technologies, the resource availability is primarily a technical issue. For biomass technologies, there is a significant socio-economic factor concerning access to and ownership of these resources. Biomass technologies have added complications in that the availability of biomass can be purposely increased if sufficient benefits can be obtained. In this case, such a use of

1. This discussion draws heavily from deLucia and Lesser (1980).

land and other resources must be examined in comparison to the alternatives. Furthermore, biomass resources often have existing uses, and the diversion costs must be assessed.[1]

The second aspect of the analysis examines the "costs" and "benefits" of the technologies. Overall, this work evaluates the technologies in light of the different energy demands and their characteristics: quality, magnitude, time pattern by day, and season. This framework requires a systems approach -- examining the different supplies and demands together.

The following is a sample analysis that will examine various interventions in a representative village in Northeast Thailand. The analysis will estimate the benefits and costs of different irrigation schemes under varying economic and technical conditions. It will specifically examine the situation of three classes of farm size. The relative attractiveness of the different technologies will be compared for varying costs of capital, shadow prices for foreign exchange, and reliability assumptions. There will also be discussion of the feasibility of the technologies, such as availability of and access to the necessary resources.

This example is limited in that it does not address all energy uses or technologies. A more complete analysis would include examination of the value of additional or substitute energy sources or technologies for other uses, such as cooking, agricultural processing, or tilling. In light of the work done examining the potential for irrigation in the Northeast, and the need for increasing agricultural production in this

1. For reasons discussed earlier, estimation of opportunity costs of land and forest products is an extremely difficult task requiring information which is not available at present. Hence, these would be ignored in what follows.

area, this issue is considered to be of high priority.

First, a picture of the economic and demographic situation and of the resource flows will be presented. This picture will represent the kind of information often necessary to analyze the impacts of intervention. Then, in the ensuing sample analysis, it will be shown how this information can be used.

Northeast Thailand Village Model

This village is representative in the sense that the per capita resource endowments, land use patterns, and general economic conditions reflect those for the Northeast in general. Therefore, much of the information used was aggregate figures for the entire Northeast that were scaled down to village-level quantities. These aggregate data were supplemented by several village-level studies of locations in the Northeast as well as elsewhere is the country.

For regional information the sources generally used were the reports by Russell Brannon, Agricultural Sector Assessment -- Thailand (January 1978) and by the World Bank, Thailand: Toward a Development Strategy of Full Participation, A Basic Economic Report (September 1978). Also used were several Agricultural Economics Research Bulletins prepared by the Division of Agricultural Economics, MOAC, as background work for Thailand's Fourth Five-Year Agricultural Development Plan (B.E. 2520-2524). The distribution of farm sizes is based on data from the General Farm Survey 1973/74 by the Division of Agricultural Economics, MOAC, which

was presented in the Brannon report. The village-level cropping pattern is based on information from all of these reports.

Village level livestock population figures were derived from MOAC and Brannon. Farm and household level information was available from the studies by the Chulalongkorn University Social Research Institute such as Village Khon Kaen -- Social and Economic Conditions of a Rural Population in Northeast Thailand by Amara Pongsapich with the collaboration of Jacques Amyot and Friedrich W. Fuhs (Bangkok, 1976). This study surveyed village and household level data for four villages in Khon Kaen province duuring the late 1960s. Other descriptions of village life were also examined. For information on woodfuel supply and demand, the FAO study Timber Trends Study, Thailand (Rome 1972) was used.

The Village Model

This village has 105 families and a total population of 677 people. Of the 105 households in the village, 100 are primarily farmers, while the remaining five include the miller, two teachers, a store owner, and possibly a Government official. The farmers can be divided into three classes: small, medium and large, according to farm land and livestock resources. The average household size for the village is nearly 6.5 people. Slightly more than half of the families are nuclear rather than extended; however, this varies over time as families pass through the cycle of nuclear to extended to nuclear as the family size expands when the children and their spouses set up separate households. Table IV-4 shows the basic demographic data along with average land and livestock resources by class. Average farm size is 23 rai.*

*1 hectare = 6.3 rai.

TABLE IV-4. VILLAGE DEMOGRAPHIC, LAND AND LIVESTOCK RESOURCES BY CLASS

PER HOUSEHOLD

Class	Family Type %Nuclear	Family Type %Extended	Person/ Household	Average Farm Size (rai)	No. of Animals Cattle	No. of Animals Buffalo	No. of Animals Pig
Non-agricultural	100%	0%	4	-	-	-	1
Poor	80%	20%	5	9.4	0	1	0
Middle	50%	50%	6.5	25.4	1	2	0.25
Rich	25%	75%	8.5	62.5	2	2.5	1

TOTALS

Class	Number of Households	Number of Persons	Total Farm Land (rai)*	Total Number of Animals Cattle	Total Number of Animals Buffalo	Total Number of Animals Pig
Non-agricultural	5	20	-	0	0	5
Poor	23	115	216	0	23	0
Middle	56	364	1400	56	112	14
Rich	21	178	1313	42	53	21
TOTAL	105	677	2929	98	188	40

*Net of two percent for household structures.

With regard to agricultural production, although rice (glutinous with some non-glutinous) is the primary crop, the principal upland crop varies depending on location in the Northeast. In this village, as is typical of the Northeast, there is no double cropping and all rice is rain-fed only. The cropping intensity (percent of farm land actually planted or harvested) was assumed to be about 60-65 percent with 70 percent of the crop land planted with rice. The cropping intensity was varied slightly by farm class, being higher for the poor and lower for the rich. Despite the availability of aggregate cropping pattern data for the Northeast, no detailed information was located on how cropping patterns vary by farm size. It was assumed that small farms grow only rice, that medium farms plant 80 percent of their farmed land with rice, and that the large farms plant slightly over half their land with rice. When a village-level average is calculated, the regional average of about 70 percent of planted land in rice is met. Table IV-5 shows the cropping patterns and the levels of agricultural production for the different classes. The yields per rai used were 220 kg. rice, 1,980 kg. cassava, 340 kg. maize, and 150 kg. kenaf.

As can be seen from Table IV.3, the village as a whole produces a surplus of rice; however, on a class level some transfer will be required, possibly in the form of income for agricultural work or for services such as rice milling. The level of this surplus reflects the fact that reportedly the Northeast as a whole presently produces a five-percent surplus and that the farm households must also supply the non-agricultural households, which are about 25 percent of the total households in the Northeast.

TABLE IV-5. VILLAGE AND CLASS CROPPING PATTERNS AND AGRICULTURAL PRODUCTION

I. Cropping Pattern*

Class	Land (rai)	Cropping Intensity	Per Farm Land Harvested (rai) Total	Paddy	Other	Per Class Land Harvested (rai) No. of Farms	Total	Paddy	Other
poor	9.4	70%	6.58	6.58	0	23	151.3	151.3	0
middle	25.4	65%	16.25	13.00	3.25	56	910.0	728.0	182.0
rich	62.5	60%	37.50	19.76	17.74	21	787.5	414.9	372.6
VILLAGE TOTALS:						105	1848.8	1294.2	554.6

Village Cropping Intensity: 63%

Percent of Land Harvested in Paddy: 70% (assumption based on NE cropping patterns)

II. Agricultural Production** (metric tons annually)

Class	Per Farm Paddy	Other Cassava	or	Maize	or	Kenaf	Per Class Paddy	Other Cassava	or	Maize	or	Kenaf
poor	1.45	0		0		0	33.3	0		0		0
middle	2.86	6.45	or	1.09	or	0.49	170.1	361	or	61	or	28
rich	4.35	35.2	or	5.96	or	2.70	81.3	739	or	125	or	57
VILLAGE TOTALS:							285	1100	or	186	or	85

*These cropping patterns do not take into account vegetable gardens. The "other" category for the NE could be cassava, maize or kenaf depending on location and market conditions.

**The yields were taken from Brannon for the NE; they were assumed to be constant over farm size though there is some evidence that the smaller farms obtain higher yields.

TABLE IV-6. VILLAGE AND CLASS FOOD BALANCES (RICE ONLY*)

	Per Household				Per Class		
Class	Paddy Production (tons)	Net Rice Availability** (tons)	Annual Demand† (tons)	Surplus (+) Deficit (-)†† (tons)	Net Rice Availability (tons)	Annual Demand (tons)	Surplus (+) Deficit (-) (tons)
non-agricultural	0	0	0.66	-0.66	0	3.3	-3.3
poor	1.45	0.80	0.83	-0.03	18.4	19.0	-0.6
middle	2.86	1.67	1.07	+0.60	93.7	59.9	+33.8
rich	4.35	2.54	1.40	+1.14	53.4	29.5	+23.9
VILLAGE TOTALS					165.5	111.7	+53.8

*Due to the varying availability of a second food crop and since it appears that possibly 80 percent of a rural NE Thai caloric intake is in the form of rice, a daily caloric intake of rice was assumed to be 1600 kcal or one pound of rice daily. This intake level amounts to .165 metric ton of rice per capita annually; this figure nearly matches the average apparent domestic per capita intake nationally over the past 10 years. Although there are undoubtedly variations in food and rice consumption across class, this was not included due to lack of specific data. An NESDB nutrition study caloric figure nationally was 1900 kcal per person, 95 percent of which was from non-meat and dairy sources. This would be comparable to the 80 percent/1600 kcal figure for rice for the NE, taking into account the probably lower average intake of the NE in comparison to the national average.

**Net rice availability is assumed to be the total amount of rice produced on the farm (65 percent of paddy production) less 10 percent for losses and seed requirements.

†Annual demand is .165 for rice per capita multiplied by number of persons per household.

††Surplus or deficit is net rice availability less annual demand.

Table IV-7 and IV-8 examine the availability and demand for animal feed. This situation could vary significantly depending on location in the Northeast. Villages growing maize will have an abundant source of feed from crop residues, whereas cassava or kenaf producing villages may require pastureland off-take to supplement their supplies of paddy residues.

These tables summarize the present agricultural situation of this village. Although a detailed calculation of the conditions of the village in the future was not undertaken, some trends seem likely based on the results of the National Crop Model of Thailand for the present Agricultural Development Plan. Two of the major pressures on the Northeast agricultural situation will be increasing population growth and decreasing soil fertility. The forecasts for 1981 indicate decreasing rice yields and an overall decrease in total crop income. The Northeast is expected to become a net importer of rice to meet household needs. Therefore, on the village level, the rice surplus will decrease as the ratio of farmland to population decreases. The poor will need to earn more income in order to be able to purchase rice. In general the per capita availability of resources will be less.

With regard to the availability of wood fuel in the Northeast, a regional average would be misleading in light of the wide variation in actual availability in different parts of the Northeast. Whereas the northern and western parts of the region still have forests, much of the rest has few forest resources.

TABLE IV-7. VILLAGE AND CLASS FOOD AND FEED BALANCES

Village Feed Requirements

Animal	Annual Intake/Need	Crop Residue, Equivalent to 60% of Intake* (tons)	Number of Head	Total Residue Demand (tons)
Cattle	5.2×10^6 kcal	1.6	98	157
Buffalo	8.3×10^6 kcal	2.5	188	470
Pig	2.0×10^6 kcal	0.6	40	24
60% Annual Feed Requirement:				651 tons

*An approximation based on the nutrient balance example examined in Table 5.

Village Feed Availability from Crop Residues

Crop Residue	Crop Production (tons)	Residues: Crop Ratio	Total Crop Residues (tons)
Paddy Straw	285	2.0	570
Paddy bran	285	0.05	14
Maize residues	186	2.5	465
Cassava leaves	1100	0.2	220
Total: kenaf growing villages			584
cassava growing villages			804
maize growing villages			1049

Village Balance

- For maize growing villages, crop residues exceed 60% of the annual feed requirements. The remainder can be met by off-take from grazing.
- For cassava growing villages, crop residues exceed 60% of the animal feed requirements. Since cassava leaves are high in protein and nutrients (see Table 3), these satisfy some 75% of the feed requirements; the remainder to be met by off-take from grazing.
- For kenaf growing villages, only 40% of the feed requirements may be met by residue. (The possible use of kenaf residue adds some unknown quantity.) The remainder must be met by offtake from grazing.

Household Feed Balances (including only paddy straw)

Class	Annual Demand of Straw for Feed (tons)	On-Farm Rice Straw Availability (tons)	Shortage (-) or Surplus (+) (tons)
non-agricultural:	Only animals in the class are the 40 pigs which are not fed straw (they are fed bran by the miller who owns them).		
Poor	2.5	2.9	+0.4
Middle	6.7	5.7	-1.0
Rich	10.0	3.7	-1.3

TABLE IV-8. FEED CHARACTERISTICS AND FEEDING REQUIREMENTS

A. Feed Characteristics for Digestion by Cattle or Buffalo*

Feed	Digestable Crude Protein (%)	Total Digestable Nutrients (%)
Paddy Straw	0.4	37.1
Paddy Bran	9.3	64.9
Maize Stalks	2.1	56.7
Cassava Leaves	15.0	60.0
Pasture Grasses	4.0	60.0

*The numbers in this table are representative of the chosen Thai feeds. This type of information varies among different crop variety, different cultivation and harvesting practices, different climates and different animals. The principal sources used were Tropical Feeds (Göhl, FAO, Rome, 1975) and Feeds and Feeding (Cullison, Reeston Pub. Co., Reston, Va., 1975). The pasture grass characteristics are rough averages of the various grasses native to Thailand noted in Göhl (1975).

B. Example Feed Balance for a 500 Kg. Buffalo

		Dry Matter (kg)	Digestable Crude Protein (kg)	Total Digestable Nutrients (kg)
Daily Feeding Requirement*:		12.5	0.6	6.35
Feeds:	Paddy Straw	7.0	.028	2.60
	Cassava Leaves	3.0	.45	1.8
	Pasture Grasses	2.5	.1	1.5
Total Feed Characteristics:		12.5	.58	5.90

*This is an analogy to bullock maintenance in India (S.P. Arora, "The Role of Treated Roughage in Animcal Production Systems in Developing Countries," in New Feed Resources, FAO, Rome, 1977). This weight is equal to that of the mature buffalo in Thailand, so it is somewhat larger than the appropriate average weight.

Note: Even with significant intake of cassava leaves and pasture grasses, the protein and nutrient in the feed fall short of the assumed feeding requirement in this example. The Thai village livestock are assumed to have somewhat deficient diets, but their exact feed parameters have not been investigated. For the crop residue balance in Table 2, a 60% intake of paddy straw and maize residues was deemed appropriate.

According to the 1972 FAO timber study, Northeast forest land had on the average about 43 m^3 per hectare standing stock with an annual increment of about 1.0 m^3.* This compares to the reestimated country averages of 71.5 and 1.8 m^3 per hectare respectively. The total Northeast demand for residential wood fuel in 1970 according to the FAO study was 16.3 million cubic meters (11.5 fuelwood and 4.8 charcoal). Comparing this demand with the total annual increment of Northeast forests of about 8 million cubic meters, the infeasibility of meeting the deficit from non-forest land clearly indicates at least one motivation for the apparent deforestation of this region. In fact, according to recent statistics, the forest area of the Northeast was reduced to 5.10 million hectares in 1973, according to the Royal Forest Department, from the estimated 7.8 million hectares in the FAO study.**

The sources of non-crop biomass for a village or household in the Northeast generally fall into the following categories:

1. forested and deforested public land,
2. farm or private land, and
3. imported or purchased biomass.

At present, information concerning the sources of wood fuel is very limited. The FAO Timber Trends study had national demand met by the annual increment of small-size forest timber plus a variety of other sources such as mangrove forests, rubber plantations, removals by shifting

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*These figures were adapted to reflect both sawlog size and small timber.

**Division of Agricultural Economics, MOAC, Fourth Five-Year Agricultural Development Plan, B.E. 2520-2524 Guidelines, Agricultural Economics Research Bulletin No. 114, August B.E. 2519, Chap. 2, p. 7.

agriculture, falling losses off crows (falling timber tops), and production from farmlands. The latter source, farmland production, was the largest of these other sources at 8 million m^3 in 1970. Given the total area of farmlands in 1970 of about 15.5 million hectares, the average off-take was about 0.5 m^3 per hectare from farmland. No regional estimates of this off-take were presented, but in light of the relatively low productivity of Northeast forest land, for the purposes of this exercise it will be assumed that Northeast farmland yields 0.3 m^3 of wood fuel per hectare annually. For grazing or animal feed purposes it will be assumed that deforested public land and non-cropped private land yields one ton per hectare of feed annually. This figure is meant to be conservative to represent the fact that if such land were significantly more productive, it would be planted; however, no actual figures concerning the productivity of this land were located.

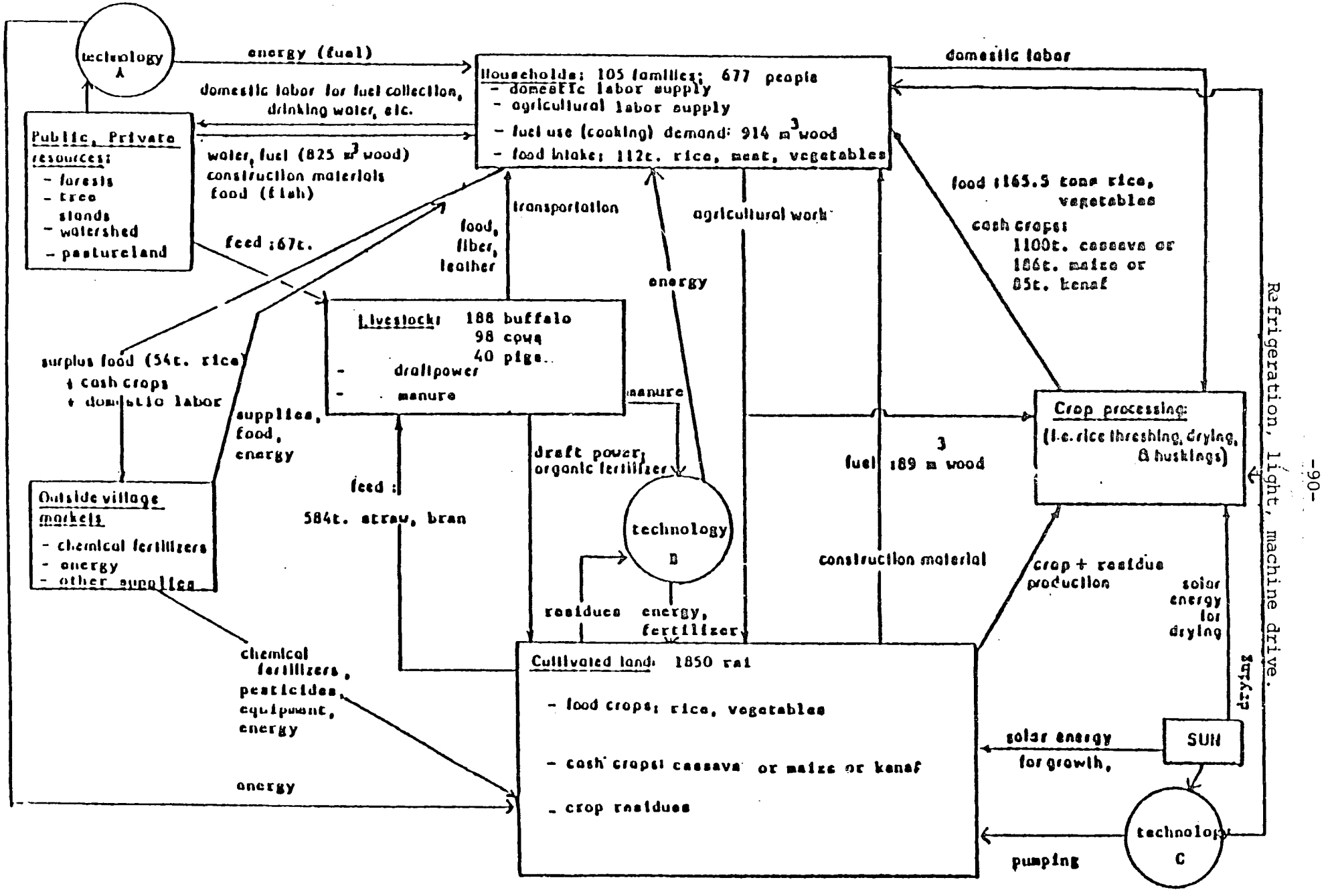
Based on these estimates of useful biomass productivity, the various land requirements involved in meeting domestic wood fuel and grazing can be examined. First the resources available from the village farmland will be summarized. Non-cropped farm land amounts to 35 percent of total farm land)after netting out 2 percent for household structures). Therefore, about 1,025 rai or 164 hectares of land is available for some animal grazing with a potential yield of about 164 tons of feed annually; this amount appears to be adequate to meet the feed requirements not met by rice straw and bran. On the household level, based on this possible off-take of feed from non-cropped land, the medium and large

farms are able to supply themselves with sufficient feed for their livestock from their residues and their non-cropped land.

