3

THE ECONOMICS OF PV HOUSEHOLD ELECTRIFICATION

3.1 Most electric utilities examine only grid-based options when planning their rural electrification programs. In Indonesia, for example, the main sources of rural electricity are diesel engines serving isolated grids or larger centralized generators that feed power to rural localities via medium-voltage transmission lines. Off-grid options such as household PV systems have generally not been considered though they can offer affordable electricity to areas and homes that cannot be economically served by a grid.

3.2 A recent World Bank review of rural electrification experience in Asia recognizes the potentially useful role of solar home systems.

> *Since rural electrification programs can easily overextend themselves, project appraisal needs to focus more attention on identifying the economic limits of extensions to the grid and on the economic potential of alternative energy sources, particularly solar energy (World Bank 1995b).*

3.3 PV projects should be appropriately integrated into the rural electrification planning process as a least-cost electrification option.[1] From the *users'* perspective, electricity from a reliable distribution grid is preferable, as long as it is affordable. From the *country's* perspective, rational economic policy dictates a least-cost path to energy service delivery. The *rural electricity planner* needs to know how to select the least-cost approach to delivering energy services at an acceptable level of reliability and quality from among off-grid options for power supply, including solar home systems; kerosene and batteries; and a grid-based power supply.

SOLAR HOME SYSTEMS VS. KEROSENE AND AUTOMOTIVE BATTERIES

3.4 The economics of providing basic electricity services to rural households should be evaluated according to the costs of supplying comparable energy services (defined by

[1] The term "economic" is used in this Report to mean that the analysis is done from the country's perspective. All transfers within the country are eliminated, including import duties, sale taxes, income taxes, and other budget transfers to and from government (such as subsidies). Shadow prices are used where market prices do not reflect true opportunity costs.

hours of service for both area and task lighting as well as watt-hours of energy used for appliances). As shown in Table 3-1, task lighting for activities such as reading, writing, and sewing can be provided by an incandescent bulb of 40-W or greater, a fluorescent bulb of 10-W or greater, or a pressurized kerosene lamp. Less intense area lighting for general indoor and outdoor illumination can be provided by an incandescent bulb of 25-W or less, a fluorescent bulb of 6-W or less, a kerosene wick lamp, or a candle.

3.5 For analytical purposes, a mix of basic lighting and other services can be defined at various service levels. Both Lighting I and Lighting II require only a solar lantern or a kerosene lamp/lantern. The Lighting/Electric I service level corresponds to about 15 kWh/month per household for grid service. The Lighting/Electric II level is equivalent to about 30 kWh/month per household for grid service. By applying these lighting and electrical service levels to Indonesia cost data, the following analysis identifies the conditions under which PV systems are the least-cost option compared with kerosene and batteries and the provision of grid services.

Table 3.1. Levelized Monthly Economic Costs of Kerosene/Battery and PV for Rural Households in Indonesia (in 1993 dollars)

Service Level	*Daily Services Provided*	*Solar Home System*		*Kerosene and Batteries*	
		Equipment	*Monthly Cost*	*Equipment*	*Monthly Cost*
Lighting I	8 hrs. area lighting	Solar lantern	2.25	Wick lamp	2.00
Lighting II	6 hrs. task lighting	Solar lantern	2.25	Mantle lantern	2.50
Lighting/ Electric I	8 hrs. area lighting 6 hrs. task lighting 60 Wh for other loads	50 Wp system	8.25	2 wick lamps 1 mantle lantern 1 battery	9.25
Lighting/ Electric II	12 hrs. area lighting 14 hrs. task lighting 150 Wh for other loads	100 Wp system	13.75	3 wick lamps 2 mantle lanterns 2 batteries	19.25

