ANNEX 2

ECONOMIC AND FINANCIAL COMPARISON OF RURAL ENERGY ALTERNATIVES

1. The economic cost analyses presented in Chapters 3 and 4 were calculated using a spreadsheet model (in EXCEL, version 5.0) which computes discounted cash flows for rural energy systems providing equivalent levels of service.

2. The economic analysis was performed from the country's perspective and indicates which alternatives best manage national resources in meeting energy requirements. All financial transfers (e.g., duties, taxes, etc.) are removed and economic (i.e., shadow) prices are used rather than market prices.

3. The financial analysis was performed from the customer's perspective and indicates customers' outlays for receiving energy services. Unlike an economic analysis, costs considered in a financial analysis are based on market prices including taxes and duties, subsidy and tax benefits, and debt servicing.

ENERGY REQUIREMENTS

4. The first step in performing the economic and financial analyses is to ensure that the compared rural energy alternatives provide **equivalent levels of energy service** to residential, commercial, and industrial customers.

5. For rural residential loads, there are generally two types of service which are cost effectively served with electricity: lighting and appliance loads (rural energy requirements for cooking, space heating, etc. are better served with other forms of energy). In addition to incandescent and fluorescent electric light bulbs, lighting can be provided with candles, flashlights, and/or kerosene lamps (pressurized or wick). The analysis in Chapter 3 defines lighting service in terms of the number of hours of "task" lighting (e.g., for reading, sewing, etc.) and "area" lighting (courtesy lighting for both interior and exterior). Electric appliance loads include radios, televisions, and fans and have been defined in terms of energy use (watt-hours (Wh) per day, month, or year).

6. Each rural energy alternative must also provide equivalent energy services to commercial and industrial customers (e.g., ice makers, rice mills, etc.). Such "productive" loads have been specified in terms of capacity (kW) and energy (kWh) requirements. For

dispersed rural energy schemes (solar home systems, kerosene/battery designs - see Rural Energy Alternatives below) productive loads are supported with dedicated diesel engine generators. In the case of isolated or central grids, productive loads are assumed to be connected to the distribution network.

CRITERIA FOR VILLAGE SELECTION

7. The second step in the analysis is to **define the characteristics of the village to receive energy services** in terms of the number of household connections, village load density, distance from the village to the central T&D grid, number and size of productive loads, and residential and productive load growth. These parameters are especially important when comparing grid and dispersed (i.e., non-grid) rural energy supply options.

8. The residential load density and the number of household connections are important analysis inputs because of their effects on distribution grid costs (i.e., capital and installation costs for MV and LV line, transformers, and service connections) which constitute a significant portion of total grid option costs. For a given number of residential connections, for example, increasing the service area (km^2) increases the distribution grid installation costs, but does not affect the installation costs of dispersed energy options. Similarly, fewer household connections within a given area result in higher grid installation costs per customer while the cost of providing each residence with solar home systems remains constant.

9. The analysis presented in Chapter 3 does not include the impact of productive loads on the economic niche for solar home systems. However, the spreadsheet model can (and proper least-cost planning analysis should) account for the number, size, and energy requirements of productive loads. For dispersed energy schemes, the analytical tool incorporates technical and cost information for dedicated diesel engines. In the case of isolated distribution grids, energy requirements for productive loads are added to those for residential loads to determine the appropriate diesels (and associated technical and cost data) for serving the combined loads. For servicing productive loads with power from a central grid, the model includes long-run marginal costs (LRMC) for capacity and energy.

10. The distance of an isolated village from the nearest MV or LV distribution line with sufficient capacity will affect the cost of grid-extension alternatives. The analyses in Chapters 3 and 4 assume a maximum LV line extension of 3 km. MV line-extension costs approach those for isolated grid service at approximately 10 km grid-extension distance. Capital, installation, and maintenance charges are included in the cost of grid-extension alternatives.

11. Because the marginal costs of providing energy services vary among supply alternatives, load growth is an important consideration when defining the village to be served. Demand can grow as a result of (a) additional connections (due to low initial grid-coverage rates, electrification rates and/or population growth), and/or (b) increased levels of service for existing end-users (perhaps due to improved economic conditions). The analyses account for residential load growth by specifying population growth rates and

annual electrification ratio increases. Although the spreadsheet model used to calculate the economic and financial costs presented in Chapters 3 and 4 cannot currently account for increased levels of service for existing end-users, the impact of increased levels of service can be determined exogenously. Furthermore, in its current form, the spreadsheet model does not provide for including the effects of growth of productive loads.