With regard to wood fuel, annual domestic demand in the Northeast, according to the FAO study, is 1.35 m^3 per person; therefore, the total model village demand is 914 m^3 annually. If the annual yield from farmland is 0.3 m^3 per hectare, this source would contribute 141 m^3 or about 15 percent of the total demand. The remaining 773 m^3 must be met by either forested public land or imported wood fuel. If this amount were supplied by the annual increment of the forests, about 770 hectares of forest would be needed -- an area equal to about 1.65 times the area of the village. For the Northeast, forest land area in 1970 was about 85 percent of the farmland, and since forest land has been decreasing, this ratio (1.65) of accessible forest to farmland is only rarely available. The remaining options for wood fuel supply are imports or deforestation. If total forest clearing were practiced, about 18 hectares of Northeast forest land would be deforested annually to meet village level requirements.

Figure IV-2 is a flowchart outlining the major resource flows within the village. The quantities indicated are all based on Tables IV-4 through IV-8 and the accompanying text. The circles in the figure represent opportunities for the introduction of village-level energy technologies. Technology A could be improved charcoal production, improved stoves, a micro-hydropower project or a village woodlot. Technology B could

FIGURE IV-2. VILLAGE ENERGY-RELATED RESOURCE FLOWS: NORTHEAST THAILAND



be biogas, or pyrolysis, or gassification (or even composting). Technology C could be solar pumping or solar drying. Because of the diverse but interdependent use pattern of different resources, the introduction of an energy technology will alter a multitude of resource flows.

The Benefits and Water Requirements of Irrigation

In this village, agricultural production is clearly the primary sector; however, in recent years this sector has exhibited some stagnation. Unit productivity or yields have remained relatively constant and in some cases have decreased. The growth in agricultural output is mainly due to the expansion of the land farmed, which in turn, along with wood fuel demand, has contributed to deforestation as well as to use of land marginally suited to agriculture. In order to increase yields, a large increase of the inputs to agriculture has been attempted: high yielding varieties, mechanization, fertilization, irrigation, pesticides. Most of these inputs reflect or require the use of greater amounts of energy.

Irrigation can increase yields of agricultural production when applied separately as well as in conjunction with other new inputs.*

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*All indications are that, at least for a significant proportion of the developing workd, pumping of water for domestic and irrigation supplies will be of paramount concern during the next ten to fifteen years. In an excellent paper on small farmers and landless in South Asia, Singh ('79) argues that the most critical input into the agricultural system in South Asia is irrigation water. He presents data from India which show that despite the dismally low average fertilizer applications, the fertilizer use on the irrigated areas is more than twice as much as on the non-irrigated areas. This implies that the binding constraint is irrigated area, not the farmers' technical know-how or fertilizer use.

Irrigation can be achieved in many ways and scales, ranging from large reservoir and irrigation canal systems supplying a large area, to a single pump for a farmer. Irrigation from pumping has significant advantages over other methods involving reservoir or tanks in that it doesn't require dam construction, land acquisition, extensive canal systems, or the establishment of a complex organizational structure. Furthermore, it can be scaled to most levels -- household, village, etc. However, pumping

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(*cont.)

Singh focuses upon the small farmers and claims that the majority of the world's poor are among the 625 million people who live in the rural area of Bangladesh, India, and Pakistan. He shows that in 1977 more than 52 million households in these three countries fell into the category of small owner and tenant cultivators with operational holdings less than 5 acres (≅2 hectares). This implies a population of more than 250 million people living on marginal holdings. If we assume that all the Bangladesh and Pakistani households and 50 percent of the Indian households have a need for irrigation and have available shallow groundwater or nearby streams, then we arrive at a staggering 30 million households in the market for low-cost irrigation water pumps. In Indonesia the island of Java is home for 100 million people. The average farm size is only about 1/2 hectare. Because of land scarcity double cropping and use of high yielding varieties are widespread. The percentage of farm land which is irrigated is well over 50%. In the rest of Asia, Africa, and Latin America, there is probably a demand for a further 10 million water-supplying devices of the same size, then a potential market of 40 million small irrigation pumping systems exists.

has several drawbacks, which are only recently being overcome. These problems are concerned with the issues of high maintenance and operating costs, dependence on fossil fuels (whose costs are rising and whose availability is uncertain) and minimum economies of scale, which are beyond the reach of many.

The benefits of irrigation in Northeast Thailand were estimated in a study by the Asian Institute of Technology (AIT) for the National Economic and Social Development Board. From this work comes a possible irrigation scheme involving pumping for both growing a dry season crop and supplementing wet season rainfall. The benefit of this setup was estimated to be about $200 for each hectare.[1] For this analysis it was assumed that the per-hectare benefits are constant for all farm sizes.

In analyzing the irrigation potential of an area, a variety of economic, social and physical aspects must be considered. In addition to the resource endowments and demographic and socio-economic data, information is needed that is more detailed and site specific, such as the degree of land holding fragmentation and the local topography. These issues would affect the feasibility and cost of irrigating with a farmer's fields from a single tubewell. In this sample analysis it was assumed that a farmer's land formed one contiguous parcel and that the topography of the land did not require or involve a significant investment in a

1. Asian Institute of Technology, Water for the Northeast: A Strategy for Development of Small Scale Water Resources, prepared for the National Economic and Social Development Board.

distribution system. An approximation used that is related to this latter issue is the efficiency of pumping and delivery, which is a function of the distribution setup and its losses. In this analysis, the field irrigation efficiency assumed is 60 percent (i.e., 60 percent of the quantity of water pumped is available to the plants in the field).

Another set of considerations is the site-specific hydrological conditions such as the depth of water table, the size of the aquifer, and recharge rates. These factors affect the depth and therefore the cost of the well and the feasibility of widespread pumping. In this analysis, groundwater was considered to be available at such depths that the dynamic head of 25 feet could be used in calculating pumping capacities. As to the size of the aquifer and recharge rates, it was assumed that these factors were not constraints. In any actual analysis, these factors should be considered to account for any drawdown of the water table as a consequence of irrigation and to assist in the design of the well.

The two major technical components of the demand for irrigation water are the quantity and seasonality of the water needed by the crops. According to the AIT study under the scenario used in this analysis, the water needs are 12,500 m^3 for each hectare annually. The seasonality of this need was defined by two peak periods and then a flat demand over the rest of the growing period. The number of pumping days annually was taken to be 250. The water demands were as follows for one hectare:

1. peak period: 200 mm over a 20-day period (100 m^3/day)
2. secondary peak period: 150 mm over a 20-day period (75 m^3/day)
3. rest of year: 900 mm over a 210-day period (43 m^3/day)

Based on this irrigation demand and the farm size, the minimum size or power of the pump required can be calculated. For some technologies an assumption has to be made concerning the maximum daily operation of the pump, which in turn affects the total amount of work which can be performed in a day. There are both technical and social aspects to this issue, such as recharge rates and work schedules. In the analysis the maximum was assumed to be 10 hours per day. As will be seen, because of the limited selection of commercially available engines, the choice of size is almost insensitive to this issue. For other technologies -- solar or wind -- this issue is different, since the total amount of daily work is a function of the weather and climate.

It is important to note that the basic parameters defining the benefits and requirements of irrigation in the Northeast are less attractive or more severe than those commonly used in this type of analysis. Often the benefits are considered or assumed to be significantly higher: $250 rather than $200 for each irrigated hectare. Furthermore only 10,000 m^3 of water is required as opposed to the 12,500 m^3 required in this example. These differences make this analysis of the overall attractiveness of irrigation much more stringent than is found elsewhere.

With this information, the pumping power required to irrigate one hectare can be calculated:

$$\frac{(62.4\ \text{lb/ft}^3\ \text{water})(25\ \text{ft})(35.3\ \text{ft}^3/\text{m}^3)}{(0.6\ \text{fe})(550\ \frac{\text{ft-lb/sec}}{\text{hphr}})} \times \frac{(100\ \text{m}^3\ \text{pwr/d})}{10\ \text{h/d max oper}} = 0.46\ \text{HP/ha}$$

Note: fe is field efficiency; pwr is peak water requirement; max oper is maximum operation.

during the peak period when 100 m^3 must be pumped in at most a 10-hour day. The three farm sizes or classes of farms being examined and their peak pumping requirements are as follows:

	Cultivated Land	Peak pumping Requirement
Small	1.05 ha	0.5 HP
Medium	2.64 ha	1.2 HP
Large	6.00 ha	2.8 HP

Identification of Irrigation Options

Given this irrigation demand, the next steps are to determine and then evaluate the feasible resources and technologies for supplying the needed pumping energy. The feasibility is based on the availability of the energy resource (fuel) and the technology of utilization. The evaluation involves estimating the capital and operating costs of the different pairings of fuel and technology.

Irrigation by pumping can be fueled by a wide variety of energy sources: human; animal; solar (photovoltaic); wind; gaseous, liquid and solid fuels; and electricity. Defining the potential technologies for use in this Thai village requires examination of the resource availabilities. In the case at hand, human and animal energy would be inadequate. Given the demand for these energies in other aspects of farming and rural life and the depth and amount of water involved, these sources would be insufficient. Under different resource conditions, these options might require consideration. Solar energy such as photovoltaics would be feasible; however, the cost of the technology is presently quite high. In addition, assessment of this possibility would also need some site specific solar insulation data. However, using representative figures, the approximate cost per peak watt of photovoltaics that would make it attractive is about $1-2. Another form of solar energy, hydropower, is rarely available in most of the Northeast and therefore was not considered.

Wind energy is another possible source that is very strongly site specific. There are portions of Northeast Thailand with significant wind velocities. However, for this example wind energy has not been considered.

As to gaseous fuels, whereas there is no natural gas available in Northeast Thailand, there is the potential to generate low BTU methane and synthesis gas via, in the former case, biogas or, in the latter,

gassification. The animal populations of this part of Thailand are large enough to consider the widespread use of biogas. As for synthesis gas from pyrolysis of cellulose, the raw materials are available though their relative scarcity is increasing.

With regard to liquid fuels, petroleum products such as diesel fuel are transported into this region (there are no local oil deposits), although their reliability and increasing cost are problems. Alcohol fuels are not very feasible because of a lack of available sugar feedstocks. There is the possibility of growing a crop for alcohol production whose use in turn would lead to a sufficiently greater overall crop production.[1] However, reliable cost and performance data of small-scale alcohol production are not available and as a result this possibility was not considered. Alcohol production is also hampered by the lack of a relatively simple process by which cellulose, a much more available commodity, could be used as a feedstock.

The only solid fuels available in this area are cellulosic: wood and crop residues. As was described above, these resources are scarce. Wood, once a plentiful fuel from forests, has become increasingly more difficult to obtain. Agricultural residues, depending on the second crop planted, are often in high demand as animal feed. The availability of these residues is strongly influenced by the existence and productivity of pastureland, which reduces the feed demand for residue. No fossil fuel (coal, peat, lignite) deposits are located nearby. Lignite is mined in Thailand, but the reserves are not very large.

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[1] Although casava (mandioca) could also be considered as feed for fuel alcohol, it has not been included on account of lack of adequate experience in this technology of producing alcohol from casava.

The last possible energy source is electricity, which is not often available in rural Thailand unless it is locally generated. In this analysis it is assumed that the village is not connected to the grid nor does it have a generator.

In summary, feasible energy sources are biogas, pyrolysis gas, and diesel fuel.

Although this discussion focuses primarily on the availability of different energy sources, these sources are obviously intertwined with the technologies of utilization (e.g., pumping) and transformation (i.e., pyrolysis, biogas), resulting in a fuel being available even though the utilizing technology may be presently impractical. An example of this is the steam engine. This engine could allow farmers to take advantage of a range of solid fuels which otherwise would have to be converted into a liquid or gas. However, at the present time there is not much information available on a well-tested practical application of this technology at scale required; therefore, this possibility is not considered.

On the basis of the source and technologies assessment, the following irrigation options will be examined:

1. diesel engine and pump run on only diesel fuel;
2. dual-fuel (diesel) engine and pump run on either diesel fuel or biogas;
3. gas engine and pump run on pyrolysis gas;
4. free piston Stirling engine using crop residues in a furnace.

All of these options require the construction of a tubewell. These

1. Intermediate Technology Development Group (ITDG), London has conducted a study on the demand for steam engines (5-50 hp units) in developing countries under the direction of Drummond Hislop. Professor Graham Rice at the University of Reading, U.K. is currently involved in an irrigation pump study, sponsored by the United Nations Development Program (UNDP) and undertaken jointly by Halcrow Engineering and ITDG.

options need to be designed to fit the needs and resources of the different farm classes.

As to the first option, for each farm size the smallest diesel pump that meets the peak power demand will be used. Unfortunately, given the limited availability of small horsepower engines, both the small and medium farmers are forced to purchase a 2 hp engine -- much larger than needed.[1] For the large farm this problem does not arise, and a 3 hp engine is considered.

The second option involves supplementing the diesel option with a biogas plant. Because a dual-fuel engine can be run on a variable mix of diesel and biogas (with a maximum of 2/3 biogas[2]), there is some flexibility in the selection of the size of biogas plant.

Plant size selection is a function of animal holdings and the trade-offs between incremental capital cost of larger plants and the resulting diesel fuel savings. Since the demand for biogas for pumping is not constant over time, constructing a plant to meet the peak demand will result in a large gas surplus over much of the year. It is important, therefore, to analyze a range of biogas plant sizes if the livestock holdings permit. For the small farm, a plant with a daily gas production of 40 ft^3, the smallest plant considered in this analysis, requires

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1. The peak power requirements for small and medium farms are 0.5 and 1.2 hp respectively.

2. Technically it is possible to run on a higher biogas mixture but present results have been able to attain only a 2/3 maximum mix over the long term.

as is discussed below, the equivalent of at least 1.7 large animals, which is larger than average for this group.[1] Therefore this plant is possible only if a farmer has two large animals or the equivalent manure available through either other small animal holdings, buying manure or cooperation among several small farmers. For the medium-size farm with about 3 large animals, 40 and 60 ft^3/d plants are feasible. For the large farms, the 4.5 large animals and 1 pig can support a plant size up to nearly 120 ft^3/d. However with some sort of manure market (either outright selling and buying or exchanging manure for digester slurry), these size limitations could possibly be exceeded if found to be sufficiency attractive.

The third option involves using a small gassifier to run the diesel pump. Based on conversations with people who have experience with large gassifiers, the impression is that the gassifier for 2 and 3 hp engines are quite feasible and would not be significantly different. Despite the uncertainty around this option, it was assumed that the same gassifier would be able to meet all the fuel needs of the gas engine for all three farm sizes. The availability of residues for gassification is a complex and site-specific issue. In the representative village the availability of residues is dependent on the specific cropping pattern and therefore can vary considerably. Furthermore, this availability is significantly affected by the nature of the dry season crop. From this perspective, the choice of a second crop or even rice variety is not only a function of the grain or crop yield and value but also of the residue yield and energy value. As will be shown below, the residue yield from the additional production due to irrigation does not have to be very large in order to supply sufficient residues for running the gassifier. This conclusion holds true for all farm classes.

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1. It is important to recall that the animal holdings per farm type were developed solely by assuming (due to lack of actual data) that larger farm sizes own more animals. For biogas analysis it is important to collect accurate detailed data on livestock holdings as well as information on livestock managment practices to assess collectability of manure.

The fourth option is the use of agricultural residues to run a Free Piston Stirling Engine (FPSE). The advantages of including Stirling engine in the analysis are: (i) Small scale Stirling engines of capacities equal to 0.3 KW (0.40 hp) to about 1 KW are likely to be available, which means that scale-disadvantage of small farmers can be overcome, (ii) The Stirling engine is an external combustion air engine, can be run on a variety of fuels and has a minimum of moving parts. These advantages are crucial in view of difficulties of repairs and maintenance and uncertainties of fuel availability in developing countries.

In the analysis of the irrigation system discussed earlier, the Stirling engine is to be considered in place of a diesel (or dual-fuel) engine, while a furnace is to be considered in place of a gasifier or a biogas unit. The rest of the irrigation system including tubewell, pumpset, etc. remains the same.

Estimation of the Cost of Feasible Irrigation Options

Estimation of the cost of these different options requires the the capital and the operating costs for each technology.

Capital Costs

The capital costs of the technologies assessed were based on rather limited cost data from Thailand and other relevant countries, in particular India. The tubewell is integral to irrigation schemes. The costs used are based on a 100-foot depth of tubewell[1] and were estimated for both steel and bamboo. These figures were based on an Indian study.[2] The bamboo tubewell has limited applicability in Northeast Thailand because there are areas where bamboo is not readily available and where soil type makes it infeasible. The tubewell costs are presented in Table 5. Local labor was shadow priced at 25 percent of its market value, whereas all metal components were assumed to have a foreign exchange component of 100 percent. The lifetime of the steel tubewell is 10 years; for the bamboo, 5 years. No maintenance costs were considered.

The smallest diesel pumps were examined, and it appeared that the only commercially available sizes were 2 hp or larger. No smaller pumps were considered to be available, and if they were, their cost would not be significantly less. For diesel and matching pumpsets, the costs used are presented in Table IV-9. The social costs are based on groundwater

1. Again, the depth is a site-specific factor based on groundwater and aquifer hydrology and soil type.

2. Project report on "Supplementary Minor Irrigation Scheme for Purnia, Saharsa and Katihar," Government of Bihar, 1977, as quoted in Bhatia (1979).

TABLE IV-9. CAPITAL COST DATA (U.S. DOLLARS)

Equipment	Market Price	Social Cost: At 25% Foreign Exchange Premium	Social Cost: At 50% Foreign Exchange Premium
Tubewell			
steel	510	440	510
bamboo	160	100	100
Diesel engines and pumps			
2 HP	400	480	560
3 HP	510	610	710
Thai biogas plants (daily gas production)			
40 ft^3/1.2 m^3	160	160	190
60 ft^3/1.7 m^3	200	200	240
120 ft^3/3.4 m^3	375	375	445
150 ft^3/4.25 m^3	420	420	500
Chinese Janata biogas plant			
40 ft^3 daily gas production	85	85	
Gas Engine (2 HP)	400	480	560
Gasifier	140	165	190
Stirling Engine and Pump			
0.5 KW	225	270	315
1.0 KW	450	540	630
2.25 KW	1,125	1,350	1,575
Furnace	100	120	140

indirect foreign exchange component of 80 percent. These costs were developed from various estimates and checked for consistency using the "six-tenths" rule.* It was assumed that these pumps have a lifetime of 10 years or 10,000 hours. The annual maintenance cost was assumed to be $110 annually. This cost is very approximate since an important aspect of this issue is the availability of maintenance, a factor which is hard to quantify. Because of the lack of detailed information on maintenance costs, this simple approach was taken as opposed to others that might include a cost per operating hour. The fuel consumption of these pumps was taken to be 0.25 liters of diesel fuel per horsepower-hour. Again, this figure is an approximation that matches the various figures found in other work. It assumed an engine efficiency of about 28 percent. The capital costs of dual fuel engines, which are able to run on diesel and biogas, and of gas engines which run on pyrolysis gas are the same as for diesel engines.

The costs for the biogas plants were based on a review of costs found in Thailand in reports and through personal communications and of costs found in India.[2] The designs and costs of biogas plants in these countries seem relatively similar. The costs used are presented in Table 5. The social costs are based on a foreign exchange component of 75 percent. The remaining 25 percent of the costs is local labor and was shadow priced at 25 percent of its cost. The daily gas production

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[1] $\left(\frac{\text{Size A}}{\text{Size B}}\right)^{.6} = \frac{\text{Cost A}}{\text{Cost B}}$

[2] The primary source for Indian costs is Ramesh Bhatia, "Energy Alternatives for Irrigation Pumping: Some Results for Small Farms in North Bihar."

was assumed to be an average value for the entire year. Since mean temperatures in this region are fairly constant, gas production will not vary significantly. However, in some areas it is important to take into account seasonal temperatures and their consequent effects on gas production and the ability of biogas to meet seasonal energy demands. Maintenance costs were assumed to be $7 annually for the two smaller plants and $10 annually for the two larger plants.

