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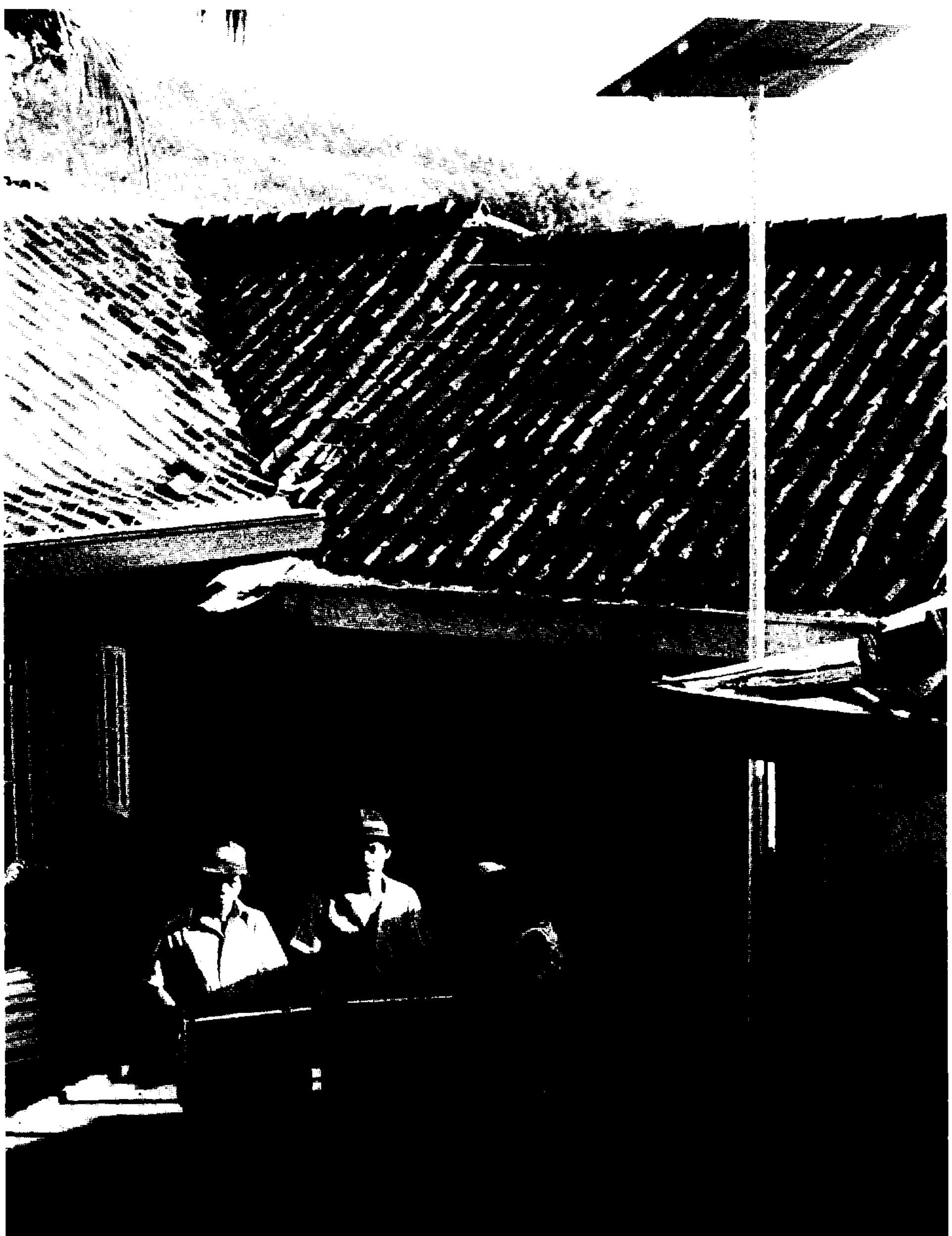
Best Practices for Photovoltaic Household Electrification Programs

Lessons from Experiences in Selected Countries

Anil Cabraal, Mac Cosgrove-Davies, and Loretta Schaeffer



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Cover photo: Solar home systems in Sukatani, West Java, Indonesia.
Credit: Courtesy of PT. Sudimara Energi Surya.

All three authors work in the Asia Alternative Energy Unit in the Asia Technical Department of the World Bank. Anil Cabraal and Malcolm Cosgrove-Davies are renewable energy specialists, and Loretta Schaeffer is the unit's program manager.

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FOREWORD

Governments across the developing world have made rural electrification a high priority over the last two decades. Yet despite the rapid expansion of the power sector during this period, by 1990, only about 44 percent of the more than 3.3 billion people living in rural areas had access to grid-based electricity. Given the constraints of high capital costs and maintenance, there is little chance of achieving universal rural electrification through conventional grid services.

Off-grid PV systems can generate sufficient electricity to provide households with lighting and power for small appliances. PV modules can also be combined to meet larger energy requirements for other household services or for productive uses in activities such as agricultural processing or cottage industries. However, formidable barriers, including the high initial cost of PV systems, keep this technically and economically viable technology beyond the reach of most rural families.

Case studies of recent experiences in Indonesia, Sri Lanka, the Philippines and the Dominican Republic have identified key ingredients for successful residential PV programs and ways to overcome financial and institutional barriers to the use of PV systems. These case studies were commissioned by ASTAE, with the cooperation of the German BMZ/GTZ. In addition to the studies, ASTAE has consulted with World Bank staff and PV professionals worldwide on experiences with PV systems in developing countries. This process has reinforced the main conclusions of this Report: that PV systems are a viable complement to grid-based energy service delivery and that within the rural electrification framework such systems can find a cost-effective niche and sustainable market. It has also yielded insights on best practices to improve prospects for successful project design and implementation.

ASTAE was created by the World Bank, with support from the Netherlands Ministry of Development Cooperation, the US Department of Energy, and other donors. The Unit's mandate is to stimulate environmentally sustainable and commercially viable renewable energy and demand-side management investments in Asia. I share, as do ASTAE donors, the belief that PV systems can provide least-cost light and power service to small, dispersed residential communities. We hope that this Report will catalyze further action among public and private planners and developers to improve the quality of life for rural families.

Harold W. Messenger

Harold W. Messenger
Director
Asia Technical Department

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This Report owes much to the pioneering efforts of the numerous governmental, private sector, and non-governmental organizations that have undertaken photovoltaic household electrification programs throughout the world. The authors are indebted to the beneficiaries to these programs for sharing their experiences and to the donors, administrators, managers, and staff. Their vision and perseverance have brought electricity to thousands of homes and paved the way to provide service to millions more.