3.6 Table 3-1 compares the costs of solar home systems versus kerosene/battery alternatives for providing various combinations of energy services in Indonesia. The levelized economic costs of each option are based on the discounted cash flows of the costs of both systems for twenty five years, including capital costs and the costs of operation and maintenance fuel, and equipment refurbishment and replacement.[2] The costs of the kerosene and battery alternative are based on the economic costs of kerosene, lighting equipment, batteries, and battery charging. The economic costs of solar home systems are derived from the border costs of the system, plus transportation, distribution, and support services. The calculations of the economic costs of these systems assume the presence of a mature two-step distribution system (that is, manufacturer to dealer, and dealer to customer) with total sales of about 5,000 systems per year and about 200

[2] In constant 1993 dollars, at a discount rate of 12 percent.

systems per year per dealer. If the sales volumes are lower, or there are more steps in the distribution chain, the costs of solar home systems will be correspondingly higher.

3.7 Table 3-1 shows that, for all but the lowest service level (Lighting I), solar home systems provide energy services at a lower economic cost than the kerosene and battery option. The service level threshold at which PV systems become an economically viable source of rural household power is therefore relatively low. In Indonesia, it is certainly an economically viable option compared with the currently favored kerosene-and-battery system. Moreover, PV systems have the added benefit of being able to provide more and better light, more conveniently, than by batteries and kerosene.

SOLAR HOME SYSTEMS VS. GRID-BASED POWER SUPPLY

3.8 Grid-based power supply and PV systems are not necessarily mutually exclusive options in delivering electricity services to rural areas. Rural electrification planners should take advantage of multiple options at their disposal. Grid-based power is the least-cost option for large concentrations of household or productive loads. It offers substantial economies of scale, owing to the large fixed-cost investment in distribution lines and generation facilities. However, grid solutions require a minimum threshold level of electricity demand and certain load densities to achieve these economies of scale. Deciding whether the grid or solar PV is the least-cost option for supplying electricity to rural areas requires attention to:

- ***Household service level:*** the daily energy consumption of the average household to be served, expressed as the number of hours of task and area lighting and the watt-hours required to operate appliances;

- ***Total number of households to be served:*** the number of households to be served, multiplied by average daily household consumption;

- ***Load density:*** as indicated by the number of households to be served per unit service area (in km^2) or by the number of households to be served per unit of distribution line (that is, per km of low-voltage (LV) distribution line);

- ***Productive loads:*** the number and power requirements of productive loads such as rice mills, grain-grinding mills, water pumping, and commercial or service sector loads; and

- ***Load growth:*** the annual increase in the load that will result from increases in both the number of customers served and the demand for energy.

3.9 Figure 3-1 identifies the "break-even" thresholds for grid-based and solar home systems for Indonesian communities with up to 1,000 households and household densities ranging from 50-150 households per km^2. The break-even point at which grid-based power supply and PV systems are equally cost-effective in this assessment depends on the

size and density of the specific load to be served as well as the distance from low- (LV) and medium- (MV) voltage lines.

3.10 The analysis assumes that households receive equivalent levels of service from both PV and grid-based arrangements corresponding to 6 hours of task lighting, 8 hours of area lighting, and 60 Wh of other loads per day (see Table 3.1). Three scenarios are presented for villages located at varying distances from the existing grid:

- ***Case 1***: a remote area where the grid option is to construct an isolated grid powered by a diesel or a small hydroelectric plant;
- ***Case 2***: a village located 5 km from an MV substation or line; and
- ***Case 3***: a village located 3 km (the typical maximum distance for LV line extension) from an LV line.

A discussion of the economic analysis and assumptions is provided in Annex 2.