In the analysis below, the case of using an alternative biogas design with significantly lower capital costs was examined. These costs were based on the Chinese-type "Janata" design.[1] This alternative was explored for the small farm situation becuase of the relatively high capital costs the farmer faces for the engine and pump. The cost for a 40 ft^3/d plant of this type is also presented in Table 5. The maintenance costs were assumed to be $7 annually.

The feasibility of biogas plants on the farm level is dependent on the supply of and demand for animal residues. Based on several surveys of the literature, it was assumed that 1.65 kilograms of wet manure (from buffalo, cows, etc.) can produce 1 cubic foot of biogas.[2] Assuming the average large animal excretes 14 kg. of wet manure daily (about 5,000 kg. annually), the animal manure required for running a biogas plant (assuming 100 percent collectability) are:

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1. The costs for 100, 150, and 200 ft^3/d plants were also presented in Bhatia's report and were scaled down for a 40 ft^3/d plant.

2. This figure was presented in ESCAP Biogas Newsletter (August 1978) and is an average of summer gas production rates in Bhatia and Niamir (1979).

biogas plant (daily gas production)	required daily wet manure input	number of large animals required
40 ft^3/d	24 kg.	1.7
60	36	2.6
120	73	5.2
150	91	6.5

Since the gas production per unit of pig manure is about twice as much as from cattle/buffalo, and pigs produce about one-fourth the manure daily, one pig is equivalent to one-half large animal for biogas potential estimations. Based on these results and the average animal resources for different farm classes, as noted above, there are significant limitations on the size of plant which can be operated. Furthermore, the required animals assume 100 percent collectability of manure. This constraint can be lessened if manure is purchased.[1]

With minor engine adjustments, biogas can be used to fuel dual-fuel engines, but only as part of a mixture of two-thirds biogas and one-third diesel. Higher gas mixtures are possible. The fuel mix used to produce 1 horsepower-hour was 10 cubic feet biogas and 0.08 liter diesel fuel.

The costs of the gasifier are extremely uncertain because of a lack of experimentation and use of this technology with very small engines (under 5-10 HP). Worldwide there has been much successful use of larger engines such as a 100 HP, and it appears that the designs could be adapted for small ones although it is recognized that some redesign will be necessary. It was assumed that the small engines considered in this

1. The price could be as little as the collection cost if manure is used as fertilizer because the corresponding digestor slurry could be returned, thereby returning the fertilizer value.

analysis could be powered by a gassifier which would cost about $100 in materials and an additional $40 of skilled labor. The foreign exchange component was considered to be equal to the total materials cost or 70 percent of total cost. Being skilled, the labor was not shadow priced. The capital costs are presented in Table 5. The lifetime was assumed to be 10 years and annual maintenance costs to be $10. Representative efficiencies were assumed to be: 1) a conversion efficiency of agricultural residues to gas of 60 percent; and 2) an engine efficiency of 15 to 20 percent. This second efficiency takes into account the downrating effect pyrolysis gas has on engine horsepower. For diesel engines this effect could be about 10 percent. Based on these efficiencies, about 2 kg. of agricultural residues could provide 1 horsepower-hour.[1]

The Stirling engine, especially the Free Piston Stirling Engine, is currently in the experimental stage and indications are that these engines will soon be commercially produced. Table IV-9 presents the best available estimates of capital and annual costs of Stirling engines of different sizes. The average costs are of the order of $450 per KW as compared with approximately $270 per KW in the case of a diesel (or dual-fuel) engine. However, since smaller units of 0.5 KW capacity Stirling engines are available, the capital cost for the small farmer is lower ($225) in the case of a Stirling engine than in the case of a 2 hp diesel engine ($400). This makes Stirling engine relatively attractive for small farmers, a conclusion supported by the results of calculations. The capital costs of a furnace are assumed independent of the engine capacity and are taken at $100 per unit.

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[1] Given that 1 hp-hr = 2.69×10^6 Joules and that 1 Kg. of agricultural residues can potentially produce 13×10^6 Joules:

$$\frac{2.69 \times 10^6 \text{ J/hp-hr}}{(13 \times 10^6 \text{ J/Kg. residue})(0.6)(0.175)} = 2 \text{ Kg. residue per hp-hr}$$

Operating Costs

Since fuel costs are the only variable operating cost in this example, an important input is the unit fuel costs. The fuels involved are diesel fuel, manure, and agricultural residues. For diesel fuel a simplified approach was taken because of the tremendous uncertainty of forecasting petroleum prices even over a ten-year period. The current price of diesel fuel at the Persian Gulf was taken to be $0.25 per liter, a figure based on $25 per barrel of oil. It was assumed that transportation and distribution would bring the price in Northeast Thailand to $.30 per liter presently. Then by assuming a 5 percent annual increase in the real cost of petroleum products over the next ten years (a 65 percent increase over the decade), the average price of diesel over this ten-year period was estimated to be $0.40 per liter* in present dollars. This price represents the social cost of diesel fuel and is used in the economic analysis.

Unfortunately, the future policy concerning diesel prices is not clear; while there is growing alarm over the oil import bill and the cost of subsidies, oil prices were recently reduced. As a result, the diesel fuel cost used for the financial analysis was also the average price of $0.4/liter. In the economic analysis when using different shadow prices for foreign exchange, the foreign exchange component of diesel fuel was taken to be 100%.

The cost for manure can be a complicated issue because of its value as fuel fertilizer or input to composting. The fertilizer value is usually higher but is very uncertain because the nutrient value is very sensitive to handling procedures. Presently in Northeast Thailand, dung is used to varying degrees as a fertilizer directly, and there does not appear to be any market for it. This valuation problem was handled by equating the fertilizer value of the dung to that of the digester slurry. Therefore no cost is assigned to the dung, and on the benefit side, no

credit is given for the removed digester slurry. In areas where dung use is more extensive, a more detailed approach could be used; but it is important to note that the procedure does attribute a cost or value to manure.

The cost of agricultural residues was considered to be zero because of their apparent underutilization in Thailand presently. The representative village shows them being used for animal feed yet the extent of this activity in reality is unknown. Survey work is necessary to determine the degree of residue utilization. If the residues are or did become fully utilized, for feed because of pastureland limitations, or for the extensive use of gassifiers, then the residue would be valued on its primary or its marginal use.[1]

The operating costs were estimated by simulating the operation of each technology. Estimating the fuel usage for the first option of using only diesel fuel involved calculating the capacity of the pump selected for each farm size and then, given the pumping requirement, determining the number of operating hours necessary. Then, on the basis of the fuel consumption of 0.25 liters/horsepower and the engine size, the hourly fuel use and the annual fuel use were calculated. The fuel use for this option can be calculated without consideration of the seasonality or daily amounts of water required because the fuel is in theory always available without any seasonal or daily limits.

Estimating the fuel use for the biogas options is more complicated because of the daily limit on gas production and therefore consumption.

1. Please see the discussion on opportunity costs at the beginning of this section.

Simulating the operating costs involved calculating the minimum daily horsepower-hour requirements for each of the three irrigation periods (the primary and secondary peaks and the remainder of the pumping year). The biogas was assumed to meet these requirements up to either the capacity of the plant or two-thirds of the total requirement.* Diesel fuel consumption was determined by the energy demand not met by biogas. The pumping period is 250 days; the biogas was assumed to be available at capacity for this period. In the sensitivity analysis presented below, reliabilities of less than 100 percent are examined.

Biogas, in other words, is the baseline fuel which, depending on the plant size and farm size, supplies a significant portion of the fuel needed during most of the pumping season. However, during peak periods it often becomes necessary to use a great deal of additional diesel fuel because of the daily limit on gas production. For a given farm size as larger biogas plants are considered, the point is reached when the additional gas production is only used for irrigation during the peak periods. As will be seen in the results below, the increased cost of a larger biogas is not matched by fuel costs foregone during the relatively limited peak periods.

Calculating the fuel costs for the third or fourth options of using a gassifier or a Stirling engine are simplified by the assumption that agricultural residue costs are zero. Therefore, these options have no fuel costs except when limited reliability is considered in the sensitivity analysis below. Maintenance costs for the Stirling engine

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*It is important to point out a simplifying assumption that biogas production was assumed to be constant throughout the year. The benefits of biogas can be more or less depending on the degree of conincidence between the peak gas production and peak pumping requirement seasons.

are estimated at $5 per year for the furnace and $50 per year for the engine for the range of 0.5 to 2.5 KW. The furnace efficiency is assumed as 60 percent, the engine efficiency as 30 percent and the pump efficiency at 80 percent. This gives an overall efficiency of approximately 15 percent.

The present value costs for the different irrigation options are shown in Tables IV-10-12. For each farm class, there are the basic costs of the diesel engine, the pump, engine and pump maintenance, and the tubewell. To these basic costs are added the fuel costs and additional capital costs for either the biogas plant or the gassifier, depending on the option.

Table IV-12 shows an additional capital cost for the large farm for a second diesel engine and pump. The lifetime of these pumps was 10 years or 10,000 hours. On a large farm, the annual operating hours are 1,160; therefore, after about 8 years a replacement pump will be needed. Since the analysis pertains to a ten-year period, the additional capital costs for a new pump for years 9 and 10 are one-fourth the cost of a new one present valued as a cost occurring at the beginning of year 9. The annual operating hours of pumps on small and medium farms are 305 and 770 respectively.

Results

As mentioned earlier, the analysis is based on benefit cost ratios.[1] The benefits from irrigation are reported to be $200 per hectare. Table IV-13 presents the present value of the benefits for the farm classes under varying costs of social rates of discount and values of shadow price of foreign exchange.

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[1] The discussion on different decision criteria has been presented earlier in Section II.

TABLE IV-10. PRESENT VALUE OF TOTAL COSTS OF IRRIGATION SCHEMES ON SMALL FARMS (10-YR. PERIOD. U.S. DOLLARS)

	Market Prices			Social Costs		
				Foreign Exchange Premium of 25%		
	5%	10%	15%	10%	15%	20%
Basic Costs						
2 HP engine, pump	400	400	400	480	480	480
maintenance ($110/yr)	850	670	550	670	550	460
tubewell (steel/bamboo)	510/290	510/260	510/250	440/160	440/150	440/140
Subtotal with steel tubewell	1760	1580	1460	1590	1470	1380
with bamboo tubewell	1540	1330	1200	1310	1180	1080
(A) 2 HP pump with diesel only						
fuel (152 liters/yr)	470	370	310	470	380	320
TOTAL COST: steel tubewell	2230	1950	1770	2060	1850	1700
(B) 2 HP with 40 ft^3/d Thai biogas plant (59% utilization for irrigation during pumping season)						
biogas plant & maintenance	210	200	200	200	200	190
diesel fuel (54 liters/yr)	170	130	110	170	140	110
TOTAL COST: steel tubewell	2140	1910	1770	1960	1810	1680
(C) 2 HP with 40 ft^3/d Janata (Chinese type) biogas plant (59% utilization for irrigation during pumping season)						
biogas plant & maintenance	140	130	120	130	120	110
TOTAL COST: steel	2070	1840	1690	1890	1720	1600

TABLE IV-10 (CONTINUED)

	Market Prices			Social Costs		
				Foreign Exchange Premium of 25%		
	5%	10%	15%	10%	15%	20%
(D) 2 HP with hypothetical gasifier						
gasifier & maintenance	220	200	190	230	220	210
TOTAL COST: steel	1980	1780	1650	1820	1690	1590
(E) 2 HP diesel only with selling water to another small farm						
TOTAL COST: steel	2700	2320	2080	2530	2230	2020
(F) 2 HP with 40 ft^3/d Thai biogas plant -- selling water to another small farm (100% utilization for irrigation during pumping season)						
additional diesel fuel (85 l/yr)	260	210	170	250	210	180
TOTAL COST: steel/bamboo	2400/2180	2120/1870	1940/1680	2220/1940	2020/1730	1860/1560

TABLE IV-11. PRESENT VALUE COST OF IRRIGATION SCHEMES ON MEDIUM-SIZED FARMS*

	Market Prices			Social Costs Foreign Exchange Premium of 25%		
	5%	10%	15%	10%	15%	20%
Basic Costs						
2 HP engine, pump, maintenance, steel tubewell	1760	1580	1460	1590	1470	1380
2 HP engine, pump, maintenance, bamboo tubewell	1540	1330	1200	1310	1180	1080
(A) 2 HP pump with diesel only diesel fuel (383 liters/yr)	1180	940	770	1170	960	800
TOTAL COSTS: Steel tubewell	2940	2520	2230	2760	2430	2180
(B) 2 HP with 40 ft^3/d Thai biogas plant (100% utilization for irrigation during pumping season)						
biogas plant and maintenance	210	200	200	200	200	190
diesel fuel (216 liters/yr)	660	530	430	660	540	450
TOTAL COSTS: Steel tubewell	2630	2310	2090	2450	2210	2010
(C) 2 HP with 60 ft^3/d Thai biogas plant (89% utilization for irrigation during pumping season)						
biogas plant and maintenance	250	240	240	240	240	230
diesel fuel (159 liters/yr)	490	390	320	490	400	330
TOTAL COSTS: Steel tubewell	2500	2210	2020	2320	2110	1940

*10-year period, U.S. dollars.

TABLE IV-11. (CONTINUED)

	Market Prices			Social Costs Foreign Exchange Premium of 25%		
	5%	10%	15%	10%	15%	20%
(D) 2 HP with 120 ft^3/d Thai biogas plant (51% utilization for irrigation during pumping season)						
biogas plant and maintenance	450	440	430	440	430	420
diesel fuel (128 liters/yr)	390	310	260	390	320	270
TOTAL COSTS: Steel tubewell	2600	2330	2150	2420	2220	2070
(E) 2 HP with hypothetical gasifier						
gasifier and maintenance	220	200	190	230	220	210
TOTAL COSTS: Steel tubewell	1980	1780	1650	1820	1690	1590

(USD, U.S. DOLLARS)

	Market Prices			Social Costs Foreign Exchange Premium of 25%		
	5%	10%	15%	10%	15%	20%
Basic Costs						
3 HP engine, pump (8 yr life)	510	510	510	610	610	610
replacement P.V. cost (yr 9 & 10)	80	60	40	70	50	40
maintenance ($110/yr)	850	670	550	670	550	460
tubewell: steel	510	510	510	440	440	440
SUBTOTAL: with steel tubewell	1950	1750	1610	1790	1650	1550
(A) 3 HP with diesel only						
diesel fuel (869 liters/yr)	2670	2130	1750	2670	2180	1820
TOTAL COSTS: Steel tubewell	4620	3880	3360	4460	3830	3370
(B) 3 HP with 60 ft^3/d Thai biogas plant (100% utilization for irrigation during pumping season)						
biogas plant and maintenance	250	240	240	240	240	230
diesel fuel (619 liters/yr)	1900	1520	1240	1900	1560	1290
TOTAL COSTS: Steel tubewell	4100	3510	3090	3930	3450	3070
(C) 3 HP with 120 ft^3/d Thai biogas plant (99% utilization for irrigation during pumping season)						
biogas plant and maintenance	450	440	430	440	430	420
diesel fuel (372 liters/yr)	1140	910	750	1140	930	780
TOTAL COSTS: Steel tubewell	3540	3100	2790	3370	3010	2750
(D) 3 HP with 150 ft^3/d Thai biogas plant (83% utilization for irrigation during pumping season)						
biogas plant and maintenance	500	480	470	480	470	460
diesel fuel (352 liters/yr)	1080	860	710	1080	880	740
TOTAL COSTS: Steel tubewell	3530	3090	2790	3350	3000	2750

TABLE IV-13. PRESENT VALUE OF IRRIGATION BENEFITS* (10-YEAR PERIOD, U.S. DOLLARS)

Farm Class	Cultivated Land	Market Prices			Social Costs**							
					Foreign Exchange Premium of 25%				Foreign Exchange Premium of 50%			
		5%	10%	15%	10%	12%	15%	20%	10%	12%	15%	20%
small	1.05 ha.	1620	1290	1060	1610	1480	1320	1100	1930	1780	1580	1320
medium	2.64 ha.	4080	3250	2660	4060	3740	3330	2770	4850	4490	3790	3330
large	6.00 ha.	9230	7360	6030	9200	8470	7540	6280	11,000	10,170	9050	7530

*Annual benefits are $200 per hectare.

**Assuming the foreign exchange component of 100%.

Using the information on Tables IV-10-13, the cost-benefit ratios presented in Table IV-14 were calculated. The ratios assumed 100 percent availability or reliability of the technical options and include only the benefits from irrigation. As can be seen, all irrigation options are attractive for the medium and large farms, with the gassifier being more attractive than biogas, which in turn is more attractive than diesel only. The small farm results show a much different picture in that none of the first four options appears attractive. These results reflect the high cost of a 2 hp pump, which is significantly oversized for the small farms' needs of only a minimum of 0.5 hp. The significantly higher ratios for large farms over medium farms reflect the higher pump utilization on the large farm, since the medium farm was also forced to use and oversized pump (2 hp versus a need of 1.2 hp). The capital costs faced by the large farm also benefit from some economies of scale.

The results show decreasing ratios as the discount rate increases, reflecting the increasing cost of capital required for all of these options. The ratios for the economic analysis (social costs) are higher than those for the financial analysis (market prices) due to the higher foreign exchange component of the benefits side (100 percent) as compared to the items on the cost side (ranging from 0 to 100 percent).

The gassifier is understandably the most attractive since its costs are relatively low and no cost for its fuel was used. It eliminates the need for any diesel use if it is sufficiently reliable, a point

TABLE IV-14. BENEFIT-COST RATIOS FOR IRRIGATION SCHEMES

	Utilization Rate During Pumping Season	Market Prices			Social Costs		
					Foreign Exchange Premium of 25%		
		5%	10%	15%	10%	15%	20%
I. Small Farm							
A. 2 HP diesel only		0.73	0.66	0.60	0.78	0.71	0.65
B. 2 HP + 40 ft^3/d Thai biogas	59%	0.75	0.68	0.60	0.82	0.73	0.65
C. 2 HP + 40 ft^3/d Chinese biogas	59%	0.78	0.70	0.63	0.85	0.77	0.69
D. 2 HP + hypothetical gasifier		0.81	0.72	0.64	0.88	0.78	0.69
E. 2 HP + selling water (13160 m^3/yr)	100%	0.90	0.83	0.76	0.95	0.89	0.82
F. 2 HP + 40 ft^3/d Thai biogas + selling water	100%	1.01	0.91	0.82	1.09	0.98	0.89
G. 2 HP + 40 ft^3/d Thai biogas + selling water + bamboo tubewell	100%	1.11	1.03	0.95	1.24	1.14	1.06
II. Medium Farm							
A. 2 HP diesel only		1.39	1.29	1.19	1.47	1.37	1.27
B. 2 HP + 40 ft^3/d Thai biogas	100%	1.55	1.41	1.27	1.66	1.51	1.38
C. 2 HP + 60 ft^3/d Thai biogas	89%	1.63	1.47	1.32	1.75	1.58	1.43
D. 2 HP + 120 ft^3/d Thai biogas	51%	1.57	1.39	1.24	1.68	1.50	1.34
E. 2 HP + hypothetical gasifier		2.06	1.83	1.61	2.23	1.97	1.74
III. Large Farm							
A. 3 HP diesel only		2.00	1.90	1.79	2.06	1.97	1.86
B. 3 HP + 60 ft^3/d Thai biogas	100%	2.25	2.10	1.95	2.34	2.19	2.05
C. 3 HP + 120 ft^3/d Thai biogas	99%	2.61	2.38	2.16	2.73	2.50	2.28
D. 3 HP + 150 ft^3/d Thai biogas	83%	2.61	2.38	2.16	2.75	2.51	2.28

to be discussed in detail below.

The biogas plants all appear to be attractive; Table IV-15 shows the benefit-cost ratio for biogas plant investment once the engine, pump, and tubewell are already purchased. These investments are even attractive for the small farms that already have the other equipment needed for irrigation. The ratios are higher for the economic analyses because the foreign exchange component of the fuel costs is 100 percent, whereas for the biogas plants it is only 75 percent. Furthermore, in the economic analysis, the unskilled rural labor is shadow priced at one-fourth its market cost. The analyses for medium and large farms show the diminishing returns to biogas after a point. The pumping demand utilizes most or all of the gas produced by the 40 and 60 ft^3/d plants on a medium farm and by the 60 and 120 ft^3/d plants on a large farm. The next larger plants for each farm size only result in small decreases in diesel fuel use, all of which occur during the relatively brief peak periods. In fact, the increased cost of a 120 ft^3/d plant on a medium farm is not recouped by the fuel saving. It should be recognized that if the excess gas can be economically utilized then the largest plants could be justified.