RURAL ENERGY ALTERNATIVES

12. Once load characteristics are defined (i.e., level of service specified, assurance of equivalent energy services, village characterized), appropriate rural energy supply technologies can be selected for economic and financial evaluation. Currently, the options for satisfying rural lighting and appliance energy requirements include solar home systems, combined kerosene lamp/automotive battery schemes, extension of the central T&D grid, and isolated distribution grids supplied with power from diesel engine generators. The following is a brief description of these rural energy alternatives:

- ***Kerosene/battery schemes***: Kerosene is used for lighting and rechargeable lead-acid batteries are used to power small appliances. Battery charging is performed at a central battery charging station which is energized either by the central transmission and distribution (T&D) grid or by a dedicated diesel engine. Each customer must transport the battery to the charging station which can be located several kilometers from the household.
- ***Solar home systems***: Lighting and energy for operating appliances are provided by lead-acid batteries charged by roof-mounted photovoltaic modules. Daily charging is dependent on sunlight availability and off-site battery-charging is not required. Battery charge controllers are used to limit the depth of discharge prior to recharging and, subsequently, preserve battery lifetimes. Fluorescent light bulbs provide area and task lighting.
- ***Isolated grids***: Diesel genset (3 - 2,000 kW) power stations serve households via a limited electrical distribution system. Only customers within reach of the isolated grid are eligible for connection.
- ***Central grid extension***: Power is provided to households from a distribution network connected to the central grid via an MV or LV line.

13. Table 1 details the equipment/energy source used to provide task lighting, area lighting, and electricity for each rural energy scheme considered.

Table 1. Equipment/Energy Source for Rural Energy Services

Rural Energy Alternative	*Lighting Equipment*		*Source of Electricity for Appliances*
	Task Lighting	*Area Lighting*	
Kerosene/Battery	Mantle lantern	Wick lantern	Battery charged at charging station
Solar Home System	10-W fluorescent bulb	6-W fluorescent bulb	Battery charged with PV panel
Isolated Grid	40-W incandescent bulb	25-W incandescent bulb	Limited distribution powered by diesel genet power stations
Grid Extension	40-W incandescent bulb	25-W incandescent bulb	Limited distribution connected to central grid

14. Once identified, the rural energy supply alternatives are sized to satisfy the defined load. For solar home systems, this step considers available insulation, and results in a system design capacity (module size in Wp and battery capacity in Ah). For kerosene/battery schemes, the type and number of lanterns, kerosene fuel consumption, battery capacity, and number of required battery charges are determined. Similarly, diesel engine size (kW), fuel and lubricating oil requirements, appropriate T&D equipment, and O&M requirements are determined for the isolated grid alternative. For the central grid-extension option, energy and capacity requirements, and T&D equipment are specified.

LEAST-COST COMPARISON (ECONOMIC BASIS)

15. After appropriate supply options have been identified and sized, the economic net present values (NPVs) of the alternatives are calculated for a 25-year period and compared. Such an analysis compares discounted cash flows over a fixed period and considers all related expenses including:

- capital costs
- installation costs
- operating and maintenance charges
- fuel costs
- replacement costs (if appropriate).

In particular, economic analysis of solar home systems should include replacement charges for the battery, PV panel and light bulbs. Similarly, kerosene/battery scheme costs include battery-recharging costs and replacement costs for batteries and lanterns. Cash flows for the isolated grid options incorporate distribution system installation and maintenance costs, connection costs, diesel engine overhaul charges, and labor costs (including any subsistence paid by the utility). Included in the NPV of the central grid-extension option are LRMC of capacity and energy supply, grid-extension installation and maintenance costs, and distribution network costs.

16. The analysis comparing rural energy alternatives on an economic basis considers economic (or shadow) prices rather than market prices. As a result, all financial transfers (e.g., duties, taxes, government levies or subsidies, and financing charges) are removed. In particular, border prices must be determined for traded inputs and outputs, and the price of non-traded goods (land, skilled and unskilled labor) must be converted from financial to economic prices.