We gratefully acknowledge the generous support of the Directorate General for International Cooperation in the Netherlands Ministry of Foreign Affairs and the US Department of Energy, the main donors to the Asia Alternative Energy Unit (ASTAE). Additional support from the German Bundesministerium fur Wirtschaftliche Zusammenarbeit (BMZ)/Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) was invaluable to this effort.

The team members for the four country case studies of PV program experience deserve special mention: Dorca Barcacel de Bencosme, Andres Doernberg, Robert Foster, and Pablo Rosenthal (Dominican Republic); Timothy Ball, Heri Lesmana Hardjo, Mayling Oey-Gardiner, and Herbert Wade (Indonesia); Klaus Pertz (Philippines); Timothy Ball, Sunil Bastian, D.G.V.K. Jayasuriya, and Neville Williams (Sri Lanka).

The authors would like to note the time, effort, and enthusiasm of the reviewers of earlier drafts of the Report, which was the subject of the Roundtable on Photovoltaics and Rural Electrification convened at the First World Conference for Photovoltaic Energy Conversion at Waikaloa, Hawaii, in December 1994. The contributions of Richard Hansen, Enersol Associates; Daniel Waddle, National Rural Electric Cooperative Association; and Herbert Wade, Asian Institute of Technology, were especially useful. This Report also reflects extensive discussions with Agus Salim Dasuki of the Indonesian Agency for Assessment and Application of Technology, Robb de Lange of Pt. Sudimara (Indonesia), and Lalith Gunaratne of Solar Power and Light (Sri Lanka).

We would also like to thank the World Bank Peer Reviewers: Doug Barnes, Andres Liebenthal, Magdalena Manzo, and Arun Sanghvi for their personal interest in the subject and their perceptive comments; our colleagues Susan Bogach and Scott Piscitello for their contributions to the economic and financial analyses; Kimberly Burns, Kerri Brady, and Maria Aquino for word processing; and Emily Chalmers for editorial support.

Finally, we are most grateful to Carolyn Tager of ASTAE for her continued guidance and insights.

EXECUTIVE SUMMARY

1. Experience across the developing world confirms the technical reliability of photovoltaic (PV) systems in a variety of settings. Under the right conditions, solar home systems (PV systems designed for home use) can offer lighting and other services to large numbers of households that are poorly served by existing energy sources or have no service at all. This Report identifies an important economic niche for such systems within rural electrification programs. PV systems are an effective complement to grid-based power, which is often too costly for sparsely settled and remote areas. For such rural conditions, fuel-independent, modular solar home systems can offer the most economical means to provide lighting and power for small appliances.

2. PV systems are safer and more convenient than kerosene lanterns and dry cell or automotive batteries which are widely used in developing countries for lighting and to power small appliances. Solar home systems are especially attractive to women and children, who rely heavily on household energy services for a range of activities. As a renewable energy source, PV systems are also environmentally friendly and reduce reliance on expensive imported fuels.

3. Despite these appealing features, solar home systems do not yet have broad market acceptance and face significant barriers to widespread diffusion. The main obstacle is their initial purchase price, which puts them out of the reach of all but upper-income households. Opportunities exist to reduce the cost of solar home systems significantly over the near future. These include the outlook for steady decline in PV module prices on the international market, the savings possible from judicious use of locally-made and/or locally-assembled components as well as the economies of scale in procurement, sales and servicing that an enlarged customer base can provide. However, even with these cost reductions, unless adequate financing arrangements, geared to low- and middle-income households, are in place, solar home systems cannot play a significant role in rural electrification.

4. Many early solar home system programs of the 1970s and 1980s failed, due to a variety of factors. These included unreliable technical performance, poor system design, lack of ongoing, qualified technical support, implementing agency shortcomings, poor attention to cost recovery, and unrealized user expectations and consequent dissatisfaction. Recent programs have benefited from the lessons learned from these experiences and from technological improvements. As a result, solar home systems now show a robust potential for long-term sustainability. ASTAE field investigations of PV household electrification programs in Indonesia, Sri Lanka, the Dominican Republic, and the Philippines indicate various paths to program success. However, as noted throughout this Report, *the need to overcome the first cost barrier is a sine qua non* in any country context.

5. Several key findings emerge from ASTAE's review of country experiences, other World Bank studies of PV programs in Kenya and the Pacific Islands, discussions with PV professionals, and the conclusions of the Roundtable on Photovoltaics and Rural Electrification (held at the First World Conference on Photovoltaic Energy Conversion in Hawaii, December 1994). These findings emphasize the need to:

- Overcome the first cost barrier,
- Establish responsive and sustainable infrastructure to deliver PV services, and
- Provide quality products and services.

OVERCOMING THE FIRST COST BARRIER

6. **Term Credit and Affordable Payment Schemes.** Affordable and accessible financing is a major consideration in the design of any PV program due to the high first costs of solar home systems. Affordability can be increased by providing households with term credit through local dealers or the banking system or by leasing or energy service company (ESCO) arrangements. The inability of borrowers to offer adequate security or collateral for the loan is a major constraint to offering term credit. Some approaches to overcome this problem include using the PV module as part-security, seed capital funds, loan guarantees, supplier credits, and equity investments or debt financing assistance from the Government. Pricing and repayment arrangements should capture households' ability and willingness to pay. For example, evidence suggests that consumer willingness and capacity to pay is influenced more by the size of the down payment for solar home systems than by the number or the size of the monthly payments. Flexible payment schemes may be needed for households with irregular income streams.

7. **Grants and Subsidies**. A judicious use of grants and subsidies can help implement household PV programs. To assure sustainable programs, such assistance should be used to build market infrastructure through planning, promotion, training, feasibility studies, quality assurance, and similar activities, or limited equity to reduce the capital costs of a project. The use of grants or subsidies to cover operating costs is dangerous and could undermine the long-term sustainability of a PV electrification program.

8. **Tax and Duty Structures**. Governments should rationalize duty and tax structures, if these discriminate against PV development. Relatively high import duties and other taxes (particularly on PV modules) can severely limit the potential for commercially viable, market-driven solar home system programs. Duties and taxes on PV system components raise the financial costs of solar home systems. At the same time, subsidies for rural grid service or for kerosene often lower the cost of competing energy options to well below their economic value. While subsidies may be justified for social or developmental objectives, they can create serious distortions that hinder household PV use in areas where PV is clearly the least-cost economic option.