The unattractiveness of irrigation on the small farm is due to the large cost of the oversized 2 hp pump. Even signficantly reducing the cost of the biogas plant (the Chinese Janata design) and of the tubewell (bamboo) is not sufficient to make irrigation attractive under any case in the financial analysis. Only at lower costs of capital and premiums on foreign exchange does irrigation become attractive. The

TABLE IV-15. COMPARISON OF CAPITAL COSTS AND P.V. DIESEL FUEL SAVINGS RESULTING FROM BIOGAS INVESTMENTS FOR IRRIGATION ONLY

		Market Prices						Social Costs					
								Foreign Exchange Premium of 25%					
		5%		10%		15%		10%		15%		20%	
	Utilization Rate During Pumping Season	Diesel Fuel Savings /Biogas Cost	B-C Ratio	Diesel Fuel Savings /Biogas Cost	B-C Ratio	Diesel Fuel Savings /Biogas Cost	B-C Ratio	Diesel Fuel Savings /Biogas Cost	B-C Ratio	Diesel Fuel Savings /Biogas Cost	B-C Ratio	Diesel Fuel Savings /Biogas Cost	B-C Ratio
I. SMALL FARM													
40 ft^3/d Thai biogas plant	59%	300/210	1.4	240/200	1.2	200/200	1.0	300/200	1.5	240/200	1.2	210/190	1.1
40 ft^3/d Chinese biogas plant	59%	300/140	2.1	240/130	1.8	200/120	1.7	300/130	2.3	240/120	2.0	210/110	1.9
II. MEDIUM FARM													
40 ft^3/d Thai biogas	100%	520/210	2.5	410/200	2.0	340/200	1.7	510/200	2.6	420/200	2.1	350/190	1.8
60 ft^3/d Thai biogas	89%	690/250	2.8	550/240	2.3	450/240	1.9	680/240	2.8	560/240	2.3	470/230	2.0
120 ft^3/d Thai biogas	51%	790/450	1.8	630/440	1.4	510/430	1.2	780/440	1.8	640/430	1.5	530/420	1.3
III. LARGE FARM													
60 ft^3/d Thai biogas	100%	770/250	3.1	610/250	2.4	510/240	2.1	770/240	3.2	620/240	2.6	530/230	2.3
120 ft^3/d Thai biogas	99%	1530/450	3.4	1220/440	2.8	1000/430	2.3	1530/440	3.5	1250/430	2.9	1040/420	2.5
150 ft^3/d Thai biogas	83%	1590/500	3.2	1270/430	2.6	1040/470	2.2	1590/480	3.3	1300/470	2.8	1080/460	2.3

underutilization of the small farm's pump leads to consideration for a water market in which irrigation can be supplied for a fee for another farm. The 2 hp pump is actually capable of supplying nearly 4 small farms if always operational. The last two options on Tables IV-10 and IV-13. for a small farm are based on supply of irrigation water for an additional small farm. The fee for such a service could be anywhere between the additional operating cost for the pump owner and the total irrigation benefits for the purchasing small farm, as in Table IV-12. For this example it was assumed that the pump owner charged one-half the total irrigation benefits; therefore, the benefits for the pump owner for the benefit-cost ratios are 50 percent higher. Under these conditions, irrigation becomes marginally attractive at lower costs of capital. These results still reflect the burden of underutilization of the pump, and they indicate the need for research into the cost of smaller engines (1/2 to 2 HP) as to whether they could be produced and marketed at a significantly lower cost than those presently available. These possible diseconomies of scale underline the need for accelerated work in other technologies such as solar and wind in order to alleviate the plight of the small farmer. These technologies appear to be more adaptable without these economies for the small farmer.

Tables IV-16 and IV-17 present the results of cost benefit analysis of irrigation systems which include Stirling engine. It is assumed, as before, that agricultural residues have a zero cost to the society. Since all the energy inputs for the Stirling engine can come from biomass (residues), the fuel costs for the Stirling engine case are zero. However, to provide a better understanding of the system, a (maximum) fuel cost as represented by the cost of diesel oil is also used in alternative calculations. The results bring out the following:

(i) Benefit cost ratios are greater than one (unity) in all cases except when fuel costs equivalent to diesel oil costs are used for small farms;

(ii) Benefit cost ratios are higher as the farm size increases; for example, the B/C ratios range between 2.54 and 4.73 in the case of social costs using a 10 percent social rate of discount.

(iii) A comparison of different systems shows that Stirling engine system consistently dominates both at market prices and at social costs (Table IV-16).

(iv) Even in the case of small farms, the irrigation is profitable only in the case of Stirling engine system. This happens if a small scale Stirling engine can be made available at the estimated cost (Table IV-17).

It should be mentioned that, both with Stirling engines and gasifiers, the strong attractiveness is overshadowed by two considerations: (1) the lack of technical certainty and (2) the availability and value of residues. The implications of both these issues will be discussed in further detail in connection with gasifiers. If adequate quantities of fuelwood are available at the same cost as crop residue, the economics of Stirling engines would remain the same. However, in the case of fuelwood, it may be easier to produce charcoal in a central facility and then use the costlier charcoal as input for a gasification unit or furnace. The economics of these alternatives would be site-specific and hence have not been considered here.

TABLE IV-16. BENEFIT-COST RATIOS FOR IRRIGATION SCHEMES IN STIRLING ENGINE CASE

	Market Prices			Social Costs		
				Foreign Exchange ∿ 25%		
STIRLING ENGINE	5%	10%	15%	10%	15%	20%
I. Small Farm						
zero fuel cost	1.40	1.21	1.10	1.54	1.34	1.17
diesel fuel cost (0.5 KW engine)	0.99	0.90	0.83	1.06	0.97	0.87
II. Medium Farm						
zero fuel cost	2.95	2.51	2.24	3.20	2.75	2.38
diesel fuel cost (1 KW engine)	1.59	1.45	1.36	1.66	1.53	1.41
III. Large Farm						
zero fuel cost	4.48	3.74	3.24	4.73	4.00	3.41
diesel fuel cost (2.25 KW engine)	1.95	1.80	1.67	2.54	1.86	1.71

TABLE IV-17. A COMPARISON OF BENEFIT COST RATIOS UNDER FOUR DIFFERENT SYSTEMS

	Market Price 10%	Social Costs 10%
I. Small Farms		
(a) 2 hp diesel only	0.66	0.78
(b) 2 hp & 40 ft 3/d Thai biogas	0.68	0.82
(c) 2 hp & hypothetical gasifier	0.72	0.88
(d) 0.67 hp hypothetical Stirling engine & furnace	1.21	1.54
II. Medium Farms		
(a) 2 hp diesel only	1.29	1.47
(b) 2 hp diesel & 40 ft 3/d Thai biogas	1.41	1.66
(c) 2 hp & hypothetical gasifier	1.83	2.23
(d) 1.33 hp hypothetical Stirling engine	2.51	3.20
III. Large Farms		
(a) 3 hp diesel only	2.00	2.06
(b) 3 hp & 60 ft 3/d	2.25	2.34
(c)		
(d) 3 hp Stirling engine	3.74	4.73

Sensitivity Analysis

In this section the irrigation options will be examined under alternative assumptions concerning the reliability of their operation or of their operating and capital costs. The approach taken is to calculate the extent to which the reliability or cost can or must be changed in order to remain or become attractive investments; in other words to determine the break-even points.

Option 1: Diesel Only

For the diesel only option, several points can be examined. For the medium and large farms, where this option is attractive, the maximum average fuel costs and the maximum capital costs under which diesel only would break even were calculated. The maximum market fuel costs per liter (as an average price over a 10-year period in present dollars) in U.S. dollars are:

	Market Prices			Social Costs (foreign exchange premium of 25%)		
	5%	10%	15%	10%	15%	20%
Medium	0.79	0.71	0.62	0.84	0.78	0.70
Large	1.09	1.05	1.01	1.11	1.08	1.04

Considering that the average market fuel price projected for this analysis was $0.4 per liter, this option would remain attractive with significantly higher fuel prices. As to higher capital and maintenance costs, the following table presents the estimated cost of the engine, pump and steel tubewell as well as the additional cost ("cost overrun") which would reduce the attractiveness of this option to the break-even point.

	Market Prices (US dollars)			Social Costs		
	5%	10%	15%	10%	15%	20%
Medium Farm:						
est. costs	1760	1580	1460	1590	1470	1380
"cost overrun"	1140	730	430	1300	870	590
% increase	65%	46%	29%	82%	59%	43%
Large Farm:						
est. costs	1950	1750	1610			
"cost overrun"	461	3480	2670			
% increase	236%	199%	166%			

Again, the attractiveness of this option for the two larger farm classes is demonstrated by the significant leeway possible in the basic costs. At higher costs of capital on the medium farm, this cushion is not very large.

With regard to the actual operational reliability of the diesel pump, whether it be limited by fuel or engine availability, there are several points. First of all, the number of hours of required operation is relatively small compared to the hours available for pumping: 770 and 1,160 hours for medium and large farms respectively out of a pumping season of 250 10-hour days or 2,500 hours. However, the actual flexibility as to when the pumping is required is somewhat less than indicated by these figures because there are periods where the water is needed over a short period of time. A problem with estimating the effects of unavailability is how to assume the benefits of irrigation are diminished. Loss of water during peak periods could nearly wipe out the crop altogether. More information is needed to do an accurate analysis, especially on the reliability of diesel pumps.

The issue for the small farm situation is the reverse: how much lower must capital or operating costs fall to the diesel only option to become attractive? The results for the small farm may be overly conservative because of the significant maintenance cost imposed despite the low level of annual use (305 hours). This cost was assumed constant for all farm sizes independent of pump use. The following table shows the reduction in this cost that would make diesel only irrigation attractive:

	P.V. in U.S. $					
	Market Price			Social Costs		
	5%	10%	15%	10%	15%	20%
Small farm: est. diesel pump cost.	400	400	400	480	480	480
est. maintenance	850	670	550	670	550	460
break-even maint. cost (steel tubewell)	240	10	-160	220	20	-140
(bamboo tubewell)	460	260	100	500	310	160

Only at low costs of capital, and assuming a bamboo tubewell, would a less costly but still feasible maintenance cost estimate make a significant difference in the attractiveness of this option. However, this cost reduction, in conjunction with the possible availability of smaller and proportionally less costly engines, could make diesel attractive. With regard to lower fuel prices or engine costs, the two costs would have to approach zero before diesel only becomes attractive on small farms.

Option 2: Biogas and Diesel

For the option of biogas and diesel, reliability issues take on a different light because the uncertainty as to the actual availability

investments can be attractive even if the plant's reliability is relatively low.

All of the above analyses only attribute benefits to biogas used for irrigation and in all cases there is extra gas available for other uses. If it is the minimum, this gas is only available during the non-pumping part of the year. Therefore, the attractiveness of biogas is underestimated significantly in some cases.

Option 3: Gassifer and Diesel

The above analysis of gassification assumed 100 percent reliability of the gassifer when needed. The practicability of this assumption is different for the three farm classes. It can be realistic for the small farm because the gassifer is only needed for 305 hours over a 250-day pumping period. The need is more intensive during the peak period, but there is still room for flexibility since the pump only requires 25 percent of the maximum pumping time available during this period. On the other hand, on a large farm the annual operating hours are 1,160 over the 250-day period, and therefore the assumption of 100 percent availability may be unrealistic. Yet even in this case the flexibility in pumping times mitigates this problem. In order to determine the minimum reliability levels required for gassification to be attractive, the minimum number of hours of operation which results in a fuel savings equal to the gassifier cost were calculated. For small and medium farms, that number is:

Market Prices			Social Costs		
5%	10%	15%	10%	15%	20%
140	160	190	150	180	200

over the 250-day pumping season. On the large farms the number of hours would be less since a larger engine is used and therefore the fuel savings per hour are greater.

Another uncertainty concerning gassification is the capital and maintenance cost. Due to lack of worldwide experience with gassifiers of this size and for this purpose, there is a great deal of uncertainty about these costs. The costs used, in present value terms, were:

1. for capital costs: market price of $140; social costs at 25 percent foreign exchange premium of $165;
2. for maintenance cost ($10 annually): ranges from $75 at 5 percent discount rate down to $40 at 20 percent.

In order to determine the sensitivity of the analysis results to these costs, the additional present value cost of gassification which would make it only break-even with the diesel only option was calculated. Assuming 100 percent availability, this additional cost is:

	Market Price			Social Costs		
	5%	10%	15%	10%	15%	20%
small farm	250	170	120	240	160	110
medium farm	960	740	580	940	740	590

These figures show that even with significantly higher costs or lower availabilities, gassification would be attractive. However, one problem with gassification, in addition to the availability and cost, would be the storage of the residues. The extent of this problem is

based on the time between pumping and harvest, the suitability of the residues to storage, and the local experience or adaptability to storing crop residues.

The strong attractiveness of gassifiers on medium and large farms is overshadowed by two considerations: 1) the lack of technical certainty and to a lesser extent 2) the availability and value of residues. The first issue can only be resolved through a program of experimentation and demonstration. The second issue has several aspects. One is that gassifiers are clearly attractive when feed use of agricultural residues is not large, such as where livestock are small, where extensive pastureland is available, or where intensive agriculture yields large amounts of residue. Central Thailand appears to be a likely candidate possibly fitting into the first and third of these conditions. On the other hand, it is important to examine the feed value of different residues and other materials versus their energy value to determine optimal uses for these resources. Furthermore, the availability of feed substitutes must be considered so that the use of residues for fuel does not cause further deforestation through overgrazing. An additional point for further research is the residue production factors, e.g., the amount of straw to product for different crops and harvesting methods.

For irrigation in the representative village, the residues needed to fuel the gassifiers annually are about:

small farm:	1.2 metric tons
medium farms:	3.1 metric tons
large farms:	7.0 metric tons

These requirements reduce to that of almost 1.2 metric tons of residue for every hectare irrigated. Supplying this residue need as well as fuel requirements is dependent on the cropping pattern and livestock

holdings. Production of the 1.2 tons of residue per hectare is quite feasible for many crops. Paddy residue equivalent to the production levels in Table IV-7 would be 2.8 MT/ha. Other grains (e.g. wheat, maize, sorghum and barley) are generally in this range (Arora, 1977). Analysis would, on the other hand, be necessary to consider the tradeoffs between the cash value and energy value of different crops. The small farmer has a residue surplus of 0.4 tons annually (Table IV-7) and therefore needs to generate an additional 0.8 tons from the additional production from irrigation. This additional residue could quite easily be produced from the small farm's 1.05 hectares. The medium and large farms in some cases, such as where maize is grown, already generate additional residues; however, only on the large farm are these residues sufficient to meet both feed and gassifier requirements. On the medium farm growing maize, the additional annual residues needed are 1.4 tons or about 0.5 tons per hectare. An important variable in determining the availability of residues is the availability and productivity of pastureland. To accurately assess the attractiveness of gassifiers in comparison to other technologies would require further analysis into these issues.

Distributional Issues

The results indicate clearly significant economies of scale and therefore some distributional problems, since the welfare focus of these interventions should be on the rural poor or small farm class.[1] In fact, due to the limited availability of small engines, the small farmer cannot reap the benefits of irrigation.[2] A crucial issue is whether very small engines will cost significantly less and then whether this possible lower cost becomes available to the consumers. The small farmer also faces this problem with regard to the tubewell cost. The poor or small farmer can only reap the benefits of irrigation by the developments of significantly lower cost equipment or by cooperative behavior among several small farms.

With regard to the biogas plants, whereas the small farm may be able to find this investment attractive, this class may be constrained by its limited animal holdings. Nevertheless, it appears that this limitation is less severe, since the plants can be easily scaled to size.

Gassification might be more attractive for small farmers given straw potential from increased agricultural production, but still, the costs of the engine and tubewell are major constraints for the single farm.

1. Ignoring in this analysis the landless and issues of job creation with irrigation.

2. Except under the use of water markets, thereby reducing the diseconomies of scale.

SECTION V

Annotated Bibliography on Social Benefit Cost Analysis and Energy Planning

A. Approaches and Methodologies

B. Estimation of Shadow Prices

C. Case Studies on Renewable Energy Projects

A. Approaches and Methodologies

OECD: Manual of Industrial Project Analysis. Volume II by I.M.D. Little and J.A. Mirrlees. OECD Development Center, Paris, 1968.

I.M.D. Little and J.A. Mirrlees: Project Appraisal and Planning for Developing Countries. Basic Books Inc., New York, 1974.

The details of the OECD or Little-Mirrlees approach along with its comparison with UNIDA Guidelines have been provided in the text. As noted in the second volume (1974) the basic concepts and principles used in the two volumes are basically similar. The additions of material in the second volume include: a discussion of relationship among project, sectoral and macro levels; the measurement of benefits of the production of non-traded goods and services; and, the treatment of shadow wage rate. Income distributional considerations in project analysis are dealt with more explicitly and at much greater length in the second volume.

The Little-Mirrlees (L-M) approach begins with the premise that prices are seriously distorted in many developing countries and some of the worst distortions have arisen as a result of government policies and bad investment planning. The policies may relate to trade policies (tariffs, quotas, subsidies) or commodity and resource prices (labor, capital and foreign exchange). The L-M approach consists of guidelines for the construction of a whole set of self-consistent "accounting prices", to be used as better guides to project selection than actual market prices. One of the important suggestions made is to use "border prices" (import or export prices) as accounting prices.

The main limitations of the approach are:

(i) The crucial assumption in the L-M approach is that there are no important political constraints preventing reform of the price system - and that the governments are willing and able to manage trade predominantly, though not necessarily entirely, by prices rather than quantity controls. In many developing countries, for various reasons, this assumption may not be valid. If the project evaluator is not powerful enough to ensure that the desired changes in trade and tax/subsidy/pricing policies are in fact made, it would be inappropriate to use "border prices" for project evaluation.

(ii) Although concepts of value of public income and numerical weights for personal income distribution have been presented, the discussion is far from complete.

United Nations Industrial Development Organization (UNIDO): Guidelines for Project Evaluation, New York 1972.

UNIDO: Guide to Practical Project Appraisal: Social Benefit-Cost Analysis in Developing Countries, New York 1978.

The details of the UNIDO approach and its comparison with the OECD Manual have been presented in the text. The above two volumes present a complete system of project evaluation in developing countries including the required theoretical background, practical aspects and case studies.

The major thrust of the argument is that valuation of goods and services in terms of market prices is inadequate in reflecting national benefits and costs and, hence, project inputs and outputs should be valued at "shadow prices". Procedures and principles for quantification and valuation of outputs are discussed at length along with the methods of estimating social rate of discount and shadow prices for investment, foreign exchange and unskilled labor. One of the important aspect of shadow pricing which receives considerable emphasis in the UNIDO approach is the distinction between social rate of discount and opportunity cost of capital. In fact, it is the divergence between the values of these two parameters that determines the value of shadow price of investment. Although other approaches have also taken this into account, the UNIDO approach is consistent with the rest of their methodology.

Another important advantage of the UNIDO approach is that it explicitly recognizes the limitations of the role the planning organizations can play in influencing trade, price and tax policies in developing countries. The UNIDO method recognizes the presence of political and administrative constraints in adjusting tariffs and tax/subsidiaries and suggests use of shadow prices in that context. There is also a greater importance given to the issues of income distribution among groups and regions than in OECD Manual.

The UNIDO approach has been used in many case studies and in estimation of national/regional parameters. There have been difficulties in the use of parameters such as shadow price of investment. The methodology may be found too academic or too difficult by some people who do not have the necessary background.*

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*One of the authors of the UNIDO Manual has presented a complete theoretical analysis of a labor surplus economy; see Marglin (1976) and Sen (1975).

Michael Roemer and Joseph J. Stern: The Appraisal of Development Projects: A Practical Guide to Project Analysis with Case Studies and Solutions, Praeger, 1975, New York.

This manual is oriented to three types of users: economics students who can use the manual for supplementary reading and case work for courses in development economics; government technicians responsible for analyzing projects; and, government officials who make investment decisions and need to become familiar with this decision-making tool. The theoretical discussions are kept relatively brief and major emphasis has been placed on developing a realistic framework for project analysis, setting forth practical rules for evaluating project costs and benefits. Apart from the theoretical discussions on shadow prices, details of estimation of values for these parameters for Ghana have also been given. The book also presents case studies on a bauxite mines expansion, a cooperative rice project, a manufacturing and spinning mill and a feeder road (transportation) project.