17. Key assumptions for the economic analysis of rural household energy systems in Indonesia are shown in Table 2.

Table 2. Key Assumptions for Economic Analysis of Rural Residential Energy Systems - Indonesia Example

Solar Home Systems		*Isolated Grid*	
Effective Sun-hours	3.5 hours/day	Diesel Capacity Cost	$625/kW (220 kW) to $1780/kW (≤ 20 kW)
Solar Home System Size	50 Wp	Diesel Engine SFC	0.3 l/kWh
System Cost	$500	Diesel Fuel Cost	$0.19/l
Module Lifetime	10 years	Lube Oil Consumption	0.0030 l/kWh
Module Replacement Cost	$300/panel	Lube Oil Cost	$1.41/l
Battery Lifetime	3 years	Overhaul Cost	$1875 (≤ 20 kW) to $28,830 (220 kW)
Battery Cost	$50	Overhaul Period	18,000 operating hours
Bulb Lifetime	1 year		
Bulb Replacement Cost	$3.50	***Central Grid Extension***	
		LRMC of Supply	$0.063/kWh
Kerosene/Battery		MV Line Costs	$9825/km installed
Battery Capacity	70 Ah, 12V	LV Line Costs	$5085/km installed
Battery Cost	$45	Load Coincidence Factor	80%
Battery Lifetime	2 years		
Recharge Cost	$1/charge	***Distribution Grid (for Isolated/Central Grid Systems)***	
Petromax Cost	$15	Distribution Line Requirements	5 km/km^2 service area
Petromax Life	4 years	Power Factor	0.8
Petromax SFC	0.06 l/h	Distribution Losses	10%
Wick Lantern Cost	$5	LV Line Costs	$5085/km installed
Wick Lantern Life	3 years	LV Line per Transformer	4 km/transformer
Wick Lantern SFC	0.04 l/h	Transformer Cost	$3415/trans. installed
Kerosene Cost	$0.19/l	Connection/Wiring Cost	$68/customer
		General	
		Discount Rate	12%
		Productive Load Capacity Factor	17%

18. Break-even conditions (i.e., conditions under which two energy options providing comparable levels of service have the same economic NPVs), such as those depicted in

Figure 3-1 - Chapter 3, may be obtained by using the "Goal Seek" function included in spreadsheet software. This function determines the value of an independent variable which equates two mutually exclusive dependent variables. For the graphs in Figure 3-1, the goal seek function was used to determine, at various household densities, the number of households for which solar home systems and alternative grid options (providing equivalent levels of energy service) had the same NPVs.

LEAST-COST COMPARISON (FINANCIAL BASIS)

19. Rural energy alternatives can also be compared on a financial basis. Similar to the economic comparison, a financial analysis uses discounted cash flows over a fixed period to determine the financial NPV and/or amortized payments for each investment.

20. The financial analysis presented in Chapter 4 is performed from the customer's perspective and utilizes market prices for receiving energy services from alternative rural household energy supply options (in general, financial analysis may be performed from a utility's perspective or that of another energy supplier). Such charges include taxes, finance charges, import duties, subsidies, and tax credits. Because most households require financing to overcome the high initial cost of PV solar home systems, the financial analysis of this option includes financing charges in addition to principal payments and other financial costs. In many developing countries, the price of kerosene is subsidized which thereby lowers the financial cost of kerosene/battery schemes. In Indonesia, all grid-connected customers (including those connected to the central and isolated grids) pay identical energy charges and flat connection, wiring, and capacity fees regardless of the economic cost of service.

CASE STUDIES: PRODUCTIVE LOADS AND LOAD GROWTH

21. The analysis presented in Chapter 3 does not include the impact of load growth or productive loads on the economic niche for solar home systems. Such simplifying assumptions are applicable to the analysis of least-cost energy supply options for rural villages in several developing countries. For example, load growth and productive loads have been found to be virtually non-existent in rural villages in Nepal and Lao PDR[1], and minimal in Indonesia. When present, however, these factors will affect the costs of rural energy alternatives, and should therefore be considered in related analyses.