ESTABLISHING RESPONSIVE AND SUSTAINABLE INFRASTRUCTURE

9. **Institutional Structure**. No single institutional arrangement is appropriate for every country. Successful PV household electrification programs have been implemented under a variety of institutional setups. Possible alternatives include:

- ***Energy Service Companies (ESCOs).*** Electric utilities, cooperatives, non-governmental organizations, and private companies can operate as ESCOs which buy solar PV systems in bulk, install solar home systems, retain ownership, and bill for services;
- ***Leasing or Hire-Purchase Arrangements***. An intermediary (a private company, cooperative, or NGO) retains ownership of solar home systems until they are paid for by customers over a period of time; the intermediary often utilizes seed money from government or donor grants to establish a revolving fund to buy the first PV systems; and
- ***Cash or Credit Sales to Consumers***. Banks and dealers provide short-term financing at market rates to help consumers finance solar home systems. Existing organizations are used whenever possible to avoid the problems associated with creating and staffing new institutions.

10. ESCO models allow for the most affordable payment schemes, and can thus reach a larger customer base than other credit delivery schemes. A local or regional electric utility or a distribution company can serve as an ESCO. With a large custom base, the ESCO can obtain economies of scale in procurement and in the delivery of support services, make product standardization and quality assurance easier, and facilitate battery recycling. While the ESCO model is an attractive concept, its long-term viability requires business management skills and technical capabilities that may be limited in rural areas. The ESCO model also carries greater commercial risk due to the longer cost-recovery period.

11. The more market-oriented PV system financing through leasing and consumer sales works well in areas in which an existing marketing and financing infrastructure is already established. Commercial marketing channels, firmly rooted in the private sector, can offer services in a competitive and efficient manner. These commercial markets may be more responsive to consumer requirements and can offer a broader array of products than ESCOs.

12. **Financial Sustainability.** PV programs must be operated as businesses. They should generate revenues sufficient to recover capital investment, service debt, pay for administrative and support services, cover payment defaults and, in the case of for-profit operations, provide satisfactory returns for investors. In the past, the fees charged under many donor- and government-sponsored programs were set at levels comparable to the monthly cost of kerosene for low-income households. This was based on the assumption that rural consumers have a very limited capacity to pay. Such PV programs are

intrinsically *unsustainable* over the long term. Experience shows that consumers are often willing and able to pay more for highly valued services than has previously been assumed. To ensure sustainability, PV programs should:

(a) set prices to allow for full cost recovery;
(b) select only consumers with a willingness and ability to pay;
(c) ensure that consumer expectations are in line with the energy services to be provided;
(d) maintain high product quality and responsive services;
(e) establish effective fee collection methods and enforce regulations to "shut off" service for nonpayment;
(f) adopt simplified administrative procedures; and
(g) select and retain quality staff.

13. **Effective Management and Support Services**. A successful PV program needs well-qualified managers and technicians. Local recruitment is advisable since people from the community who are known and trusted are more effective than workers from a central agency located outside the area. This, however, will often necessitate extensive training. Managers need to be proficient in business, marketing, and financial operations and to have access to information, technical assistance and ongoing training to update their skills. Adequate salaries and benefits are also required to retain qualified managers in rural areas. In addition, technicians must be trained (and given periodic refresher courses) in order to assure responsive repair and maintenance services – an often underemphasized aspect of PV programs. Technicians also need appropriate tools and transportation as well as locally available supplies of spare parts.

PROVIDING QUALITY PRODUCTS AND SERVICES

14. **Technical Quality**. The long-term sustainability of a PV program depends on well-designed products (including proper assembly and installation procedures) that meet consumers' expectations and capacity to pay. Only field-tested systems should be used in a PV electrification program. If untested PV systems are introduced and fail, the credibility of PV as a viable energy source for rural consumers can be seriously undermined. Low-capacity, high-quality products should be offered to those potential customers with only a limited ability to pay. Costs should never be reduced by compromising system quality or by decreasing support services. Where low-cost systems must be used, customers need to be fully aware of and accept a limited level of service. Large-volume procurements can also be used to help in the acquisition of high-quality products and to take advantage of bulk purchase discounts.

15. **Consumer Awareness**. User education is essential for PV program success. Information and training in simple maintenance and safe operating procedures should be targeted to those persons in the households who will have primary responsibility for the system. Users need to understand that good operating practices minimize recurring costs and enhance battery life.

THE ROLE OF GOVERNMENTS AND DONORS

16. Grid-based electricity has only been the mainstay of rural electrification efforts. However, the increasingly high cost of serving isolated and remote communities burdens government budgets. A large proportion of rural needs for household lighting and small power requirements can be met by solar home systems at a lower economic cost than grid service. In locations where PV household electrification is the economically viable option, governments must explicitly consider and encourage solar home system diffusion in lieu of grid extension. Political reluctance to specify areas unlikely to be served by electricity grids within 5-10 years raises unrealistic expectations among consumers, who may believe that grid service will arrive in the near future. This expectation dampens efforts to market PV systems. Consumers are reluctant to purchase what is perceived to be only a short-term solution. Instead, explicit government support of solar home system programs for isolated, or remote villages, or unserved portions of electrified communities can help PV meet low load demands and prevent uneconomic extension of the rural electrification grid. Private sector participation in such programs should also be encouraged.

17. A multimodal approach to rural electrification considers PV systems along with other options to complement grid extension. The choice of technology should be based on consumer needs, economic viability, technical and institutional capabilities, and consumers' willingness and ability to pay for the service. The approach chosen should allow for energy service delivery through a range of public and private sector institutions, as well as local cooperatives and NGOs.

18. The key role of government is to guarantee an appropriate institutional and regulatory environment. As noted earlier, governments should rationalize duty and tax structures as well as incentive or subsidy programs to reduce market distortions and facilitate access to credit. Other governmental functions include the setting of technical standards, monitoring and overseeing programs, and disseminating information on PV technology and the performance of solar home systems. By investing directly in PV equipment as part of education, health, and other social programs, governments can also play an important role in establishing the infrastructure needed to sustain PV systems.

19. Donor support for PV programs requires coordination with government programs, local organizations, other donor agencies, and private sector stakeholders. Donor agencies can help in technology transfer and in financing investments in PV systems as part of rural electrification and rural development projects. The World Bank (and other multilateral banks) should actively promote a multimodal approach to rural electrification. The Bank can advise on how to create the necessary enabling environment. The Bank can also help its clients explicitly consider PV systems and other off-grid options within Bank-supported projects; strengthen government's ability to identify and assess rural energy options; and make available financial resources to prepare and implement such projects.