The book discusses the need for project analysis, divergence between social and market prices and presents problems of measurement and valuation of benefits and costs. It presents a useful discussion of the role of discounting in comparing costs and benefits but uses the opportunity cost of capital (or shadow interest rate) as the appropriate discount rate. Unlike UNIDO Guidelines (1972) and other theoretical literature, the opportunity cost of capital is not considered different from the discount rate. The estimated value for opportunity cost of capital in Ghana (1972) is taken as 12 percent based on available rates for investment demand and supply of savings. The shadow wage rate for unskilled labor is estimated as 50 percent of average urban wage rate based on estimates of agricultural wages for casual workers and adjustments for subsistance production. The shadow rate for foreign exchange is taken as cedis 1.75 per dollar (against the official exchange rate of cedis 1.28).

The main limitations of the book are:

(i) One of the major advantages as well as the drawbacks is its simplicity. For the economist who is to estimate the values of national or regional parameters for a given country, the book is too simplistic. For the economist who is appraising a project and has to use the available values for various parameters, the book is rather superfluous. It is a useful initial orientation to the non-economist planner who is told, convincingly, about the need for using shadow prices instead of market prices. However, even for him, the book seems to indicate that the adjustments made are very simple and gives a too simplified perspective of the complex problem of shadow pricing. The reader should be cautioned against thinking that the concept and methodology of estimation of shadow prices is just a simple matter of increasing or reducing some values.

(ii) Although reference to the important question of distribution has been made, the authors have succumbed to "the traditional and most widely accepted practice" of excluding equity considerations from cost-benefit calculations.

Russell J. deLucia, Henry D. Jacoby, et al. LDC Energy Planning: A Study of Bangladesh. Cambridge, MA, June 1980, Draft for Review and Comment*

This book covers a broad range of issues associated with energy planning in developing countries. Although drawn primarily from the Bangladesh Energy Study** it presents much methodology that has broad conceptual applications. While the book does not focus purely on renewable energy issues there are a number of sections in the individually authored chapters that are particularly relevant. Chapter 1, "Energy Planning in Bangladesh" by deLucia and Jacoby, presents a useful discussion of the characteristics of an Energy Sector study. Chapter 3, "Agricultural Analysis for Energy Planning" by James Gavan and Rodney Tyers, and Chapter 4, "Traditional and Renewable Energy Sources" by Russell deLucia and Richard Tabors present ideas relevant to the consideration of biomass based energy alternatives including: approaches to estimating agricultural residue availability through agricultural sector analysis, difficulties in firewood and other survey techniques, and approaches to examining technical, economic and social factors in analysis of rural energy options. The chapter by Henry Jacoby and Joseph Stern "Economic Objectives, Parameters and Assumptions" gives examples of the estimations of economic parameters including shadow prices necessary for investment analysis of either renewable or conventional technology alternatives.

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*The book has been submitted for publication review, it is available from the authors, c/o R. deLucia, Meta Systems Inc., 10 Holworthy St., Cambridge, MA, 02138.

**Bangladesh Energy Study for the Government of the People's Republic of Bangladesh, administered by the Asian Development Bank under United Nations Development Program Project BGD/73/038/B/01/45, prepared by the Montreal Engineering Co., Ltd., Snamprogetti S.p.A., Meta Systems Inc., and C. Lotti & Associates S.p.A., November 1976.

Efficient Use of Energy (The APS Studies on the Technical Aspects of the More Efficient Use of Energy). AIP Conference Proceedings No. 25, American Institute of Physics/American Physical Society, Washington, D.C., 1975.

This monograph focuses on technical issues of efficient energy use. It is an important comprehensive effort by a group of physicists. The monograph takes a physics perspective establishing norms or standards of performance against which uses of energy can be evaluated. The discussion is heavily theoretical but also practical in terms of basing efficiency measures in the laws of thermodynamics and presenting discussions of energy use examples in a fashion that encourages practical analysis. The approach focuses on the use to which the energy is applied, rather than the energy-using device. This focus on task, or energy end-use, pervades the monograph. First and second law (of thermodynamics) efficiency definitions are presented including the concept of "available work" which makes possible the measurement of the APS second law efficiency.

Discussion and examples including coverage of such issues as household energy using tasks (heating, lighting, etc.), transportation and the automotive and industrial processes.

B. Estimation of Shadow Prices

S.N. Mishra and John Beyer: Cost Benefit Analysis: A Case-Study of the Ratnagiri Fisheries Project (India). [Appendix III on Methodology and Estimates for Social Rate of Discount, Accounting Price of Investment (Savings), Accounting Price of Foreign Exchange and Accounting Price of Unskilled Labor] Hindustan Publishing Co., Delhi, 1976.

John Beyer: "Estimating the Shadow Price of Foreign Exchange, An Illustration in India," Journal of Development Studies, July 1975.

This appendix has been provided to describe the basis on which the particular values used in the case study in India have been selected. The results reported here are based on one of the most detailed exercises done by professional economists for an individual country. The methodology used broadly follows the UNIDO Guidelines (1972) and the effort is towards a review and adoption of alternative methods of estimation of shadow prices. Details of alternative estimates for India have been given in the two studies. The most important contribution of the studies is to show that suggested methodologies for estimating social rate of discount and shadow prices can, in fact, be used to calculate these parameter values for a given country.

The major limitations of the study are:

(i) In estimating the social rate of discount, they have used estimates for ε (the elasticity of marginal utility of consumption) ranging between -1.5 and -3.0. They have not given much thought to the fact that in a poor country where even the necessities for the entire population may not be available in the next one or two decades, the marginal social significance of additional consumption may not decline over time. Besides, they have ignored the role of "PTP", i.e., pure time preference, in estimating the social rate of discount.

(ii) The range of estimates for all the parameters is too wide to be used for actual project selection and ranking. A lot of subjective judgments are involved in picking up values for variables (growth of consumption, opportunity cost of capital, rate of reinvestment etc.), which have a compounding effect on the estimates of national/regional parameters. Thus, the planner is left with the use of intuitive reasoning and value judgments in selecting values for these parameters. In this context, it becomes debatable if it is worthwhile to spend the effort on using elaborate methods to calculate range of values for these parameters if they are unusable for project analysis.

(iii) Their estimates for shadow wage rate are rather unsatisfactory. They have used the Little-Mirrlees approach of calculating marginal product of labor from market wage rates and average product. This is rather unsatisfactory as the literature on difficulties of estimation of marginal product would suggest. They have also not calculated the seasonal variations in shadow wage rates which is rather crucial in the context of rural-oriented projects.

(iv) These studies have completely ignored the problem of giving explicit weights for income distribution and regional development. If project selection is to be used directly to "correct" the unequal distribution of income among groups and regions, this becomes quite an important aspect of the economic framework for project analysis.

World Bank: Estimating Shadow Prices for Colombia in an Input-Output Table Framework. World Bank Staff Working Paper 357, Sept. 1979, Washington, D.C.

This paper explains the calculation of shadow prices at the national level using the Input-Output technique. The methodology outlined here permits easy calculation of Border-Price-Ratios (accounting prices for commodities) for a large number of traded commodities and non-traded commodity sectors. The values for 22 traded sectors and 9 non-traded sectors for Colombia have been given in the report. The advantages of the I-O approach are easy calculation of conversion factors and quick sensitivity analysis of results using computerized I-O approach. The limitations relate to non-availability of I-O tables in some countries, the problem of classification of sectors, and updating of I-O tables. Even in this approach the basic problems in estimation of opportunity cost of capital and other parameters in social pricing, e.g. the elasticity of marginal utility of consumption and the rate of pure time preference, remain.

Other limitations of this study are the same as discussed in the context of the paper on Ivory Coast. Although multi-sector conversion coefficients can be mechanically calculated and applied, the real issues relating to social pricing, consumption distribution weights, the value of public income and derivations of marginal propensities to save are as difficult to handle under this approach as in any other.

World Bank: Economic and Social Analysis of Projects: A Case Study of Ivory Coast. World Bank Staff Paper No. 253, May 1977, Washington, D. C.

This paper is a good attempt to demonstrate in a specific country context the application of the methodology for economic and social analysis of projects developed by Lyn Squire and Herman G. van der Tak. Two steps in project evaluation are recognized: efficiency analysis which is designed to select projects compatible with an optimal allocation of resources; and social analysis, which explicitly allows for the distributive and growth objectives by attaching appropriate weights to private costs and benefits. The study presents estimates of the parameters required for efficiency and social analysis and applies the results to three projects in Ivory Coast.

The approach outlines the following steps: adjustment for transfer payments such as all tariffs, duties and taxes from the costs and benefits; use of shadow exchange rate, shadow wage rate, and of conversion factors for converting each particular input from domestic prices to border prices. The social analysis uses marginal consumption distribution weights for various income groups and the value of public income which is estimated in terms of the consumption stream generated by a unit of public investment.

The World Bank approach seems to use ideas from the Little-Mirrlees method as well as the UNIDO Guidelines. The result is a combination of concepts which are difficult to evaluate on a priori basis. Although the efficiency pricing step borrows heavily from Little-Mirrlees, the 'social pricing' aspects use distributional weights and shadow price of investment from the other approaches. The real merit of the World Bank approach would depend on the results of its application for a variety of projects. As is evident from the three case studies presented in this report, the use of this methodology would require a correct specification of the private sector savings propensities as well as identification of beneficiary families, and subjective weights on distribution. If this information is not available, the use of suggested methodology would not give any different answers.

Food and Agriculture Organization of the U.N. (FAO): Economic Analysis of Forestry Projects. FAO Forestry Paper 17, Rome, 1979.

The purpose of this volume on Economic Analysis of Forestry Projects (EAFP) is (as stated in the Preface) "to provide a practical, workable approach. . .and, hence, [it] does not contain a rigorous methodology which has to be followed step by step in order to come out with a "good economic analysis of a project". It contains chapters on identification and valuation of inputs and outputs. It also presents sections on the role of discounting, decision criteria, treatment of uncertainty and the use of economic analysis in project design.

This document provides a good discussion of the problems of valuation of output when project output is substituting for existing domestic supply. Especially interesting is the discussion where a fuelwood project output substitutes for animal dung and crop residues and/or fuelwood presently being collected by people from nearby forests. Similarly a simplified presentation of valuation of import substitutes or export commodities is helpful for the non-economist. In valuation of inputs, especially land and unskilled labor, the document gives a lucid presentation of the several issues involved including the possibilities of over-valuation of land in estimating its opportunity cost.

The major limitations of the document are:

(i) It does not give details of the methodology of estimating national/regional parameters and assumes that these values are available from the planners;

(ii) The approach outlined is not based on social benefit cost analysis in the sense of using social rate of discount or shadow price of investment and putting weights on distribution of income to groups or regions. However, it does use the concepts of opportunity costs and shadow prices and looks at the benefits and costs from the viewpoint of the society. Thus, the approach can be described as "economic analysis" as distinguished from "financial analysis" but still does not incorporate all the concerns of social benefit cost analysis.

(iii) The discussion on rate of discount and decision criteria is rather elementary and does not go beyond what is usually done in financial analysis. The document neglects the use of benefit cost ratios and suggest that "consideration of choices among projects for a limited budget, i.e. decision making, is beyond the subject of EAFP. . .". It is difficult to accept this view of the authors because ranking projects in the same sector as well as providing B/C ratio for comparison with projects in other sectors should be an important aspect of the Economic Analysis of Forestry Projects.

C. Case Studies on Renewable Energy Projects

David French: The Economics of Renewable Energy Systems for Developing Countries, Draft, Washington, D.C., January 1979.

This paper provides most detailed benefit-cost analyses for three representative renewable energy systems: (i) a 40-hp solar thermal irrigation pump near Bakel, Senegal; (ii) a family-scale Indian biogas plant; and (iii) a 5.5 kw solar cell irrigation pump on the borders of Lake Chad.

The study presents details of financial analysis and suggests the major adjustments required for economic analysis, e.g., shadow pricing, the calculation of social costs and benefits, and consideration of secondary effects. The results show that neither the solar thermal pump nor the family-scale biogas plant appears to be profitable in either financial or economic terms under any plausible set of assumptions. The solar cell pump has positive net benefit by economic measures but is unlikely to be competitive with diesel power for another decade. There is also a good discussion of the analytical issues which arise in pursuing benefit-cost analyses of renewable-energy devices.

The main limitations of the study are:

(i) There is a misunderstanding in valuation of benefits in two studies. In the case of the 40 hp solar thermal irrigation pump as well as the 5.5 kw solar cell irrigation pump, economic benefits have been calculated in terms of the value of output of rice, maize, sorghum, wheat or cotton grown by using the irrigation water supplied by the pump. The NPVs and IRRs have been calculated using these benefits adjusted for shadow prices. This method is termed as "viewed strictly in its own terms. . .without reference to competing systems." However, this method is not appropriate if the choice for the society is to use either a solar irrigation pump or a diesel irrigation pump for providing irrigation water to the crops regardless of the additional benefits from irrigation. (The valuation of irrigation water is a separate and a more complex matter.) The introduction of a solar system replaces an existing (or potential) diesel system and, hence, the "true" benefit of the solar system is the savings in resources (capital, foreign exchange and labor) which would otherwise have been devoted to the diesel system. Thus, the correct method of estimation of benefits from a solar system is in terms of the costs (saved) of the competing system and not "in its own terms." The latter, in fact, would involve attributing the benefits from the use of irrigation water to solar system although the same quantity (and quality) of irrigation water could be provided by a competing diesel system.

(ii) The cost data used as well as the available technologies have undergone significant changes in the last four years. For example, the economics of family biogas units in the report are reversed if higher kerosene prices and lower capital costs of Chinese-type biogas units are taken into account.

(iii) There is no effort to include distributional -- personal or regional -- considerations into project analysis and ranking.

Douglas V. Smith: Photovoltaics in Less Developed Countries. MIT Energy Laboratory, March, 1977 (revised August, 1979), Cambridge, MA.

Douglas V. Smith and Steven Allison: Micro-Irrigation with Photovoltaics. MIT Energy Laboratory, April, 1978, Cambridge, MA.

The above two studies present two alternative methods of economic evalution of non-conventional energy alternatives such as photovoltaic powered irrigation pumpsets. In the first study, the photovoltaic system is compared with diesel system and it is concluded that at a diesel fuel price of 35 cents per litre, photovoltaic power is competitive at solar array costs of $1300 per peak w. In the second study by Smith and Allison, they have used an alternative method of evaluating the "economic viability of solar pumping of irrigation water." They estimate the potential increment to income from irrigated rice as $250/ha/year (assuming 2.5 tons/ha of additional output due to irrigation) and, from this they calculate the affordable unit costs of a pumping energy package which lies between $7.6 and $8.6 per peak watt. Taking $8 per peak watt as the current (1978) price, they find solar pumping of irrigation water as economic.

It may be noted that of the two methods presented above, the first method of comparing it with diesel alternative is the correct procedure. The second method of calculating "economic viability" or "affordable cost" is misleading becuase this method attributes the benefits from use of irrigation water to photovoltaic power. Since photovoltaic arrays (and the system) provide an alternative energy source for pumping water, it would be necessary to analyze the economic viability of photovoltiacs in terms of the costs to the society of the lowest-cost energy alternative available for pumping. the benefit of using photovoltaics is the saving in the "resource costs" of diesel (or other) alternative for pumping the same quantity of water.

"Annex 1 Lake Chad Project: Pumping Matrix" in Working Draft Report: Analysis of "Revelle" Polder Development Scheme and Design for a Long Range Lake Chad Basin Study. Prepared for U.S. Agency for International Development by Meta Systems Inc., Cambridge, Mass., October 1974.*

This is an example of analysis in which a very wide range of technical alternatives was considered. Alternative individual devices (engines, pumps) and combinations to produce pumping systems were included. The range of systems included human power based systems (Shadoof), animal powered systems (e.g. camel-power Persian pushing wheel), and a number of gasoline, diesel and electricity powered alternatives. Limits on residue and firewood prevented consideration of other alternatives (Stirling engine, etc.). Subsequent work** by individuals engaged in the project examined photovoltaic alternatives. The analysis included both economic and financial analysis with consideration of some shadow prices.

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*A version of this work is available from Dr. R. Tabors, MIT Energy Laboratory, Cambridge, Mass.

**See Tabors (1979), and Smith (1979).

John Briscoe: The Political Economy of Energy Use in Rural Bangladesh. Harvard University Environmental Systems Program, August 1979. (Also published in Population and Development Review , December 1979).

This study was conducted using the method of participant observation for 48 families of Ulipur village in Bangladesh. The study sheds light on the relationship between ownership of energy-producing assets and the processes of generation and use of energy by various households of different economic status/occupation.

One of the most important contributions of the study is to highlight the complex system of alternative uses of crop and animal residues and the pattern of their present and future uses. Each crop produces several products, each of which can be used for several purposes. Food grains can be used as human food or animal feed; crop residues as fodder, fuel, fertilizer or construction material; animal residues as fertilizer, fuel or cleaning material.

He has also pointed out that social organization of the village determines the control and distribution of energy resources and shows that ownership of energy producing assets is highly concentrated. Given this unequal distribution, rich farmers have no incentives to improve the efficiency of utilization of fuels since these fuels are surplus for them anyhow. Another chief merit of the study is to show the dynamics of energy availability and use over time and to speculate how poorer villages would be adversely affected by introduction of irrigation, high yield variety seeds and other development projects.

The main limitations of the study are that no effort was made to estimate the actual energy content of different type of fuels and adequate emphasis not put on estimating the efficiency of various end-use devices. Nevertheless, the study provides a rich background of the type of information that has to be collected to evaluate socio-economic impacts of non-conventional energy technologies.

U.S. Agency for International Development (AID): Philippines Reforestation/Rural Energy Project, AID Project Paper, July 1980, Washington, D.C.

This project covers the techno-economic and financial anaylsis of reforestation in the Philippines, both as an ecological necessity to present erosion, and as a source of energy. The proposed power generation plant (3Mw) is by means of a steam turbine fueled by the direct combustion of harvested wood. It is estimated that in a 3 Mw plant using fuelwood the costs of electricity generation would be $0.08/kwh as compared to the power cost of $0.091/kwh from a diesel plant.

The economic analysis gives considerable details of the capital costs required for the forestry project and includes income estimates for a "tree farmer" as well as the profitability of the power plant. The national economic benefits have been calculated as a net savings in foreign exchange of the order of $0.8 million per year for a 3 MW unit. The social soundness analysis has also been included in the report and project beneficiary families and groups have been identified. There is an attempt to quantify details of income, housing, settlement, environmental, industrial, and power benefits to various categories of beneficiaries.

The major drawbacks of the analysis in the report are:

(i) The entire issue of "economic cost" of producing fuelwood, especially the opportunity cost of land, labor and other inputs into fuelwood plantations has been bypassed. It is assumed that the cost of fuel to the power plant (including transportation) will be $25/green ton and the "tree farmer" will be paid at $17/ton. The basis for estimates of fuelwood yield per hectare and labor inputs have also not been provided. The results of economic analysis would be very different if the "opportunity cost" of land is included in the costs of fuelwood.

(ii) Capital costs of the power plant have been assumed at $1400/kw although there are indications that similar plants (excluding installation) $800/kw. No attempt has been made to get more representative estimates of the capital costs. Detailed breakdown of capital costs of the power plant have not been provided.

(iii) A 60 percent load factor for the power plant has been assumed. This seems to be much higher than the achieved load factors in various countries where electricity is primarily used for lighting, irrigation and small industries owing to seasonality of demand. If a lower load factor is considered and if the fuelwood cost includes the opportunity

cost of land in terms of benefit foregone (value of agricultural output or fodder), the generation cost of electricity would be much higher than the estimate of $0.08 per kwh. In fact, the "corrected" costs may show that generation from a diesel plant is cheaper than a biomass-based thermal plant. If this turns out to be true, the whole economic analysis of this project report would be misleading.

(iv) There is no effort to use shadow prices in economic analysis or performing sensitivity analysis to important techno-economic parameters.

Hodam Associates, California: Cogeneration of Process Heat and Electricity from Rice Hulls in the Philippines. Report prepared for the USAID, January, 1980, Washington, D. C.