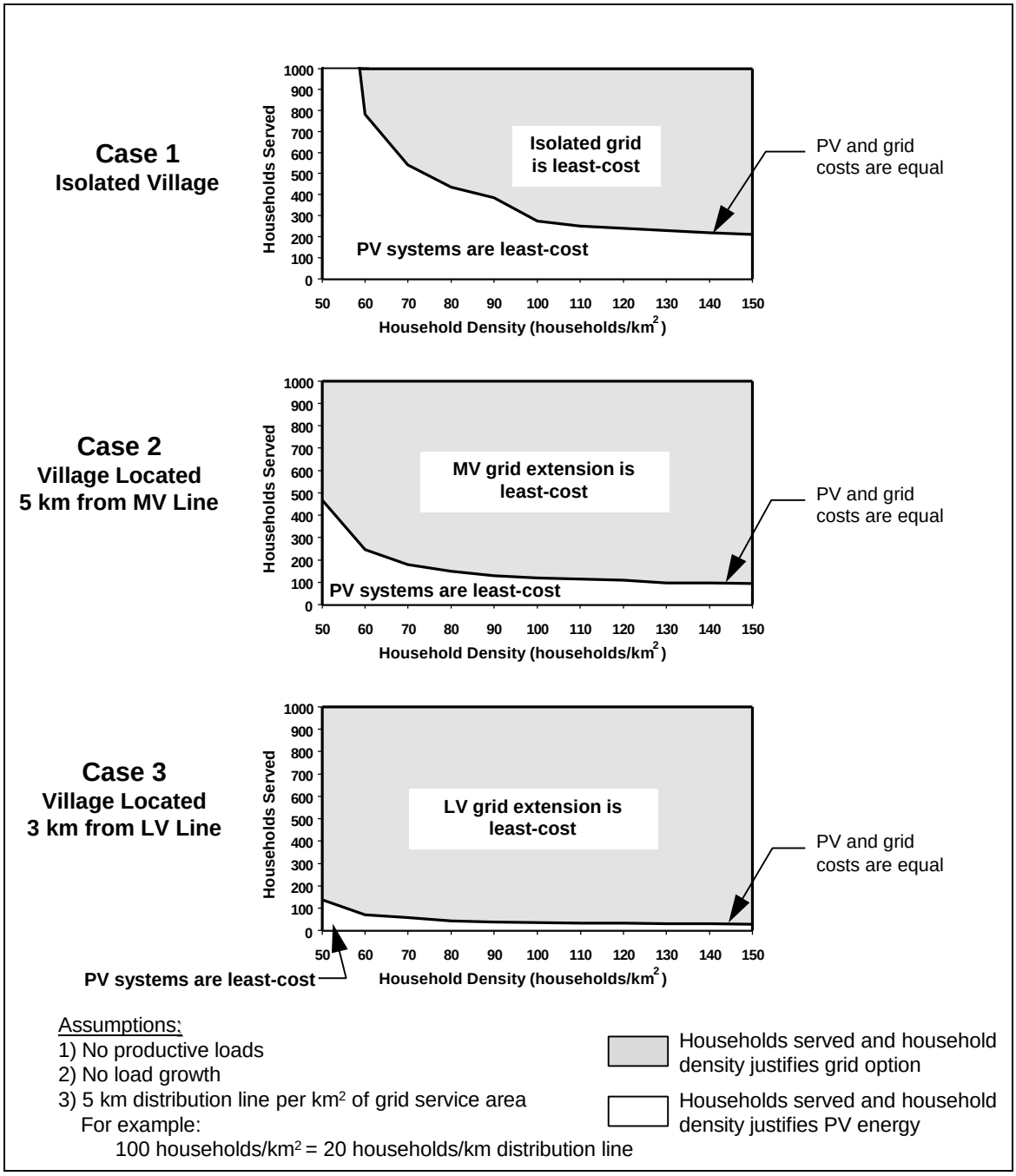
3.11 The break-even curve in each graph traces the line along which the levelized costs are the same for either PV household systems or grid-based power, given specific combinations of load (household connections) and load density (household connections per km^2). PV electrification is the least-cost option below the line and grid-supply is the least-cost option above the line. For example, in Case 1, an isolated diesel-powered grid is the least-cost option for a village with 400 household connections and 100 households per km^2. If this village had half the number of household connections and a lower household connection density (for instance, $65/km^2$), PV household systems would be the least-cost choice. (The analysis in Figure 3-1 is based on grid service and PV systems cost data for Indonesia.)