ABBREVIATIONS AND ACRONYMS

A	Amps
AC	Alternating current
ADESJO	Asociación de Desarrollo de San José de Ocoa (Dominican Republic)
ADESOL	Asociación para el Desarollo de Energía Solar (Dominican Republic)
Ah	Amp-hours
ASTAE	Asia Alternative Energy Unit of the World Bank
B&W	Black and white (television)
BANPRES	Indonesian solar home system project, financed under a presidential aid program
BMZ	Bundesministerium fur Wirtschaftliche Zusammenarbeit
BPPT	Indonesian Agency for Assessment and Application of Technology
CFL	Compact fluorescent light bulb
Coop	Cooperative
DC	Direct current
ESCO	Energy Service Company
GEF	Global Environment Facility
GTZ	Deutsche Gesellschaft fur Technische Zusammenarbeit
HVD	High-voltage disconnect
JRC	Joint Research Council
km	Kilometer
kWh	Kilowatt-hours
LED	Light emitting diode
LRMC	Long-Run Marginal Cost
LVD	Low-voltage disconnect
m	Meter
NEA	National Electrification Administration in the Philippines
NGO	Non-Governmental Organization
NOCT	Nominal Operating Cell Temperature
NREL	National Renewable Energy Laboratory
PV	Photovoltaics
REC	Rural Electric Cooperative in the Philippines
Rp.	Indonesian Rupiah
SCE	Southern California Edison
SELF	Solar Electric Light Fund
SSID	Servicios Sociales Inglesias Dominicanas (Dominican Republic)
T-Bill	Treasury Bill
TSECS	Tuvalu Solar Electric Cooperative Society
TV	Television
UL	Underwriters Laboratory (USA)
V	Volts
VAT	Value-added tax
VCR	Video cassette recorder
W	Watts
WB	The World Bank
Wh	Watt-hours
Wp	Watts peak

CURRENCY CONVERSION ASSUMPTIONS

US$	1.00	=	12.40 RD (Dominican Republic)
			2100.00 Rupiah (Indonesia)
			25.50 Peso (Philippines)
			50.00 Rupees (Sri Lanka)

1

INTRODUCTION

1.1 Most governments in the developing world give high priority to rural electrification to meet economic, social, political, and regional development goals. By 1990, after nearly two decades of aggressive public investment in the energy sector, an additional 1.3 billion persons in developing countries had gained access to grid-based electricity.[1] Of these, about 500 million lived in rural areas. Despite these efforts, the pace of electrification could not keep up with world population growth, which increased by 1.5 billion persons during this same period. In 1990, about 1.8 million people in rural areas of developing countries were still without grid-based electricity.

1.2 Grid-based electricity is more expensive in rural than in urban areas due to lower load densities, lower capacity utilization rates, and often higher energy losses. Rural customers increase the costs of generating electricity disproportionately, since rural areas add to the evening system peak, when power is more expensive. The costs of grid-based rural electrification extensions have ranged from $230 - $1,800 per connection, with a median cost of about $520 per connection (excluding the cost of basic generating equipment and high-voltage transmission lines) (Mason 1990).[2] Since these costs rise considerably in areas with small loads and low load densities (i.e., areas with low population density), alternative approaches are necessary in order to meet rural electricity needs in the least expensive way.

1.3 Over the past decade, the use of photovoltaic-(PV-) powered solar home systems in remote communities has received increasing attention as an economically viable alternative to grid connections, kerosene lighting, and rechargeable or disposable batteries that power appliances. Governments, non-governmental organizations (NGOs), the private sector, and the donor community have acquired considerable experience in the design and implementation of solar home system projects. The PV niche within a national rural electrification strategy would comprise those areas where small amounts of electricity are required and load densities will remain modest.

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1 World Bank Industry and Energy Department estimate, compiled from a survey of World Bank project and sector reports and published and unpublished material for several countries, June 1995.

2 Costs are escalated from 1987 to 1994 dollars at 2.5 percent per annum.

1.4 Early solar home system programs encountered a variety of difficulties. These included unreliable technical performance, organizational and cost recovery problems, and user dissatisfaction resulting from unrealized expectations. More recent projects utilizing improved systems have incorporated lessons learned from these experiences and are performing quite well. As a result, the number of PV programs has grown substantially. About 400,000 solar home systems are now installed worldwide. These include 50,000 in China, 40,000 in Mexico, 20,000 in Kenya, 20,000 in Indonesia, 10,000 in Brazil, 4,500 in Sri Lanka, 4,000 in the Dominican Republic, 4,000 in the Pacific Islands, and 1,000 on the Navajo reservations in the southwest United States.

Box 1-1
Government Initiatives in Indonesia

In Indonesia, the government-supported BANPRES Project has installed more than 3,300 solar homes systems in 13 provinces since 1991. The project has also led to commercially oriented initiatives and additional government-sponsored programs that have installed nearly 20,000 systems to date. The BANPRES Project makes effective use of existing rural structures and capabilities. With the assistance of local governments, participating villages are selected. Selection criteria is based on factors such as the community's desire for electricity, lack of access to grid services, householders' ability to pay, and the effectiveness of local cooperatives which play a key role in project implementation. The cooperatives collect down payments and monthly installments and employ technicians to provide maintenance services. Despite the low monthly fees of the BANPRES Project, which are about the same as those for grid-connected service, the collection rate has hovered at around 60 percent. The Project included pilot demonstrations and tests to identify the optimal solar home system configuration which are now being replicated, virtually unchanged, in both commercial and government-sponsored programs.

1.5 To identify commonalties and best practices, ASTAE commissioned four in-depth case studies of solar home system programs in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic.[3] These programs were implemented by governments, NGOs, cooperatives, and the private sector, sometimes with donor assistance. The case studies have yielded valuable insights into the elements for successful solar home system initiatives. The individual reports, available on request to ASTAE, are summarized above and below in Boxes 1-1 to 1-4. Further details on each country's experience are provided in Annex 1.

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3 The German BMZ/GTZ conducted the case study in the Philippines and assisted in the case study in the Dominican Republic.

1.6 In addition to the case study findings, the Report reflects ASTAE's consultation with World Bank staff and PV professionals around the world. Experiences with solar home system initiatives in Kenya and the Pacific Islands, documented in other World Bank studies, have added to our understanding of successful programs (World Bank 1994a). The Report has also benefited from a review by an international panel of PV program experts, convened at the Roundtable on Photovoltaics and Rural Electrification held in Waikoloa, Hawaii, in December 1994.