This report covers the techno-economic feasibility of conversion of rice hulls to energy in the Philippines. Two technologies -- direct combustion followed by a steam cycle, and gasification followed by a diesel cycle -- have been discussed. Issues of equipment - availability of appropriate scale at reasonable cost, the availability of skilled labor, and experience with rice hulls as fuel have been considered in defining feasibility. Economic analysis presents a comparison of 15-year costs of current system, gasification system and steam cycle system. The gasification system with cogeneration is found more economic although its technical reliability is in doubt. The nation-wide benefits in terms of savings of diesel fuel are mentioned but not quantified.

The following limitations of the analysis must be noted:

(i) Although technical details have been covered in detail, the efficiency estimates, especially those for gasifiers and turbines, are open to debate.

(ii) The entire economics of the project depend on the sale of excess power to the utility since this accounts for 60 percent of the total savings. There is very little analysis of this aspect except for emphasizing its importance. If lower load factor or capacity factor reduces this savings, the economics would be seriously affected.

(iii) When diesel engines are run on gaseous fuels, diesel fuel is (generally) still used for ignition. This diesel oil consumption (ranging between 10 to 30 percent of that for diesel oil alone option) has not been included in the annual costs.

(iv) Although rice hulls are the major input, these have not been included on the cost side. From the society's point of view, rice hulls definitely have an "opportunity cost" which can be estimated in terms of the benefit in alternative uses. This would considerably alter the economics of power generation.

(v) No effort has been made to do social benefit cost analysis or perform sensitivity analysis to important techno-economic parameters.

Ramesh Bhatia: "Economic Appraisal of Biogas Units in India: Framework for Social Benefit Cost Analysis," Economic and Political Weekly, 1977.

This paper is based on an extensive review of the literature on techno-economic and social aspects of biogas technology in India. The article discusses valuation of capital costs, operating costs (dung and labor) and major benefits (gas, slurry) as well as secondary benefits and indirect costs. Using shadow prices, the results of NPV estimates of systems to produce two or three cubic meters of gas per day (family units) have been presented. The study indicates that (i) the economics of biogas crucially depends on the pattern of utilization of gas for cooking or lighting. Since use of gas for lighting replaces imported kerosene, it is more economic to use gas for lighting rather than for cooking; (ii) the technolo-economic parameters for biogas technology are not based on proper field testing and scientific monitoring of biogas plants. There is need to do R&D work on firming up details of gas availability, gas consumption for various activities, optimization of the design of the plant, estimation of the quality of slurry, etc.

The main limitations of the study are:

(i) The data used are for the years 1976 and 1977. Price increases in kerosene and diesel have increased the profitability of biogas units if gas is used for lighting and for pumping water for irrigation/drinking.

(ii) Technological breakthroughs such as adoption of drumless Chinese-type biogas plants in India have reduced the capital costs by 40-50 percent. This has resulted in a higher benefit-cost ratio for investment in biogas plants.

Food and Agricultural Organization of the U.N. (FAO): Economic Analysis of Forestry Projects: Case Study No. 2 Village Fuelwood Plantations in Korea. FAO, Rome 1979.

This report is one of the case studies of forestry and forest industries projects prepared by the FAO in order to demonstrate methods of preparing and appraising projects in the forest sector. The fuelwood project discussed is a part of an integrated rural development program in Korea and is aimed at establishing about 11,000 village fuelwood blocks covering 127,000 hectares.

The case study provides a good format for the detailed assessment of technical considerations, project costs and benefits. Shadow prices for foreign exchange and labor as well as direct and indirect project benefits have been considered. Detailed sensitivity analysis of results to the changes in a number of assumptions has been presented. The study is very useful as a prototype for carrying out similar studies provided the drawbacks mentioned below are taken into consideration:

(i) The cost of land, which is the most important component in fuelwood plantation scheme, has not been given due importance. The project just mentions two lines: "It is considered that land under the project would have no alternative economic use for the period of the project. Therefore, land is valued at zero." There is no justification provided for this assumption. It is inconceivable that an area of 127,000 hectares (approximately 11 hectares per village) can be found which is not being used currently as marginal agricultural or pasture land. Even if it is currently not being used, it is difficult to accept the assumption that this land has no potential alternative economic use in the next twenty years. Inclusion of land costs in opporunity cost terms is expected to change the economics considerably.

(ii) Although a shadow wage rate for unskilled labor is used, its estimation is rather unsatisfactory. Since "there is some self-employment, notably the weaving of bags from rice straw, for which the net value of production is about won 450/day -- this value has been used to represent the opportunity cost of unskilled labor during the period November to March." It is not clear as to how many people in the region can earn this much money per day during the entire period. If many workers (higher than the number employed by the project) remain unemployed or earn less than won 450/day, a lower shadow wage rate should be used.

(iii) The valuation of fuelwood is very arbitrary. It is mentioned that since fuelwood is not traded at present, the

fuelwood has been valued in terms of the value of fuels that it would replace, namely agricultural residues and coal. Although the methodology used is correct, the details of the values of proportion of agricultural residues replacing fuelwood, the calorific contents of residue of fuelwood and the price of agricultural residue have not been given. The price of both fuels (residue and coal) is taken as won 12/kg without providing any basis or source of data. The entire economics may be different if this estimate of benefit is changed. Similarly, no basis for fuelwood yields of 5 tons/ha have been provided. As shown in sensitivity analysis, the project is uneconomic if benefit is reduced by 40 percent.

Ramesh Bhatia: "Energy Alternatives For Irrigation Pumping. Some Results for Small Farms in North Bihar India," Paper presented at the International Seminar on Energy, Hyderabad, India, January 1979.

This paper presents a detailed economic analysis of using biogas, photovoltaics, diesel and electricity (regional grid) for pumping irrigation water for small farms in Bihar, India. Apart from providing a literature review, the paper also outlines techno-economic and social aspects of using renewable energy sources for irrigation pumping. The methodology used is:

(i) To define alternative irrigation systems which are equivalent in the sense that each provides the same quantity and quality (timing) of irrigation water. Each system includes tubewell, a pump, a prime-mover (a diesel engine or a duel-fuel engine or an electric motor) and an energy source (a biogas unit or regional electricity grid).

(ii) To rank these technical alternatives on the basis of the sum of the present value of investment and operating costs at a given social rate of discount. Since benefits from irrigation are the same (since the systems are equivalent) the alternative with the lowest present value of total costs is considered the best, i.e. giving the highest benefit-cost ratio. The analysis is done both at "market prices" and "shadow prices". The results indicate that use of biogas for irrigation pumping is economic at current prices since it reduces the consumption of diesel by 20 to 100 percent while the use of photovoltaics (solar cells) would become economic only if capital costs can be reduced significantly.

One of the important points made in the paper is about the use of the correct methodology of benefit-cost analysis. One should be cautious against attributing benefits from the use of water to benefits from a particular irrigation alternative as has been indicated in the review of some other studies. The correct procedure is either to define "equivalent" irrigation system and use the method of cost effectiveness as used in this paper, or estimate the benefits of one system in terms of savings in the costs of the least expensive alternative. The main limitation of the paper is that the alternatives covered do not include micro-hydel, windmills, village level electricity generation from biomass or human and animal power. A more comprehensive coverage of energy alternatives along with a number of methods of conveyance and distribution of water in the field will be a useful extension of the present study.

Russell J. deLucia and Michael Lesser*: "Energy from Organic Residues in Developing Countries: Present Use, Potential and Observations on Feasibility." Paper presented at Bio-Energy World Congress and Exposition Bio-Energy '80. April 1980, Atlanta, Georgia.

This paper reviews the existing energy uses of crop and animal residues with particular reference to their use in rural areas. The present role of these energy sources in relation to both other traditional (woodfuel) and commercial energy sources is then presented.

An illustration of the complexity of village resource systems is presented, outlining the diverse, often competing, uses of organic residues: food, fertilizer, fiber, and fuel. In this context, the issues and problems associated with the use of traditional energy sources are discussed.

The potential for increased use of organic residues for energy is presented for a variety of alternative country settings. In light of this potential, a framework for examining village energy needs and energy related technologies is discussed. The presentation indicates the importance of integrating physical, environmental, social, and economic issues in the evaluation of proposed intervention using organic residues (such as biogas). A sample analysis of such an intervention is presented based on recent work on Thailand with particular emphasis on differential class impacts.

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*Paper available from R. deLucia, Meta Systems Inc.

Alcohol Production from Biomass Potential and Prospects in the Developing Countries. Report No. 3021. Industrial Project Department, World Bank, June 4, 1980.*

This monograph is an extensive review of many of the issues associated with the potential for biomass based alcohol production in developing countries. Its focus is ethanol; methanol is not discussed in any detail. The treatment includes a discussion of ethanol characteristics in relation to current and potential uses such as boiler fuel, gasoline substitute, diesel substitute, and chemical feedstock (or final product). The report reviews historic production and consumption figures of ethanol and discusses both alternative raw materials (sugars, starches, celluloses) and production technology. The economics of ethanol production and use are considered for a series of generalized cases (high, medium, and low cost country groupings) based on capital costs for different raw material based alternatives and scales of production. The analysis includes a discussion of the relative attractiveness of ethanol depending on use. A discussion of overall prospects for alcohol production is presented. While the document does include a limited discussion of some wider economic policy issues such as the food-versus-energy crop competition and the need for integrated policies, the report does not sufficiently highlight these broad questions; they are left to the closing section of the document.

* At that date this was a Gray Colored Cover "For Official Use Only" document. It may subsequently receive a wider distribution.

M.J. Groeneveld and K.R. Westerterp, "Social and Economic Aspects of the Introduction of Gasification Technology in Rural Areas of Developing Countries. (Tanzania)", in Thermal Conversion of Solid Wastes and Biomass, Jerry L. Jones and Shirley B. Radding, editors; ACS Symposium Series 130. American Chemical Society, Washington, D.C. 1980.

This study describes gasification processes in general terms, outlines how a system can be assembled and organized, and reports on a pilot plant using 2.5 Kg fuel per Kwh (mechanical). The authors have presented a sketch of the gasifier unit, but no dimensions or scale are shown, thus making it difficult to judge on the size of the unit. In analyzing the social and economic costs and benefits of adoption of such a plant, the authors argue, the following evaluation criteria should be used: a) that wastes for use as a fuel are available and useable without damaging the agricultural system of the environment; b) that the technology be congruent with the existing social and cultural system so as to facilitate adoption; c) that among the alternatives available, the technology chosen has the largest positive impact on the conditions of the poorest stratum in the society; d) that profitability criteria for the owners and users of technology are met; and, finally, e) general and overall considerations of national interest and agreement with national economic and other objectives. They then describe the applicability of such a technology in a Tanzanian village. They examine different production possibilities (of different crops) for their potential useability in the biomass fueled plant: they report that three products -- corn (cobs), coffee (skin), and wood (sawmill wastes) -- look promising, whereas the other five -- sorghum (straw/plume), millet (straw/chaff), cotton (straw/seeds/press residue), wheat (straw/chaff), and groundnuts (shells) -- need further study. Since currently there is no other use for corncobs, they argue, they are suitable candidates for use as fuel. The authors then carry out a social benefit cost analysis for a 20 Kw corn mill run on a gasifier costing about $300 (1977). The analysis and presentation are fairly confusing, but they result in showing: (i) a net benefit of $1181.25 per year (at market price), and (ii) a net benefit of $1947.30 per year (at estimated shadow prices). Hence, they conclude that gasification of corncobs is economically and socially beneficial in Tanzania, this particularly so since the technology presented here is relatively simple and can be locally manufactured. While the study shows no great light on the economic evaluation methodologies for either biogas projects or for choice of technology in general, its chief merit lies in being a relatively rare, and certainly new, attempt at asking such questions in African contexts.

SECTION VI

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ANNEXES

A. Economic Evaluation of a Village Level Community Biogas Plant

B. Electricity Generation from a Village-Scale Biogas Plant

C. Estimates of Calorific Value Parameters

Annex A

Economic Evaluation of a Village Level Community Biogas Plant[1]

There have been a number of studies on technical and economic aspects of biogas technology in India and other developing countries. A detailed analysis of the various techno-economic-social aspects is found in Barnett et al (1978), Bhatia (1977, 1979), French (1979), Ghate (1979), Cecelski et al (1979), Tyner and Adams (1977), Disney (1977) and Parikh & Parikh (1977). It has been pointed out that private biogas plants to meet the energy demands of a particular household would restrict the technology to a relatively richer stratum of the rural communities who own more than three heads of cattle per household. Community biogas systems have been suggested as one of the most efficient and equitable ways of meeting the energy needs of the poor in the villages. Such community plants are said to have the following advantages:

(i) These units being large scale plants should have economies of scale in capital costs, while having smaller heat losses, requiring less precision in temperature maintenance and feeding, and permitting design modifications to improve efficiency more easily than small plants;

(ii) The community plant would provide employment through labor-intensive dung collection and by-product fertilizer distribution as well as on account of increased labor demand resulting from irrigation and small industries powered by gas;

(iii) The benefits of such a plant in the form of cooking and lighting fuels will be available to the relatively poorer sections of the community who for various reasons are unable to install individual household plants;

(iv) The large scale plant can generate enough gas to run dual-fuel engine for running of tubewell for drinking water and irrigation. for operation of flourmill, chaff-cutter and thresher. It could also produce enough gas to run an electric generator to provide

[1] For further details, see Bhatia and Niamir (1979).

electricity for street lighting, house lighting and television as well as for running various machines;

(v) The community plants can serve as a vehicle for the cooperative community action and can provide a forum for decision-making for the benefit of a large number of people.

As against these advantages it is mentioned that community plants have significant diseconomies of scale on account of higher costs of distribution of gas and collection of cow dung and there would be considerable problems in implementing a scheme which requires management skills, cooperative action and decision-making in a rural setup characterized by unequal access to resources.

Although there have been reports of successful operation of large scale biogas plants in India, Korea and Philippines (See Barnett et al., 1978), there are relatively few known cases of community biogas plants in operation. Researchers have pointed out that the organizational and technical problems of establishing and running either private or cooperative biogas systems are formidable but, there is absolutely no literature based on an actual experience in the field. Although the problems connected with collecting cow dung, maintenance of the plants and collection of gas are recognized, there is no documentation available on the nature of these problems in different community settings. It is imperative to analyze the techno-economic and social aspects of this technology if the great potential of community biogas plants as an efficient and equitable source of energy in rural areas is to be exploited. The present case study is an attempt to fill this crucial gap in the available literature on renewable energy sources.

Tables A-1 and A-2 provide data on the major characteristics of the village as well as some main components of the project. It is recognized that these conditions will vary from one region to the other and a project can be varied from one location to the other on the basis of the perceptions of the planners as to which aspects are important for the village in question. It is hoped that this case study will provide some lessons for determining the various components of the project on the basis of explicit priorities in allocation of gas for different activities.

Benefit Cost Analysis

The methodology of Social benefit cost analysis has been used to answer some of the questions raised above. The analysis is done in two stages: first, it is assumed that the maximum amount of cow dung (100%) will be diverted to the community biogas plant and the allocation of gas is done as stipulated in the project. In other words, the plant is analyzed under "best conditions." In the second stage of analysis, an attempt is made to study the case when there is a reduction in available cow dung. This can happen in situations where the number of cattle decreases. Another possibility is that villagers contribute less than the total available dung to the plant, because of their preference for using dungcake for specific cooking needs.

In the cases of Benefit Cost Analysis (BCA) of a biogas plant, estimation of benefits is very crucial. Since the capital and operating costs are quite straightforward, the results of BCA depend on the assumptions

made regarding benefits. For the purposes of demonstration, we have discussed alternative measures of benefits both from the point of view of the users as well as from that of the society. The objective of this is to make explicit all the assumptions involved and to see their implications for different plans of utilization of gas from the plant.

Tables A-3 and A-4 give details of present pattern of energy use in the village. Table A-5 provides per hour gas requirements for the operation of different activities. These are standardized requirements and do not equal the present use of gas for different operations necessarily. It can be seen that cooking requires the heaviest use of gas, followed by flour milling and threshing. The percentages vary slightly in daily use because of the varying hours of use. It can be seen from Table 22 that cooking (by all households) uses more than half of the daily gas availability in the summer, but almost 3/4 of the availability in the winter.

Quantification and Valuation of Benefits

Estimation of Benefits of Cooking

Alternative estimates of benefits of using gas for cooking under different assumptions are detailed below:

Assumption 1: Saving in Labor Cost or Time.

The opportunity cost of labor/hours released from collecting firewood and plant residue, and for making dungcakes cannot be quantified since there is no reliable data for how much labor energy is

expended on these activities. Besides, labor will still be used in transporting cow dung daily to the biogas plant and removing slurry from the plant to the slurry pits. This method has not been used in order to avoid the arbitrariness involved in quantification and valuation of labor.

Assumption 2: Opportunity Cost in Terms of Value of Alternative Use Plant Residue, Firewood and Dung:

In this context, the basic question to be answered is what is the benefit of using these resources when these are released from their present use as a consequence of availability of biogas.

a. Plant Residue: A total amount of 2733.4 kg/month or an equivalent of 1.8 million kilocalories (net) are currently used for all households. This constitutes approximately 60% of the total net energy used for cooking. If this quantity of plant residues is released from cooking, there will not be any economic value added, since the villagers do not perceive a market for it. It can be used for livestock fodder, but no data are available on fodder consumption to assess this benefit. Finally, a possible benefit is the agricultural use of the plant residue, but again there are not enough data to evaluate this benefit. It is not known whether the villagers perceive a need for using plant residue as organic fertilizer. It may be that there is no alternative use for plant residue since soil characteristics and cropping patterns may not indicate any benefit from it, and so burning plant residue for cooking may be the most efficient use of these resources.

b. Fuelwood: A total of 442 kg/month of fuelwood (or equivalent of 0.28 million kcal) is presently used. If this amount is released from cooking, there can be two forms of benefits. The first would depend on whether the wood which is still being collected is now sold in the market. The price of firewood in small towns (including transportation costs) is estimated at $0.38 per kg, therefore, the total value

added is $166 per year.[1] This represents the maximum gain, although it is not known whether all the firewood released will be sold and, hence, this benefit will, in fact, be attained by the villagers.

The second form of benefit is the ecological benefits of not cutting the wood. There are no data to evaluate this benefit. It is not known what type of firewood is collected. Cutting branches, collecting fallen branches and twigs or cutting bushes may not have as much of an adverse impact on the ecology as is generally associated with felling trees for firewood.

c. Dung: With the total dung production of 1392 kg/day, 44.5% or 619 kg/day dung was used for producing dungcakes (123.8 kg dry dung x 5). Thus with the biogas plant, this quantity of 619 kg/day is released and can potentially be used for manure. Assuming that approximately 4% is still used for cleaning and other domestic uses, 1336 kg/day is the total slurry available for manure, which is the equivalent of 12.6 kg/acre of operational agricultural landholding per day, whereas before the introduction of the biogas plant, a total of 700 kg/day of dung, or 6.6 kg/acre was used. For each household, it would have differential impact since size of holding varies from one to the other. It must be noted that all of the dung released may not necessarily be used as manure. This will depend on whether the farmers were using the dung primarily for its NPK content or for its soil building characteristics (in which case they may use more dung if it is released). Alternatively, if their priority was on using dung for manure then, presumably, the use of 55.5% of the dung produced may be the optimal amount, and so the farmers may not use more dung for manure than they already do. In case all of the dung released is assumed to be used as manure, there will be a value added in terms of N, which is estimated as follows: N content is 1% per kg of slurry dung; therefore, with a total of 619 kg/day or 18570 kg per month of wet dung or 185.7 kg of nitrogen per month is available. The net import cost of N is $0.7 per kg. Assuming N content

[1] All the calculations here, as well as those made in Tables A-7 to A-13 were originally made using figures in Rupees. These have been converted into U.S. dollar figures using $1 = Rs.8 rate. Due to rounding, the numbers here and in tables do not match exactly.

of urea is 45% and import cost of 1 kg urea is $0.25 per kg and local transport and distribution cost is $0.12 per kg. Therefore the value added by N is $125 per month or $1500 per year.[1] (See Table A-7.)

However, it should be mentioned that with the present information on hand, it is difficult to judge which resource has a perceived benefit in alternative uses. If, however, there are no alternative uses for any of the released resources, then it would be more efficient not to intervene at all into the village energy system and to allow present cooking habits to continue. The usual argument used to justify biogas plants, namely that gas must be used for cooking so that the valuable manure can be diverted for use as fertilizer, would no longer apply. And the biogas plant would provide much higher benefits if gas is used for other operations such as tubewell, etc. The details of the latter assumption are examined later in this case study.