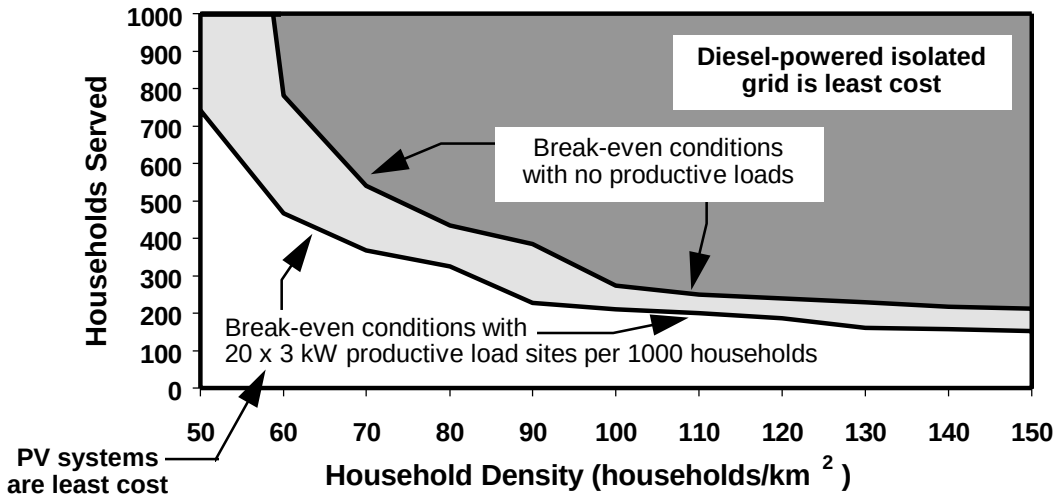
22. **Productive Loads.** Figure 1 shows the effect of productive loads on the economic niche for solar home systems when compared to an isolated grid. Two break-even curves (similar to those presented in Figure 3-1) are plotted on the same axes: a) one for villages without productive loads, and b) one for villages with 20 x 3 kW productive load sites per 1,000 households. As in Figure 3-1, each break-even curve represents the conditions (i.e., household density and number of households served) under which the levelized costs of providing equivalent energy services with two options are equal. For

[1] Personal communication with A. Inversin, NRECA, January 1995.

the isolated grid option, each productive load is assumed to be connected to the distribution grid; for the solar home system alternative, each productive load is assumed to be met with a dedicated diesel engine generator.

23. Figure 1 shows that the presence of productive loads reduces the number of communities for which the solar home system alternative is the least-cost option. For example, solar home systems are the least-cost economic option for a remote village with no productive loads, 400 households, and a household density of 80 households/km^2. However, an isolated grid would be the more economic option for the same village with 20 x 3 kW productive load sites for each 1,000 households. Because the cost of servicing productive loads with dedicated diesels (i.e., the solar home system alternative) exceeds the marginal cost of servicing the productive loads with the isolated grid, the economic niche for solar home systems is reduced. Therefore if productive loads are likely for a particular village, they should be included in the electrification planning analyses.

Figure 1. Effect of Productive Loads on Break-Even Conditions - 50 W_p Solar Home Systems and a Diesel-Powered Isolated Grid in Indonesia



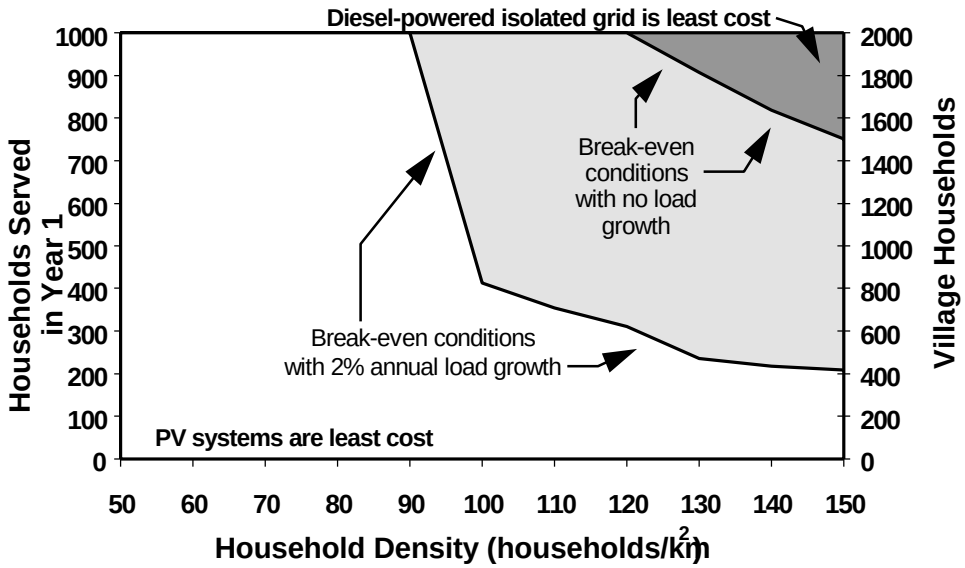
Assumptions:

1) Level of Service:
   a) 8 hours area lighting
   b) 6 hours task lighting
   c) 60 Wh for other services
2) No Load Growth
3) 5 km distribution line per km^2 of grid service area.
   For example:
   100 households/km^2 = 20 households/km distribution line

24. **Load Growth (Addition of New Customers).** Figure 2 examines the impact of load growth on the break-even conditions for solar home systems and an isolated grid. Load growth occurs as existing customers increase their level of energy consumption and/or as new customers receive energy services. For the solar home system alternative, new customers simply receive a solar home system (i.e., panel, wires, battery, etc.). For grid supply alternatives, new customers may result as new households are connected to an existing distribution grid (i.e., new service drops from an existing grid) and/or from an increase in distribution grid coverage over a particular area. Figure 2 assumes load growth due to an increase in the percentage of households connected to the grid (i.e., an increase in the "electrification ratio"). Once again two break-even curves are shown: a) one for villages with a constant electrification ratio of 50%, and b) one for villages with an initial electrification ratio of 50% and a 2% annual increase in electrification ratio. Identical electrification ratios are applied to the solar home systems and isolated grid options. To simplify the analysis it has been assumed that the levels of service for all customers is constant and the distribution grid completely covers the serviced area (i.e., 100% grid coverage).

25. As shown in Figure 2, load growth due to additional household connections narrows the range of conditions under which solar home systems are the least-cost option (note the break-even curve for villages with no load growth and that for villages with no productive loads, Figure 1, are different because the former assumes a constant 50% electrification ratio; the latter assumes a constant 100% electrification ratio). In the figure, solar home systems are always the least-cost economic option for a village with 1,600 households (800 households served in year 1) at a density of 70 households/km^2. If the same village were to have a household density of 110 households/km^2, a solar home system would be the least-cost alternative if there was no load growth; the isolated grid would be more economic if a 2% annual increase in the number of households served was expected. For a village with 1,600 households and a density of 150 households/km^2, the isolated grid is always the least-cost option. Because the incremental cost of providing additional households with electricity from an isolated grid is less than that with a solar home system (see Table 3-3), the economic niche for solar home systems is reduced. If, however, additional distribution grid coverage is required to service the additional households, the incremental costs of the grid option will increase, thereby limiting the reduction of the economic niche for solar home systems. The degree to which the reduction is limited, however, is a function of the cost of additional distribution grid coverage.

Figure 2. Effect of Load Growth on Break-Even Conditions - 50 Wp Solar Home Systems and a Diesel-Powered Isolated Grid in Indonesia



Assumptions:

1) Level of Service:
   a) 8 hours area lighting
   b) 6 hours task lighting
   c) 60 Wh for other services
2) 50% Initial Electrification Ratio
3) SHS Electrification Ratio = Isolated Grid Electrification Ratio
4) 100% Grid Coverage
5) 5 km distribution line per km^2 of grid service area.
   For example:
   100 households/km^2 = 20 households/km distribution line

CONCLUSIONS

26. The analysis presented in Chapters 3 and 4 represents a simplified application of a spreadsheet model and highlights the economic and financial niche for solar home systems in providing rural household energy services. When performing a least-cost analysis of energy alternatives for an actual village however, it is necessary to relax the simplifying assumptions and determine specific village characteristics including potential productive loads and expected load-growth patterns. As shown in Figures 1 and 2, these parameters can have a substantial impact on the least-cost rural energy option. In addition, other village-specific characteristics, such as different energy requirements among households, partial grid coverage, and seasonal productive loads, should be considered.