Box 1-2
The Solar Home System Market in Sri Lanka

Solar home systems in Sri Lanka have been supplied through a combination of private sector, NGO, and government-sponsored programs. The 4,500 systems installed since 1982 serve a small portion of the 2 million households without access to grid-based electricity services. The private sector sells the PV systems through its own distribution network, providing trained technicians who make house calls and customer education on proper maintenance techniques. NGO projects, which rely on local technicians, are characterized by active local participation in project design and maintenance and in the collection of loan payments. Government programs, executed by private firms, also offer maintenance services. Sri Lanka has some experience in solar home system financing through bank credit or hire purchase agreements. However, the limited availability of long-term credit in Sri Lanka presently constrains solar home system use and more than 80 percent of private sector sales have been cash transactions.

1.7 The Report is organized as follows:

- Chapter 1 sketches the evolution of household PV systems.
- Chapter 2 describes solar home systems, their costs, consumer perceptions and the potential niche for household PV in rural electrification.
- Chapter 3 analyzes the economics of solar home systems vis-à-vis grid and off-grid options.
- Chapter 4 outlines financial constraints to solar home system diffusion, such as first-cost barriers and market distortions.
- Chapter 5 examines vehicles for program implementation such as energy service companies (ESCOs), leasing arrangements, consumer financing, and direct cash sales. It also identifies how government and donor agencies can assure sustainable household PV electrification programs.

- Chapter 6 sets out financing and cost recovery requirements.
- Chapter 7 focuses on technical standards.
- Chapter 8 lists the main conclusions and recommendations.
- Annex 1 summarizes the four ASTAE case studies of household PV experiences in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic.
- Annex 2 details the economic analysis and assumptions used to define the economic niche for solar home systems in rural electrification. It also examines the impact of productive loads and load growth on solar home system competitiveness.

Box 1-3
Bilaterally-Assisted Programs in the Philippines

The dissemination of solar home systems in the Philippines has been dominated by two rural PV electrification programs assisted by the German BMZ/GTZ. In addition, about 10 local private companies sell 100-150 units annually. Such efforts have begun to tap the potential market of the more than 6 million Filipino families not connected to the grid. After the first PV project was initiated, demand for solar home systems grew faster than the program could accommodate. This led to the creation of the Philippine/German BMZ/GTZ Special Energy Program (SEP) in 1987.

The SEP's strategy is to distribute small solar home systems in clustered sites, gradually increasing the demand for electricity and the area covered until grid extension becomes economically feasible. Rural cooperatives oversee servicing and fee collection, and local NGOs have direct responsibility for collections, maintenance, and monitoring. PV modules are purchased in bulk to help lower costs to consumers. Only about 10 percent of the households can pay cash for the systems. For the others, the SEP has established revolving funds to finance some systems and is seeking to expand its credit supply.

Box 1-4
The NGO Experience in the Dominican Republic

The Dominican Republic currently has 400,000 households without access to grid services. NGOs are working with the private sector to facilitate the distribution of solar home systems. NGOs promote PV technologies, provide technical and management training, and finance sales through revolving funds. Businesses supplying equipment are able to meet the demand but lack the training, working capital, and physical resources to develop further. In addition, lack of access to credit and price increases (due to the devaluation of the peso) have severely constrained the dissemination of solar home systems.

Because commercial banks in the Dominican Republic do not typically offer credit, NGOs have set up revolving funds with international donor organizations and have successfully begun offering credit to consumers to purchase systems from local entrepreneurs. Thirteen small businesses have sold over 2,000 systems throughout the country.

2

THE PLACE FOR PHOTOVOLTAICS

2.1 Electricity provides services such as lighting, power for agriculture and industry, water pumping, refrigeration, telecommunications, and entertainment. The most familiar delivery mechanism for electricity is the conventional power grid which consists of generation facilities, long-distance transmission lines, and local distribution equipment. Other energy sources such as PV systems, batteries, diesel engines, kerosene or gas lighting, candles, wood, agricultural residues, or animal power have a role to play in rural energy service provision.

2.2 Photovoltaic systems are already used in a broad array of rural energy applications. They provide households and small businesses with services such as lighting, refrigeration, and entertainment; they are used to pump water for agricultural purposes; to deliver public services, including health care, water purification, and street lighting and to power remote telecommunications facilities (Shepperd and Richard 1993). PV systems are modular. They can thus serve loads ranging in size from milliwatt (for instance, a pocket calculator) to megawatt (for bulk power supply). Over the past decade, considerable experience has been gained in designing and implementing solar home system programs in remote areas. The current costs of PV systems make them an economical option in situations where conventional power is too expensive for the small amount of power required, where the supply must be absolutely reliable (as for vaccine refrigerators in rural health clinics) or in areas too remote or geographically isolated for grid connectors.

THE SOLAR HOME SYSTEM

2.3 A typical solar home system includes a 20- to 100-Wp photovoltaic array[1]; a rechargeable battery for energy storage; a battery charge controller; one or more lights (generally fluorescent); an outlet for a television, radio/cassette player, or other low-power-consuming appliance; switches; interconnecting wires; and mounting hardware (see Figure 2-1). Both the array size and the sunlight availability will determine the