Assumption 3: Resource Cost in Terms of Equivalent Soft Coke.

Under this assumption, benefits from the use of biogas in cooking are estimated in terms of the resource costs of providing alternative fuels for plant residue, dung and firewood. This method assumes that plant residues, and dung have better uses than being burnt and, hence, the society should provide some alternative fuel (say, soft coke) to villagers. Since the choice from the viewpoint of the society is to employ either soft coke or biogas for cooking and if both fuels are

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[1] This, however, assumes that the N content per kg of digested slurry (1%) is the same as that for ordinary organic manure (non-scientific composted), since 96% of total dry dung produced is used, as opposed to 52.7% (or the amount added to existing use). There is some disagreement on this point as discussed in detail in Bhatia (1977). Besides, it is also pointed out even though the quantity of N per kg remains the same, it is the quality that is improved. Digested slurry is reported to have more ammoniated N (which is picked up easier by the plant than ordinary manure. Since the quality of N in biogas slurry will depend on the handling practices and in dry farming slurry is usually dried for months before it is used on the field, we have assumed that N content remains the same as in cow dung.

considered of equal quality by planners (not by users), the benefits to the society from biogas used in cooking are the savings in resources.

a. Cost of Soft Coke -- Plant Residue: Assuming that there is a definite benefit in releasing all of the plant residue from cooking, we can convert the energy from the plant residue (1765766 kcal/month) to an equivalent of 1728.5 kg of soft coke per month, or 20742 kg/year. (Soft coke has a gross energy content of 5772 kcal/kg, which at an efficiency rate of 17.7%, gives a net energy content of 1021.6 kcal/kg.) The cost of soft coke (including transportation) has been estimated at $17 per ton (see Bhatia, 1977). Therefore, the resource cost of equivalent quantity of soft coke is $350 per year and this can be used as the benefit to the society of providing gas for cooking.

b. Fuelwood: A total of 442 kg of fuelwood is used monthly by all households. Most of this is used for cooking, but an insignificant amount is also used for crafts and construction. It is not at all certain what type of fuelwood is collected. Probably, most of it is in the form of twigs and branches which do not create as much of an environmental hazard as cutting logs. From the societal point of view, the benefits of replacing fuelwood with biogas can be quantified by finding the cost of the equivalent amount of soft coke required. 442 Kg of fuelwood is equivalent to 284736 kcal of energy every month. This is equal to 278.7 kg of soft coke per month or 3344.6 kg of soft coke per pear. At a cost of $17 per ton, the benefits amount to $57 per year.

c. Dung: The resource cost of dung, from a societal point of view, is substantially higher than for fuelwood. A total of 3714.7 kg of dry dung is used by all households per month. This is the equivalent of 1 million kcal of net energy. Converted to soft coke, it would take 995 kg of soft coke per month to replace it giving the resource cost of $200 per year. The resulting estimates of benefits in terms of resource costs of substitute (soft coke) are given in Table A-13.

Estimation of Benefits in Lighting

Table A-4 shows actual use of kerosene for lighting. In total, there is a need for an equivalent of 49.16 cft of gas per day for lighting in the houses. A total of 59.94 litres of kerosene was used per month. At a purchase cost of $0.25 per litre (including transportation and marketing) the total saving in the cost of kerosene is $15 per month, $180 per year.

Furthermore, there is the additional benefit of having street lighting. Street lighting if provided through petromaxes using kerosene, may be assumed to give equivalent quality of lighting as is available from electricity. The resource cost in terms of kerosene is as follows: with the assumption that one litre kerosene produces the same lighting requirement as two kwh of electricity and the total energy required for street lighting is 2.88 kwh per day (.72 kw for four hours), therefore 1.44 litres of kerosene per day or 518.4 litres per year are needed. Thus the equivalent resource cost is $130 per year for street lighting. To this we should add the annualized capital costs of petromaxes. However, this is ignored since no data is available.

Another important benefit that cannot be quantified is that kerosene used for lighting may be seen as a superior product than electricity or lighting. Kerosene is more flexible and can be turned on and off by each individual household at will, and there is less wastage of the resource. Besides, kerosene lamp is more mobile and can be easily taken outdoors for various uses. Biogas lighting, whether from the generator or direct gas lamps, is controlled by a central committee. The hours of operation are open to collective discussion, but it can never have the flexibility that kerosene can provide.

Estimation of Benefits from Tubewell Irrigation

Before the introduction of the community biogas plant, a man from outside the village was supplying water for irrigation by hooking his pump to the existing stream. He was charging $1.25 per hour for his services. In the winter period, the tubewell run by biogas will supply irrigation for 2.5 hours per day, therefore the savings for the village is $3 per day or $365 for four winter months. The savings will be less in the summer time since normally the canal would overflow and provide free irrigation for at least half the acreage, therefore the savings can be estimated to be $365 for the eight summer months, giving a total of $730 per year.

Another way of estimating the benefits from biogas is in terms of savings (to the society) of diesel oil estimated as follows: a total of 1560 litres of diesel fuel is used per year in the pump. Since the tubewell continues to use 20% diesel[1] (i.e. 312 liter per year), the total savings are 1248 liter, of diesel, and at a cost of $0.25 per liter, a total of $312 per year is saved. But the annualized capital and O & M cost of the diesel engine are $115, which should be excluded from operating costs or added to the benefit side. Therefore, the benefit from the tubewell is $427 per year. The second alternative is used since in the former case the hours of operation used are potential and not necessarily the actual use. Furthermore, computing by wage may give the wrong impression that there is a cost in terms of one less person employed, although the pump man does not belong to the village in any case.

[1] In the project report, it was assumed that a mixture of 20% diesel and 80% gas will be used for running for dual-fuel engine for the tubewell. Actual consumption of diesel turned out to be different. A mix of one-third diesel and two-thirds gas.

Table A-10 provides a breakdown of the quantificable benefits of the community biogas plant under the two assumptions discussed above.

Estimation of Costs

Table A-11 presents capital costs of the plants while Table A-12 gives details of operating costs. It may be noted that of the total capital costs of $17293 at shadow prices, biogas plants (including gas distribution network) account for 60 percent. Electricity generator and the distribution network account for another 20 percent. In the case of operating costs, skilled labor for supervision accounts for about half the costs while fuel costs (diesel plus lubricating oil) account only for about 14 percent.

Benefit Cost Ratios

Table A-13 presents the Net Present Values (NPV) and Benfit Cost Ratios for the two alternatives. The results show that under the assumptions outlined above from the society's point of view, investment in community biogas plant is not profitable. If Assumption 3 is considered, i.e. if the value of gas is taken in terms of resource costs of providing equivalent soft coke, the B-C ratio is very low, i.e. only 0.012. The NPV will be marginally positive if the annual benefit is on the order of $3386 in place of $1585. This would be the case if the price of soft coke is doubled and the import cost of kerosene/diesel also increases approximately by 100%. Hence, the investment in community biogas plant would become socially profitable only when fuel costs increase by 100% from their present levels. In the case of Assumption 2, the B/C ratio is 0.596 and it would be

marginally greater than unity if the annual benefit is higher by $ or so, i.e. by about 27% of the present estimate. However, it must be remembered that in this method of Assumption 2, about half of the estimated annual benefits are from value of additional N content of manure which may or may not be available to the farms or may not be as beneficial to the farms as is assumed here. This indicated that there is immediate need to firming up data on NPK contents of cow dung, dried cow dung manure, dried slurry from biogas plant, etc. under field conditions.

Conclusion

The analysis above shows that if priority is given to cooking and lighting in utilization of gas the benefits of a community biogas plant do not outweigh its costs.

The method of "Alternative Uses" in estimating benefits provides a better B/C ratio than using Resource Cost Analysis, but both methods are based on equally shaky assumptions. It is clear that there is a need for more in-depth observation of the circumstances surrounding the introduction of this community biogas plant.

The present analysis was based on the assumption that there will be a 100% availability of dung to be used in the biogas plant. Such an assumption may be unrealistic. If the dung is reduced, less gas is supplied and thus already precarious benefits from the plant are reduced even further, while the costs will remain the same.

It is interesting to note that the economics of biogas technology depend on the following assumptions:

(i) The calorific content of different fuels such as cow dungcakes, fuelwood used in cooking, plant residues, kerosene and biogas.

(ii) The efficiencies with which these fuels are being used currently or the possible equipments which could lead to higher efficiencies.

(iii) The NPK contents of different organic fertilizers and the yield-fertilizer response functions for organic fertilizers under different agronomic conditions and crop rotations.

(iv) The behavioral aspects of use of energy sources or organic fertilizers, such as present use patterns, actual and perceived constraints to their use, etc.

It is not clear how the benefits of the project are perceived and received by different beneficiaries. The richer farmers view lighting benefits as most important while others do not attach too much importance to lighting and are not willing to pay Rs five per month per household for the bulbs. Benefits from cooking and tubewell operation are also distributed unequally.

It must be kept in mind that this village is not a typical village in India. It provides particularly favorable conditions in which a biogas plant was implemented. There are ample supplies of cow dung, the distribution of land and income is relatively even and the literacy rate is higher than average. If a community biogas plant is uneconomic and difficult to operate in such favorable conditions, it is difficult to justify its use in other situations.

TABLE A-1

MAJOR CHARACTERISTICS OF THE VILLAGE

LOCATION: About 4 miles from a railway station in Etawah district of Uttar Pradesh, India

POPULATION:

Adults	81
Minors	96
Total	177

Number of Households - 27
Number of Cultivative Households - 25

LIVESTOCK

Cows and Bullocks	41
Buffaloes (male and female)	35
Young Calf and Buffaloes	35
Goats	25
	136

DUNG PRODUCTION

Kgs per day	1362
Tons per year	490

LAND USE AND CROPS

Total Land Area (operated)	106 acres
Irrigated Area	25 acres
Major Crops	Paddy, Ashar (Lentils), Mustard

ENERGY SOURCES

No Electricity

Kerosene for Lighting

Plant Residues, Dung Cakes and Fuelwood for Cooking

Animals for Crop Production

TABLE A-2

MAJOR COMPONENTS OF THE VILLAGE LEVEL COMMUNITY BIOGAS PROJECT

A. Biogas Plants

Two units: 35 M^3 + 45 M^3 per day capacity

or 2800 F^3 (cft) per day capacity

B. Dual-Fuel Engine and Related Machinery

Duel-Fuel Engine	5 HP
Tubewell	4 HP
Flour Mill	5 HP
Thresher	5 HP
Chaff-cutter	2 HP

C. Electricity Generator

Electricity generator coupled with a dual-fuel engine 3.5 HP

D. Distribution System

Gas through pipes for cooking for 27 households and electricity through distribution lines for street lighting and houses.

TABLE A-3. KCAL EQUIVALENTS OF PRESENT ENERGY USE BY DIFFERENT SOURCE FOR EACH CATEGORY OF HOUSEHOLDS PER MONTH

Category (Size of Operational Land Holding	No. of Households	Dung Cake		Plant Residue		Firewood		Total	
		Net. Kcal/ Month	% of Total	Net. Kcal/ Month	% of Total	Net. Kcal/ Month	% of Total	Net. Kcal/ Month	% of Total
Small (Less than 1 ha)	5	216223	21.3	406908	23	0	0	623203	
% of total small category energy consumption.		35		65		0		100	20.3
Medium (1 ha - 2 ha)	11	324253	31.9	610470	34.6	46383	16.3	981105	
% of total medium category energy consumption.		33		62		5		100	32
Large (> 2 ha)	10	476238	46.8	748326	42.4	238354	83.7	1462918	
% of total large category energy consumption		33		51		16		100	47.7
Total	26	1016714	100	1765776	100	284736	100	3067226	100

TABLE A-4. CONSUMPTION OF FUELS FOR COOKING AND LIGHTING PER MONTH PER HOUSEHOLD

Category of Farmer (Size of Operational Holding)	Cooking Needs				Lighting	
	Dung Cakes (kilograms)	Plant Residues (kgs)	Fuelwood (kgs)	Total Useful Energy (Net) (Thousand kcals)	Kerosene (litres)	Net Useful Energy (Kcal)
Small (Less than 2.3 acres)	158.0	126.0	-	124.6	1.60	2752
Medium (2.31 to 4.49 acres)	107.7	89.9	36	89.2	1.54	2649
Large (More than 4.5 acres)	217.5	144.8	74	146.3	3.50	6020
Total	483.2	360.7	110	360.1	6.64	11421

NOTES:

1. Effective heat available is estimated on following assumptions:
   Dungcakes: 2444 kcal/kg @ 12.2% efficiency = 273.7 kcal/kg

   Plant Residues: 3800 kcal/kg at 17% efficiency = 646 kcal/kg

   Fuelwood: 4702 kcal/kg at 13.7% efficiency = 644.2 kcal/kg

   Kerosene: 11,110 kcal/kg or 7936 kcal/litre @ 21.7% = 1720 kcal/litre.

2. For assumptions and further discussion, SEE Bhatia (1977), Harrington (1977), NCAER (1965).

3. Every Household does not consume each fuel in the same quantities. Hence, the totals only indicate average consumption.

TABLE A-5. GAS REQUIREMENTS PER HOUR OF DIFFERENT OPERATIONS (IN CUBIC FEET)

Operation	Case I With Electricity Generator	Case II Without (Using Gas For Lighting
Cooking *2 26 Burners	247	247
Lighting (26 Homes) (180 Watt)*4	41	117
Lighting (Streets) (720 Watt)*4	11.5	63
Drinking Water *1 From Tubewell	6.56	6.56
Slurry Water *1 From Tubewell	.04	.04
Tubewell For Irrigation (4 HP Used)*5	53.4	53.4
Flour Milling (5 HP Actually Used)	75	75
Threshing (5 HP)	75	75
Chaff-Cutting (2 HP Used)	30	30

*1. Of the total water in overhead tank, 53.f^3 is used to mix with slurry - since it takes total of 6.6f^3 of gas (60f^3 gas/hr 6.6 minutes to fill tank, then only .04f^3 of gas is used for slurry water and rest for drinking water.

*2. Each burner requires 9.5 cft/hour of operation.

*3. Flour milling, threshing, chaff cutting and tubewell require 15f^3/HP/hr. estimated total based on HP actually used.

*4. Generator uses total of 52.5 cft gas/hr - i.e. 15cft/HP/hr and only 3.5 HP used. For gas lamps, 4.5 cft/lamp hr. is used.

*5. In the first hour of operation, 6.6 cft used for drinking and slurry water, and 53.4 cft for irrigation - in all other remaining hours of day, all of tubewell operates (60cft) is used for irrigation.

TABLE A-6. DAILY USE OF GAS BY TYPE OF ACTIVITY IN SUMMER AND WINTER

Type Of Activity	SUMMER (Mar.-Oct.) Total (cft/day)	SUMMER % of Total Demand	WINTER (Nov.-Feb.) Total (cft/day)	WINTER % of Total Demand
Cooking*7	1482	54.3.	1358.5	72.9
Generator For Lighting*2 *6 Project case	210	7.7	236.3	12.7
Tubewell For Irrigation	320.4	11.7	133.5	7
Flour Mill*3	112.5	4.1	75	4
Thresher*3	300	10.9	-	-
Chaff Cutter*4	60	2.2	60	3.2
Total Demand	2485	100	1863	100
Total Supply*8	2728		1893	

NOTES:

*1. Dual-fuel engine runs a thresher (4 hrs/day in summer) chaffcutter (2hrs/day in summer and winter each), flour mill (4 hrs/day in winter and 1 hr/day in summer) and tubewell (2.5 hrs/day in winter 6 hrs/day in summer) and 1 hr/day (winter), .5 hr/day (Summer) extra thus the total gas required for dual-fuel engine in summer is 885 cft and in winter is 285 cft.

*2. 46 x 40 watt bulbs for houses and 18 x 40 watt tubelights for street lighting - 2560 watt = (.746 kw/HP) = 3.4 or 3.5 HP (+ loss) x 15f^3 = 52.5 cft gas/hr used by generator.

*3. 75 f^3/hr

*4. 30 f^3/hr each

5. Only 6.6 minutes used for filling overhead tank of 357 f^3 capacity (.9 f^3/sec.) assumption still held that it requires 60 f^3 gas/hr to run tubewell.

6. Alternative 2: One lamp per household, used 4 hrs/day, requiring 4.5 f^3 of gas/hr., that is 468 cft/day in both summer & winter.

7. 1 burner per household, used 6 hrs/day, requiring 9.5 f^3/hr.

8. From 2 plants (one of 35 m^3 and other 45m^3) - summer conversion rate of 1.96 f^3/kg/day. winter conversion rate of 1.36 f^3/kg, and total of 1392 kg. gobar/day.

9. Total capacity of plants is 2857 f^3/day, but since gas is being continually used and generated, more gas than above can be produced.

TABLE A-7. YEARLY VALUE ADDED FROM THREE SOURCES OF ENERGY FOR COOKING BY HOUSEHOLD CATEGORY

tegory (Size of erational Land lding	Number of Households	N Content of Dung $	Plant Residue $	Fuelwood	Total $
all (Less Than 1 ha)	5	320		-	320
dium (Between 1 ha d 2 ha)	11	480	unquantifiable	27	507
rge (More Than 2 ha)	10	705		139	844
tal	26	1505		166	1671

Note: 1. see text for calculations

TABLE A-8. SAVINGS IN COST OF KEROSENE FOR HOME LIGHTING PER HOUSEHOLD

Category (Size Of Operational Holding	Number Of Households	Savings In Kerosene Per Year $	Average For Households $
Small (Less Than 2.3 Acres)	5	24	4.8
Medium (2.31 - 4.49 Acres)	11	50.8	4.6
Large (More Than 4.5 acres)	10	108	10.1
TOTAL	26	182.8	

TABLE A-9. YEARLY RESOURCE COSTS BY HOUSEHOLD CATEGORIES FOR COOKING

Category (size of operational land holding)	number of households	soft coke replacing dung cakes $	soft coke replacing plant residue $	soft coke replacing fuelwood $	Total
Small (less than 1 ha)	5	66	114.5	18.4	198.9
Medium (between 1 ha-2 ha)	11	45	78	12.16	135.6
Large (more than 2 ha)	10	90.7	157.5	25.4	273.6
Total	26	201.7	350	56.4	608.1

TABLE A-10. YEARLY QUANTIFIABLE BENEFITS BY ACTIVITY

Activity	Alternative Use Method $	Resource Cost Method $
Cooking	1670	608
Lighting	281	281
Tubewell	427	427
Flour Mill*[2]	272	272
Total	2650	1588

Notes: 1. See text for calculations

2. Assuming that Rs 5 or $0.63 will be earned for grinding a quintal of wheat in an hour. It is assumed that the flour mill will be operated for 435 hours per year.

TABLE A-11. CAPITAL COSTS OF VARIOUS UNITS AT MARKET AND SHADOW PRICES

Unit(s)	At Market Prices		At Shadow Prices	
	$	Per cent of Total Costs	$	Per cent of Total Costs
1. Bio-Gas Plants	8908	45.5	7159	41.4
2. Gas Distribution	3325	17	3540	20.5
3. Dual-fuel Engine and Related Machinery*	3598	18.4	3265	18.9
4. Electricity Generator	2794	14.3	2533	14.6
5. Electricity Distribution	938	4.8	797	4.6
Total	19563	100	17294	100

SOURCE: For details of assumptions see Annex Table 1 in Bhatia and Niamir (1979).

*1. There is a subsidy for 54 burners (two per household), at an approximate cost of Rs. 20-25 (or $2.5-3) each, which is not included in the capital cost since it is relatively marginal.

*2. Excludes cost of chaff cutter and threasher.