3.12 Case 1 highlights an economic niche for PV home systems in small, sparsely settled, isolated communities. Here, solar homes systems are less expensive than either kerosene and batteries or grid-based power. This is true for villages of widely varying sizes and household densities. Typically, PV household systems are the least-cost option for villages with fewer than 200 connections.

3.13 Case 2 highlights a second economic niche for solar home systems: in communities near (5 km or less) an existing MV line, PV systems are the least-cost option, if few households are to be served. Typically, PV household systems are the least-cost option for villages up to 5 km from the grid but with fewer than 100 connections.

3.14 Case 3 defines a third economic niche for PV service in villages located near an LV line (3 km). Grid extension is normally the least-cost option for such settlements. However, PV systems are the least-cost option, even in Case 3, if fewer than 50 households are to be connected. Often, these sparsely settled communities are passed over in the rural electrification process and remain unelectrified pockets locked inside electrified regions.

Figure 3-1. Indonesia: Break-Even Thresholds for PV- and Grid-Based Electricity Supply, by Village Location



LOAD GROWTH IMPACT

3.15 The analysis in Figure 3-1 does not take into account the potential for load growth or productive loads. Load growth will narrow the economic niche for PV systems, due to the relatively low marginal cost of adding adjacent households to a grid and of increasing the supply of electricity to a household already connected to a grid. Table 3-2 indicates that the levelized costs of providing an additional household with a solar home system at $8.25/month, compared with the $4.25/month required to add a household to a grid (if the household is located within 100 meters of an LV line). To double the energy service to a household already using a solar home system would add $5.50 in additional levelized monthly costs, compared with a levelized cost of $1.00/month to double the level of grid service from 15 to 30 kWh per month. Thus, the prospects for early and significant load growth need to be factored into the rural electrification analysis. Productive loads also need to be considered, since they also shift the break-even curve downward and reduce the economic niche for PV home systems. In situations where significant productive load growth is expected, a least-cost comparison should be done for an isolated grid versus a combination of solar home systems for domestic loads and dedicated diesels for productive loads. (See Annex 2 for an analysis of the impact of load growth and of productive loads.)

Table 3-2. Load Growth: Incremental Economic Costs for PV- and Grid-Based Systems in Indonesia (in 1993 dollars)

Load Growth	*Incremental Cost (per household)*	*PV System*	*Grid*
Connecting new household within 100 meters of an LV line	First cost	500.00	335.00
	Levelized monthly cost	8.25	4.25
Doubling service to an existing customer	First cost	275.00	13.00
	Levelized monthly cost	5.50	1.00

3.16 The analyses summarized in Tables 3-1, 3-2, and Figure 3-1 yield some simple rules of thumb for determining the least-cost option for rural electrification programs.

- PV home systems are economically the least-cost option, compared with kerosene mantle and wick lamps for lighting and rechargeable batteries used for operating small appliances such as televisions and radios.
- PV home systems are economically the lower-cost option, compared with grid-based service, *if* the average incremental cost of grid service is greater than $8.25 per month per household.[3] This rule applies at a service level equivalent to 8 hours of area and 6 hours of task lighting (plus 60 Wh of other services daily), assuming a cost of $500 per 50 Wp solar home system.

[3] The average incremental cost is the levelized life-cycle cost in 1993 dollars computed in economic (not financial) terms.

- If the level of service is doubled, PV systems are economically the least-cost option when the average incremental cost of grid service is greater than $13.75 per month per household.

Solar home systems being transported by Yak to remote customers in Qinghai Province, China. Source: Qinghai New Energy Research Institute.

3.17 This Chapter has compared PV household electrification to grid, kerosene and battery alternatives from the country's economic perspective, which is to provide least-cost electricity services to rural and isolated populations. Chapter 4 focuses on affordability and quality of service from the user's perspective.