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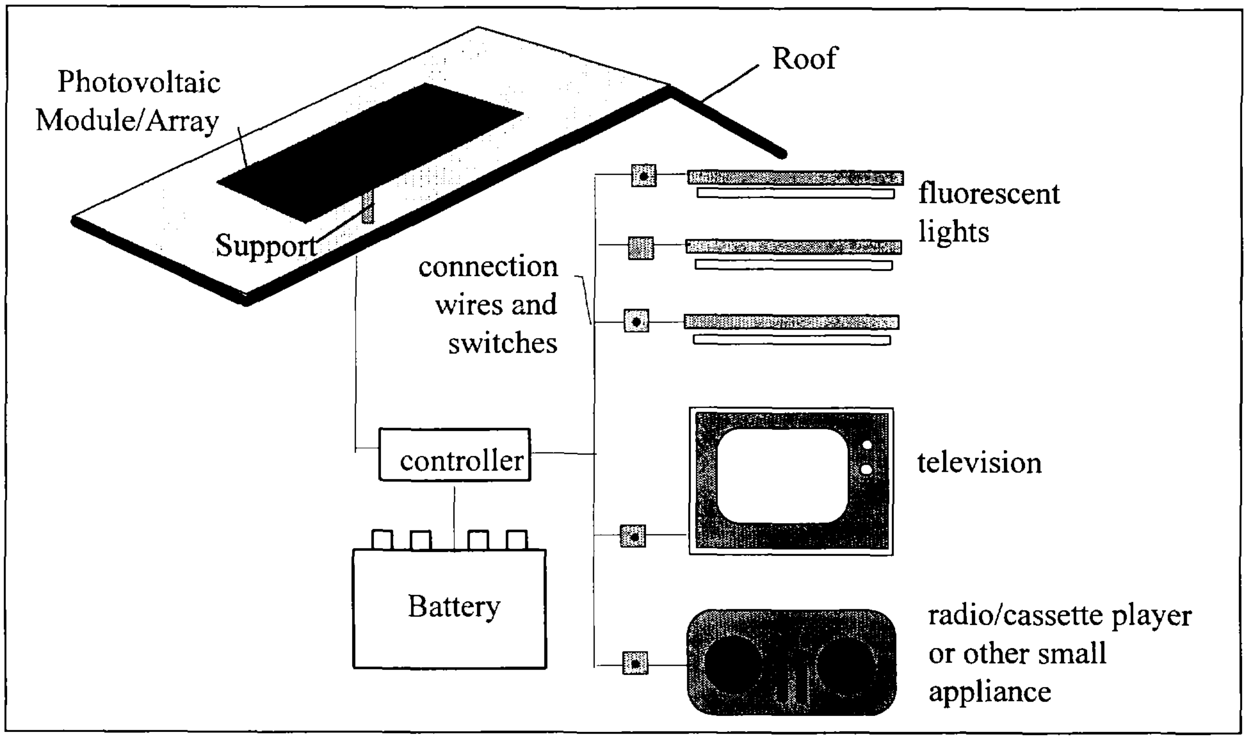
1 The capacity of a photovoltaic module is defined in terms of watts peak (Wp) of output. The rated peak output is measured under standard test conditions of 1,000 watts per meter squared (W/m^2) solar radiation, and 25°C cell temperature, among others. Solar home systems are often designed to be smaller than 20 Wp and larger than 100 Wp.

amount of electricity available for daily use. In a country such as Indonesia, a 50-Wp system can provide enough energy to operate four small (6- to 10-W) fluorescent lights and a small 15-inch black-and-white television for up to five hours. In areas with longer hours of sunlight, a similar level of service can be obtained from a smaller system. Solar home systems can also help households generate income from business activities.[2]

Figure 2-1. Typical System Components



THE COST OF SOLAR HOME SYSTEMS

2.4 The cost to consumers of solar home systems varies significantly from country to country (see Table 2-1). This is due to:

- The sophistication of the system;
- The number of systems purchased;
- Duties, taxes and subsidies;
- The scale of the manufacturing and assembly processes;
- The scale and cost of marketing and other services, including the number of "reseller" steps in the distribution chain;
- The degree of competition in the marketplace;
- Capacity utilization in manufacture, sales and servicing; and
- The cost of funds for working capital and capital investments.

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2 A recent survey shows that 30 percent of installed systems in the Dominican Republic were used in this way. (Hansen 1994).

Table 2-1. Solar Home System Prices in Selected Countries

Country	Year	Size (Wp)	Price ($)	Unit Price ($/Wp)
Kenya	1993	53	1,378	26.00
China	1994	10	93	9.33
		20	160	8.00
		20	280	14.00
Indonesia	1994	6	125	21.00
		12	215	18.00
		40	400	10.00
		53	425–700	8.02–13.10
		53	620[a]	11.68
		100	715	7.15
Philippines[b]	1993	48	640	13.33
		53	900	16.98
Sri Lanka	1995	20	340	17.00
		30	460	15.33
		40	560	14.00
		50	674	13.48
Brazil	1994	50	700	14.00
		100	1,100	11.00
Dominican Republic	1993	25	450	18.00
		35	575	16.42
		48	700	14.58
Mexico	1994	50	700	14.00
USA				
—Idaho Power Company	1994	1,000	10,000[c]	10.00
—Navajo Housing Services Dept.		90	1,500	16.67
——(DC and AC output)				

Note: All costs are in US dollar equivalents. Some programmatic costs, particularly for government or donor-assisted programs, may not be included.

[a] Government program sales.

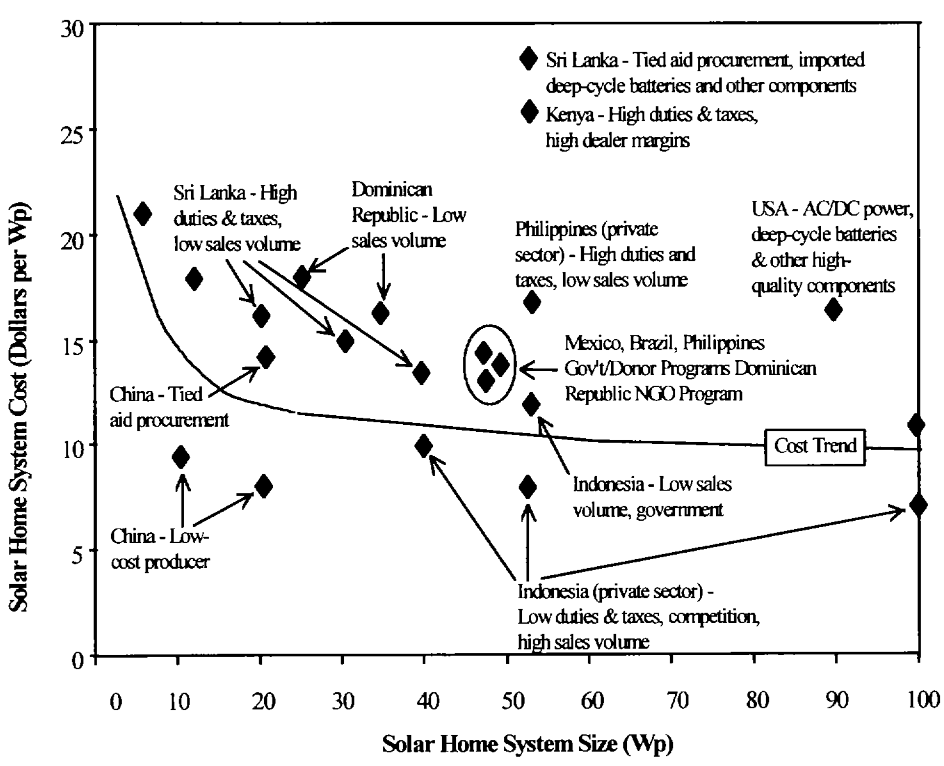
[b] The private sector cost of a system in the Philippines is significantly higher than the cost of a system in the donor-assisted project because of taxes and duties.