TABLE A-12. ANNUAL OPERATING COSTS OF COMMUNITY BIO-GAS PLANT

Units	At Market Prices		At Shadow Prices	
	$	Percent of Total	$	Percent of Total
1. Bio-Gas Plants	700	34.3%	256	16.4%
2. Fuel Cost of Duel Fuel Engine and Related Machinery*[2]	1082	53%	1066	68%
3. Fuel Cost of Generator and Electricity Generation	246	12%	228	14.6%
4. Kerosene Cost For One Month of Lighting	15	.7	15	.1%
Total	2043	100	1565	100

TABLE A-13: NET PRESENT VALUES AND BENEFIT COST RATIOS UNDER ALTERNATIVE ASSUMPTIONS

	Assumption 2 (Benefits in Alternative Use)	Alternative 3 (Resource Cost of Soft Coke)
1. Annual Benefits (B)	$ 2649	1587
2. Present Value of Benefits Over a 20 Year Life, PV (B)	$ 25169	15077
3. Annual Operating Costs* (C)	$ 1565	1565
4. Present Value of Operating Costs* PV (C)	$ 14869	14869
5. Present Value of Capital Costs* PV (I)	$ 17292	17292
6. Net Present Value NPV=P(B)-P(C)-P(I)	$ 6992	17084
7. Benefit Cost Ratio $\frac{B}{C}$ $\frac{P(B)-P(C)}{P(I)}$	$ .596	.012

*Excluding the costs of chaffcutter, and thresher machines except the fuel costs which are treated as benefits from the bio-gas plant.

Annex B

Electricity Generation from a Village-Scale Biogas Plant

In this case study, we will present some results of the economic analysis of electricity generation from a village-scale biogas plant. It may be mentioned that the size of the electricity generation equipment in this village is limited by the availability of cow dung and other animal wastes in the village since the present technology does not enable the use of crop residues or water hyacinth as biogas input. Based on the availability of 1400 kgs of wet dung per day, the gas production in summer has been calculated as 2760 ft^3/day (@ 1.96 ft^3/kg) and in winter as 1900 ft^3/day (@ 1.36 ft^3/kg). If it is assumed that a 15 HP dual-fuel engine coupled with an electricity generator will be used and fuel inputs would be in the ratio of one-third diesel and two-thirds biogas, then the available quantity of gas can be used to run a 15 HP engine for 12 hours/day during winter and 1.75 hours/day during summer.

The capital and operating costs of electricity generation are set out in Table B-1. It may be noted that annualized capital charges account for a little over 50 percent of the total annual costs. Using the figures of annual electricity generation (implying a load factor of 66 percent), the unit costs of electricity generation from biogas are $0.0584/kwh at market prices and $0.054/kwh at shadow prices.

For the sake of comparison, one can estimate the costs of central electricity generation from a conventional coal-based thermal power plant (100-200 MW capacity) in India. Average capital costs of generation and high voltage transmission are assumed at $1000/kw while the capital costs

of distribution lines (LT lines) are estimated at $2000 per kilometer. Assuming a 66% load factor (5880 hours/year as in biogas unit), 1.14 kgs of coal/kwh, and $20 per ton of coal, the average costs of generation and transmission can be estimated at $0.046 per kwh excluding the costs of LT distribution lines. The effect of costs of LT lines on the unit cost of electricity generation would be site specific and would depend on the additional power demand that is served by this LT line. If it is assumed that the extension of the LT line for a distance of one kilometer is undertaken exclusively for the village where the biogas plant is to be installed, the entire capital cost of $2000 (for a length of one km) should be attributed to the delivered cost of electricity made available to this village from a central generating station. The additional annual costs on this account are estimated as $0.0034/kwh, giving a total cost of $0.0494/kwh which is somewhat lower than the costs of generation of $0.0584/kwh at market prices using biogas for electricity generation. The costs of central electricity generation would be lower than those for electricity from biogas unit if the length of distribution (LT) lines is less than 3.5 kilometers. This shows that under the assumptions outlined above, decentralized electricity generation from biogas will be economic vis-a-vis central generation based on coal if biogas plant is located more than 3.5 kilometers away from the nearest HT/LT distribution line. Similar calculations can be made for regional/central electricity generation based on fuel oil or biomass or with hydroelectric power.

It is recognized that the above cost estimates as well as load factor assumptions may have to be modified for other regions/countries. However, the above calculations are intended to show the type of economic calculations

that should be made in order to provide background for the role of biomass-based electricity generation.

Electricity Generation from Biomass: Comparative Cost Estimates for 3MW and 20 MW Units.

In this section an attempt is made to illustrate the use of economic principles involved in estimating costs of electricity generation from biomass sources, especially fuelwood. Two examples have been studied:

(i) A 3MW unit using fuelwood produced under a Social Forestry type of scheme and meeting the electricity demand of a few villages and

(ii) A 20MW unit using fuelwood from a forest area and catering to the electricity demand of one or two large scale industrial units, a few small scale units and agricultural demand of a few villages.

Ideally, the illustrative economic analysis performed below should be done in the context of location-specific details about capital costs of equipment and transmission, fuelwood costs, O & M costs, costs of transportation of fuelwood, etc. However, such information for site-specific projects in developing countries is not readily available. Hence, the calculations made below on the basis of available project reports have to be considered in the nature of "order of magnitude" figures and should be modified for specific projects.

The following points may be noted from the data on costs of electricity generation from fuelwood presented in Tables B-2 and B-3.

(i) In the case of capital costs per kw, the figures used are $1400/kw for a 3MW unit and $1361/kw for a 20MW unit. This does not show any appreciable economies of scale which are known to exist in

power plants of this range. This may be due to differences in sources of data, number of items included in capital costs and the methods of calculation of costs and differences in location. Given the lack of disaggregation in available data, it was not possible to make these data comparable. However, these data do indicate "order of magnitude" figures.

One other aspect of cost data that needs to be looked into carefully is the "mark-ups" of capital costs which are built into the estimates of capital costs of imported machinery in a developing country. For example, in this case the cost figure used is $1400/kw which may be inclusive of these "mark-ups."

(ii) The major difference in costs is in terms of fuelwood costs. In the case of a 3MW plant, it is assumed that it will use fuelwood which will be specially grown for this unit in a social forestry type of scheme. This would require diversion of existing land from other uses to fuelwood plantations. It is generally assumed[1] that marginal land for fuelwood is available free of cost since this land would have no alternative economic use for the period of the project. It must be emphasized that this is a very important assumption since in the case of most of the land-scarce developing countries, land may be in current use as pastures or as low-yielding crop land. In the case of 2389 hectares of land required to produce fuelwood for the 3MW plant, it is difficult to assume that such land would be available which has no alternative economic use. Hence, it is assumed that land is either being used or can be potentially used to grow low-yielding food crops (or equivalent fodder) giving a crop/fodder output of one ton per hectare valued at $200/ha. This is the figure that has been used in these calculations. The costs would be location-specific and would have to be modified in the context of a particular site/project.[2]

In the case of a 20MW plant which is using fuelwood available by cutting existing forests, the valuation of opportunity cost of fuelwood becomes very difficult. If wood from the concerned forest area could be used for timber or paper industries, the opportunity cost of this wood be equal to benefit foregone in these alternative use(s). If, however, the quality of wood is such that it can be used only as fuelwood, the opportunity cost of fuelwood has to be estimated in terms of opportunity costs of inputs used in fuelwood, i.e. land, labor and other resources.

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[1] For example, see the FAO case study on Village Fuelwood Plantations in Korea, FAO Forestry Paper 17, FAO, Rome, 1979.

[2] The estimation of opportunity cost of land and other inputs used is a very complex issue and is discussed elsewhere in the report.

The opportunity cost of land would, in turn, depend on the value added in using this land for growing crops or for growing fodder for livestock. The opportunity cost of labor can be estimated in terms of its shadow price. Since such valuation would require a detailed economic analysis of alternative uses of land, labor and other resources, it is considered beyond the scope of this case study. For the sake of illustration, we have used a figure of $20 per ton as the cost of fuel as indicated in the Philippines Reforestation/Rural Energy Project cited earlier. In addition, we have used a transport cost of fuelwood of $5/ton in line with the data used in the case of a 3MW unit.

(iii) The O & M costs of electricity generation plants have been taken from their individual source reports.

The results of the cost estimates in the two cases are presented in Tables B-1 and B-2. The following points about these results may be noted:

(i) The costs for 3MW unit range between 10.87 cents/kwh at market prices to 9.6 cents/kwh at shadow prices. This difference is mainly on account of shadow wage rate of zero used for unskilled labor for weeding, maintenance and transport.

(ii) The costs for a 20MW unit are 8.5 cents/kwh at market prices, about 20 percent lower than in the case of a 3MW unit. As was pointed out earlier, this difference is not on account of economies of scale in capital costs. This is arising, mainly, on account of costs of input which go into fuelwood production. In the case of a 3MW unit, opportunity cost of land was valued as benefit foregone in terms of value of agricultural crops. However, in the case of the 20MW unit, similar estimates were not used and a national figure of $20/ton was used reflecting the costs of inputs in fuelwood production.

(iii) The costs of electricity from fuelwood in the above examples is considerably higher (40-50 percent) than the cost of electrictiy from biogas in the earlier example. Although capital costs and other assumptions are not strictly comparable and an analysis for a site-specific case should be done, the above results do indicate the need for a careful comparison of available alternatives.

TABLE B-1: COSTS OF ELECTRICITY GENERATION FROM A VILLAGE-SCALE BIOGAS PLANT

	Market Prices	Shadow Prices
A. Capital Costs		
15 hp generator set	4560	4190
civil works for	1000	884
distribution cost	900	800
Biogas plants.	12,233	10,697
	18,693	16,571
B. Annualized Capital Charges at 10% discount rate	1869	1657
C. O&M Costs		
Fuel costs (including lube oil)[1]	1081	1081
generator maintenance	420	376
(including biogas maintenance)	1501	1457
D. Annual Costs (B&C)	3370	3114
E. Annual electricity generation (kwh)	57,685	57,685
F. Cost of electricity generation	$0.0584/kwh	$0.0540/kwh

[1]Gas Production: 2760 ft^3/day during Summer (March-October), 1900 ft^3/day in Winter (November-February) due to lower output of gas per kg of cow dung.

[2]Summer operation 210 days at 17.5 hours/day producers 41400 kwh.
Winter operation 120 days at 12 hours/day produces 16285 kwh.
(Engine/generator capacity 15 hp, Gas consumption 14 cft/kwh).

Diesel/Price - 0.25 $/liter, 0.05 liter/hp-hr (diesel consumption).
Lube Oil Price - 0.375 $/liter, 0.017 liter/hp-hr (lube oil consumption).

TABLE B-2: COSTS OF ELECTRICITY GENERATION FROM FUELWOOD: 3MW PLANT

	Market Prices	Shadow Prices
A. Capital Cost		
$1400/kw	$ 4.2 million	$ 4.95 million
B. Annualized Capital Cost (at 10% discount rate)	$ 0.42 million	$ 0.495 million
C. O and M Costs		
Fuelwood Costs:		
Opportunity Cost of Land ($200/ha for 2389 ha)	$ 477,800	$ 477,800
Labour Costs ($60/ha)	$ 143,340	0
Transportation of Fuelwood ($5 - $2/ton)	$ 95,550	$ 38,220
Operation and Maintenance of the Plant	$ 6,517	$ 1,997
D. Total Annualized Cost (C + B)	$ 1.1428 million	$1,013,017
E. Annual Electricity Generation (kw/hr)	$10.512 million	$10.512 million
F. Overall Cost $/kw/hr	$ 0.1087	$ 0.096

SOURCE: Reforestation/Rural Energy Project for Phillippines, USAID, Project Paper, July 1980 and Survey of Rural Energy Consumption in Northern India by NCAER (1978).

ASSUMPTIONS:

1. Foreign exchange is given a premium of 25% under shadow prices while unskilled labor is valued at zero.

2. Wood production 8 tons/ha/year; 6000 Btu/lb of wood; load factor 40% system efficiency 15.1%.

3. It has been assumed that benefit foregone from land used for fuelwood is one ton per hectare of food grains valued at $200/ton.

TABLE B-3: COST OF ELECTRICITY GENERATION
FUELWOOD: 20MW PLANT

(Million $)

	Market Prices	Shadow Prices
A. Capital Costs $(136./kw)	$ 27.22	$ 32.22
B. Annualized Costs at 10%	$ 2.72	$ 3.222
C. O and M Costs		
1. Input: Costs for Fuelwood Production (excluding Land) @ $20/ton	$ 2.548	$ 2.548
2. Opportunity Cost of Land	*	
3. Transportation Costs of Fuelwood ($5 - $2/ton)	$ 0.637	$ 0.254
Operation and Maintenance of the Plant	$043.	$ 0.013
D. Total Annual Cost (B + C)	$ 5.948	$ 6.037
E. Annual Electricity Generated (kw-hr)	$ 70.08	$ 70.08
F. Cost/Kw-hr (D/E)	$ 0.085	$ 0.086

*Discussed separately in the text.

SOURCE: Data obtained from North-West Pacific Corporation, Seattle, USA for a unit in Oak Ridge, USA on load factor.

ASSUMPTIONS:

1. System utilization 40%, system efficiency 15%.

WOOD PRODUCTION:

127,400 tons from 15,900 hectares assuming 8 tons/ha/yr and 6000 Btu/lb. Shadow price of unskilled labor zero; 25% premium on Foreign exchange in capital cost.

Annex C

Estimates of Calorific Value Parameters

In this appendix, we describe the various estimates of values of important parameters used in different studies. The objective of this note is to show that the available information is rather inadequate on crucial parameters which determine the social profitability of biogas plants. The estimates of the following parameters are discussed: calorific value of biogas efficiency of biogas utilization; calorific value of soft coke and its utilization efficiency; calorific value of cow dung cake and its utilization.

Calorific Values of Gas

The fuel value of biogas is directly proportional to the amount of the methane[1] it contains since other gases (carbon dioxide, hydrogen, nitrogen) are not combustible. Most of the studies assume a thermal value of biogas instead of indicating how much combustible methane is in the gas. ICAR (1976) has quoted from a paper by Biswas (1974) saying that the appropriate composition (by volume) of the gas evolved from a cow dung gas plant is as follows: Methane 50-60%, Carbon dioxide 30-40%, hydrogen 5-10% and nitrogen 4-6%. The gas burns with a smokeless blue flame and has a calorific value of 550 BTUs per ft^3 or 135 kilocalories per ft^3.

1. On an average, methane has a fuel value of 950-1,050 BTUs (British Thermal Units) per cubic foot (cft or ft^3). If the biogas contains 60 percent methane, its value will be between 570-630 BTUs. (One BTU is the amount of heat required to raise the temperature of one pound of water by 1° F. at STP).

No experimental data has been reported in the paper indicating calorific value of biogas actually obtained from the plant.

Parikh (1976) has also accepted the assumption of 135 kcal per ft^3. NCAER (1965) have assumed a methane content of 60 percent implying a calorific value of 575 BTU/cft or 141 kcal per ft^3. KVIC (1975) says that "gobar gas consists of approximately 55 percent methane and 45 percent carbon dioxide."

Sathianathan (1975) has pointed out that compared with other gases biogas has very low fuel value, though like most other gases the efficiency is 60 percent. He has indicated a range for fuel value of biogas as 540-700 BTUs per ct^3 as against the ft^3 the fuel value of 2,900-3,400 BTUs per ft^3 for butane. He has quoted J. Patel who gives the following calorific values for the various compositions of digestion gas:

S. No.	Proportion			Net Calorific Value per ft^3	
	CH_4 (Methane)	H_2 (Hydrogen)	CO_2 (Carbon dioxide)	BTU	Kcal
1	60	10	30	579.2	145
2	50	10	40	492.2	124
3	45	10	45	441.2	110
4	40	10	50	359.2	90
5	35	10	55	349.2	87

It is not very clear if these values have been estimated from some experimental data or these are just hypothetical estimates. He has also mentioned that "in many so-called family plants, about half of the total

gas produced is carbon dioxide, and sometimes its proportion is even higher." This would imply a 40 percent methane ratio giving a calorific value of 359 BTUs (90 Kcal) per ft^3. Bhavani (1976) has calculated a median value of the figures given by Sathianathan and used a calorific value of 111.2 $kcal/ft^3$. Harrington (1977) has noted that calorific values range between 87 and 145 $kcal/ft^3$ and pointed out that an assumption of 135 $kcal/ft^3$ would imply rather good digestion conditions.

Efficiency of Gas Utilization

Regarding the efficiency of gas utilization, no estimates of actual utilization are available. Almost all the studies have assumed a 60 percent thermal efficiency. KVIC (1975) indicates that special burners developed by the Commission have to be used to get 60 percent efficiency. It has also pointed out that if coal gas or Burshane burners are used for gobar gas the efficiency is very low (35 percent instead of 60 percent). NCAER (1965, p. 114) gives results of two experiments on fuel efficiency in which the calorific value of gas is taken as 473 BTU (or 118 kcal) per ft^3 and utilization efficiency ranges between 54.8 percent and 55.9 percent. In view of lack of reliable data on the actual efficiency of utilization with the burners being used currently, it is difficult to accept the assumed value of 60 percent. However, we have not changed the value of this parameters in our sensitivity analysis. Instead, we have assumed an effective heat utilization of 70 $kcal/ft^3$ in one which may be obtained by a number of combinations such as 117.7 $kcal/ft^3$ with 60 percent efficiency or 120.8 $kcal/ft^3$ with 55 percent efficiency and so on.

Calorific Value of Soft Coke and the Efficiency of Utilization

KVIC (1975, p. 13) has used a calorific value of 6,292 kilocalories per kilogram. The Commission has not indicated any source for these figures. It has indicated a thermal efficiency of 28 percent. NCAER (1965, p. 112) has quoted figures for efficiency of various appliances as per experiments in Shri Ram Research Institute, New Delhi. Out of the ten experiments conducted on soft coke, the calorific value in nine experiments was taken as 6,297 kcal/kg (or cal/gms). The percentage of heat utilized in eight out of ten experiments ranged between 22.2 percent and 28.7 percent. Parikh (1976) has also used a figure of 28 percent efficiency of coal burning. However, NCAER (1965, p. 110) has given the following figures: one tonne soft coke, heat content of 5,772,000 kilocalories (i.e., 5,772 kcal/kg) and the efficiency of utilization in domestic oven is 17.7 percent. These figures are also in line with those used in the Report of the Energy Survey Committee of India submitted in 1965. On account of the significant variations in these two estimates, we have used the first estimate in our Reference Results and the second estimate (lower figures) in our sensitivity analysis.

Calorific Value of Cow Dung Cakes and Efficiency of Utilization

KVIC (1975, p. 13) has assumed that the calorific value of cow dung cakes is 2,092 kcal/kg and the efficiency of utilization in open chulah is 11 percent. NCAER (1975, p. 114) uses a figure of 2,130 kcal/kg and gives efficiency figures of 10.7 and 10.1 percent. In its conversion factors given on p. 110, NCAER (1965) gives a value of 2,440 kcal/kg and 11.2 efficiency of utilizations. Parikh (1976, p. 98) has given a calorific value of 3,300 kcal per kg (dry weight) for dung cakes and burning efficiency of 11 percent.

It may be seen from the above discussion that there is need to conduct experiments under different field conditions and standardize the values of these parameters for various regions in the country.

In addition, the calorific content of other energy sources are as follows:

plant residue	= 3800 kcal/kg at 17% efficiency	= 646 kcal/kg
fuel wood	= 4702 kcal/kg at 13.7% efficiency	= 644.2 kcal/kg
kerosene	= 11,110 kcal/kg or 7,936 kcal/litre at 21.7%	= 1720 kcal/litre

The other assumptions made in the paper are summarized below:

1. Daily dung production rates by type of animal, by household category:

cow/bullock:	12.73 kg	(small category)
	12.7 kg	(medium category)
	12.75 kg	(large category)
buffalo:	18.45 kg	(small category
	14.42 kg	(medium category)
	18.43 kg	(large category)
young cattle:	9 kg	(small category)
	9 kg	(medium category)
	7.5 kg	(large category)

2. Gas requirements per operation.

cooking burner:	9.5 cft/hour
to fill water tank:	6.6 cft/day
tubewell irrigation:	53.4 cft for first hour of day, 60 cft/hour rest of day
flour milling, threshing and chaff cutting:	each 15 cft/HP/hour
generator:	15 cft/HP/hour
gas lamps:	4.5 cft/lamp/hour

3. Gas production from a combined capacity of $35m^3$ plant and $45m^3$ plant:

summer conversion rate = 1.96 cft/kg/day
winter conversion rate = 1.36 cft/kg/day

4. 1 kg dry dung = 5 kg wet dung

5. Nitrogen content of dung:

N content = 1% per kg of wet dung (since it is used after being dried in the open)

6. 1 litre kerosene = 2 kwat/hrs of lighting

7. Costs (including transportation):

net import cost of nitrogen	=	Rs 5.4/kg
net import cost of urea	=	Rs 2/kg
price of fuel wood in small towns	=	Rs .25/kg
cost of soft coke	=	Rs .135/kg
cost of kerosene	=	Rs 2/litre