[c] Present-value estimate including battery replacement and service), based on a 5 percent down payment, a monthly cost-recovery factor of 1.6 percent of net installed cost, and an expected minimum monthly charge of $150, as proposed by the utilities.

Sources: ASTAE Case Studies and field investigations in China, the Dominican Republic, Indonesia, the Philippines, and Sri Lanka; World Bank 1994a; US PV trade newsletters; Shepperd and Richard 1993; and Personal Communication, Chris Rovero, Meridian Corporation, Alexandria, VA, USA, 1996.

2.5 Figure 2-2 identifies some reasons for unit price ($US/Wp) variations in selected countries. The price of a solar home system in many parts of Indonesia is as low as $7.15/Wp for a 100-Wp system. However, in some areas of Indonesia, where sales volumes are low and the population is more dispersed, manufacturers have to offer significantly higher margins to their retailers. This can add about $300 to the retail price (more than $5.00/Wp higher) of each system. As sales volumes increase, manufacturing and marketing infrastructure matures, and financial distortions are reduced, there is every reason to expect that prices in many countries will reach the low unit prices of solar home systems now generally available in Indonesia and China.

Figure 2-2. Some Reasons For Unit Cost Variations of Solar Home Systems



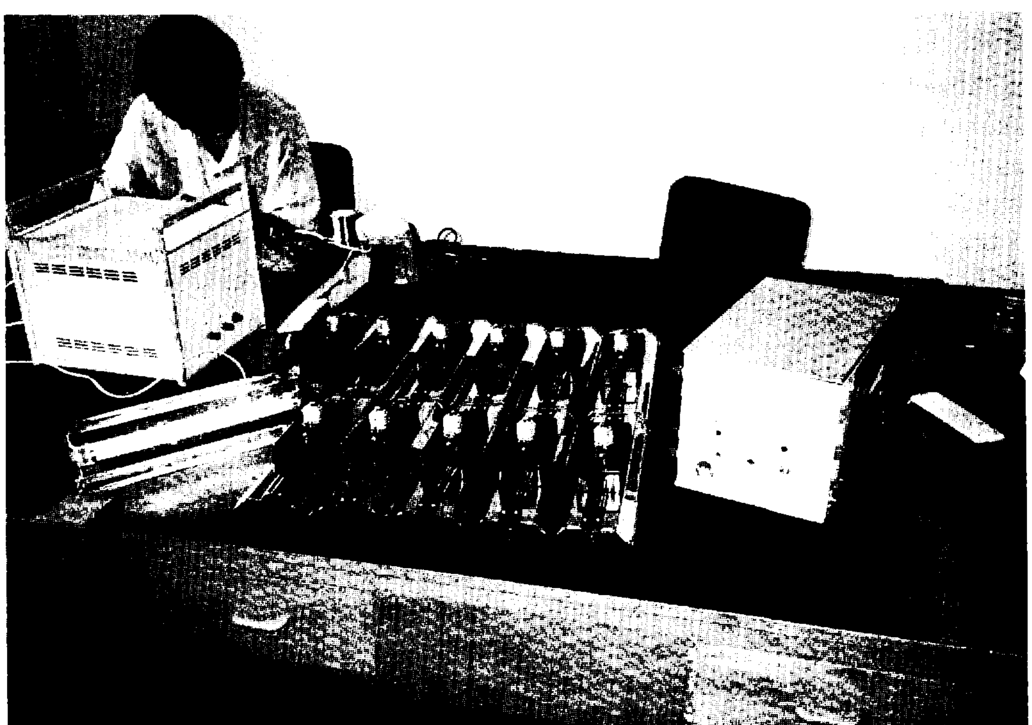
Note: Programmatic costs of government and donor-led efforts may not be fully reflected in the cost of PV systems. Cost per Wp is also affected by the size of the PV system, variations in the quality and features of systems and components, services provided by the seller or implementor, and input factor cost differences among countries.
Source: Table 2-1.

2.6 Table 2-2 compares unit costs for solar home systems by component in the Dominican Republic, Indonesia, and Kenya. There are significant opportunities for reducing costs through high-volume purchases of modules and other components; assembly line solar home system manufacture/integration; better utilization of production, sales and service capacities; reduced taxes and duties on PV panels and components; and larger sales volumes which would allow dealers to reduce their margins (see Box 2-1).

Table 2-2. Variations in PV Costs by Components in Selected Countries

Country	*Dominican Republic*		*Indonesia*[b]		*Kenya*	
PV Module Size (Wp)	48		53		53	
Battery Capacity (Ah)	90		70		100	
Implementing Agency	Private business/NGOs		Private		Private	
Component	Cost	Percent	Cost	Percent	Cost	Percent
—Module & Support	340	49	200	47	340	25
—Battery	70	10	40	9	115	8
—Controls	44	6	35	8	66	5
—Lamps, wiring, switches	47	7	35	8	138	10
—Deliver/Install/Retail Margins	129	18	75	18	456	33
Duties and Taxes	70[a]	10	40	10	263	19
Total Cost	700	100	425	100	1,378	100

Note: a. Import duty only.
b. Based on annual sales of 5,000 systems per manufacturer and 200+ per dealer.
Sources: ASTAE Case Studies and field investigations, World Bank 1994a.



Locally made components, such as these light fixtures made in China can reduce system costs and generate local employment. Source: SELF, Washington, D.C.

Box 2-1
Cost Reduction Opportunities for Solar Home Systems

Promising opportunities for reducing unit costs in the near future include the following:

Photovoltaic Modules. PV modules can be purchased in bulk at about $4/Wp (Indonesia). With smaller orders, unit prices can exceed $8/Wp (the Dominican Republic). For large procurements, some PV module suppliers are also offering interest-free supplier credit for six months.

Electronic Components. Evidence from China and Sri Lanka demonstrates that significant cost savings can be achieved by purchasing electronic components in bulk.

Batteries. While deep-cycle (marine-type) batteries are preferable for use in solar energy systems, they are relatively expensive and difficult to procure locally. For these reasons, automotive batteries are more commonly used. Should the demand for deep-cycle batteries increase, then lower-cost local manufacture of such batteries can help reduce life-cycle costs.

Economies of Scale in Production and Sales. Production costs depend heavily on volume. As demand increases, the costs of manufacturing solar home systems should fall. As more suppliers enter the market, competition should also drive prices down.

Support Service Costs. Support services costs will also fall as sales volume per dealer increases, spreading the fixed costs of sales and servicing over a larger number of units.

Local Manufacturing and Assembly. If there is a comparative local advantage in manufacturing and assembling the units, capability may be developed to realize cost savings, as long as quality is not compromised. On the other hand, import barriers to support domestic production will increase the prices and reduce demand. In Sri Lanka, tariff barriers to protect a local module encapsulation plant increased module costs by $2.50/Wp. Indonesia's low duties on PV module imports have resulted in relatively low unit costs.

Duties and Taxes. Duties and taxes significantly increase the cost of solar home systems. Reducing or eliminating these fees can help make systems more affordable.

2.7 At present, varying degrees of backward integration in solar home system production are occurring in developing countries. These range from the importation of complete systems to in-country production of all components, including the PV array. For example, as a direct result of its national industrial development policy, India produces single-crystal wafers as well as all system components. In other countries, only low-technology components, such as mounting poles, wires, light fixtures, and automotive batteries, are manufactured locally.

THE SOLAR HOME SYSTEM NICHE

2.8 Household PV electrification is typically suitable for households located in remote unelectrified locations. However, households in "electrified" communities may also be good targets for solar home systems. Many households in "electrified" areas are too far from the grid (200 meters or more), or have too small a load to warrant a connection. In Bali, Indonesia, for example, while 98 percent of the villages are classified as "electrified," only 41 percent of the households are connected. Of the remaining 59 percent of households, many may never receive grid service, given their distance from the grid lines or their location in difficult terrain. PV home systems are a practical and permanent source of electricity for these households. In other areas, households may gain access to grid-based services as electricity demand increases due to a rise in personal and community incomes. Here, solar home systems can still serve as an effective interim measure. When the grid does arrive, the used solar panels can be sold (if the household owns the system), or the utility can transfer them to another location, thereby recovering a sizable portion of the initial cost.

Solar home systems also are used in schools and other community buildings such as this school in Sukatani, Indonesia. Source: PT. Sudimara Energi Surya.

2.9 Rural households that currently use kerosene lamps for lighting and disposable or automotive batteries for operating televisions, radios, and other small appliances comprise the principal market for solar home systems. In Sri Lanka, there are about 300,000 such households (about 10 percent of unelectrified households). Java, Indonesia, has an estimated 1 million such households, or about 12.5 percent of unelectrified households. On average, a single such household uses about 0.5–1 liter of kerosene daily and about 2–16 dry cell batteries per month; automotive batteries are recharged about four times a month at a cost of $1–$2 per recharge and must be replaced every two to three years at a cost of $40–$60. Recurring costs for these households are estimated to range from $10–$30 per month. Solar home systems, at today's prices, are an affordable alternative for such families.

CONSUMER PERCEPTIONS

2.10 Solar home system users in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic indicate that the systems are valued for more than just monetary savings in kerosene or battery costs. Consumer income and expenditure surveys show that a willingness to pay for a solar home system is greater than what might be expected from a simple avoided-cost analysis. Rural consumers frequently note the following non-monetary advantages of PV home systems over kerosene lighting and rechargeable batteries:

- Higher-quality light, both in terms of lumen output and color rendering ability, making such tasks as reading and studying easier;
- Improved safety levels. Solar home systems eliminate dangers from accidental fires and burns from kerosene devices, candles, or acid spills from batteries;
- Cleaner indoor air, due to reduced (or eliminated) soot and fumes from kerosene and candles;
- Greater reliability and freedom from fuel need;
- Convenient, instantly available light and access to services such as TV and radio, without the need to purchase and transport supplies; and
- An elevated social status associated with electrification.

2.11 Field observations indicate that women and children generally benefit the most from PV electricity services. In both Indonesia and the Dominican Republic, women account for about 25 percent of the signatories on loans for solar home units. Case studies of the Dominican Republic and the Philippines show that women value good-quality lighting, which allows them to perform domestic tasks in the evening, leaving time for activities outside the home during the day. In the Dominican Republic, 10 percent of the women interviewed revealed that the time they saved with their improved lighting allowed them to carry out additional income-generating activities. Similarly, in the Philippines, solar home systems helped women earn money by affording them time to manage local cooperative stores. Women also note that better lighting enables them to respond more quickly to infant needs at night. Children value the additional time to study, watch television or listen to the radio provided by a solar home system.

2.12 While consumers clearly prefer PV home systems to kerosene lamps or candlelight, the solar home systems currently used in developing countries are considered inferior to grid electricity for several important reasons:

- Solar home systems services are limited. The amount of electricity available from a solar home system depends on the capacity of the PV array and the available sunlight. The incremental cost of obtaining more electricity from a solar home system is relatively high for the consumer. In contrast, grid service can offer unlimited amounts of low-cost electricity (unless utilities curtail service hours, impose capacity constraints on consumers, or are unreliable). For example, in Indonesia, rural household power consumption is limited to 450 W with a circuit breaker; diesel-powered isolated grid service is limited to 4–12 hours at night.
- Solar home systems usually require DC appliances. While DC black and white televisions, radios, and some other small appliances are generally available, other DC appliances are not widely available or cost more than their AC equivalents.
- Subsidized grid connection fees are generally lower than down payments required for credit sales of solar home systems.[3]

A Sri Lankan woman sews at night with PV lighting. Source: SELF, Washington, D.C.

[3] Grid connection costs are about $25–$50 per household in lower-income countries and around $200–$400 per household in higher-income countries (for the service drop and house wiring). In Brazil, however, farmers in one state had to pay an average of $4,000 for a grid connection (Mason 1990).

- Since most rural electrification programs are heavily subsidized, grid-based electricity tariffs are also significantly lower than fees or finance charges for solar home systems.[4]

2.13 Consumer education is directly related to consumer perceptions. It is important that customers understand the capabilities of a solar home system before acquiring it. In the past, unrealistic perceptions (such as the belief that small 50-Wp systems can power large household appliances) have led to customer dissatisfaction. Widespread dissatisfaction can sabotage efforts to promote the use of solar home systems.

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4 For example, in Indonesia and Sri Lanka rural residential consumers pay only about 20 percent of the economic costs of electricity from the grid.

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.

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[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.

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 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

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

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 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.

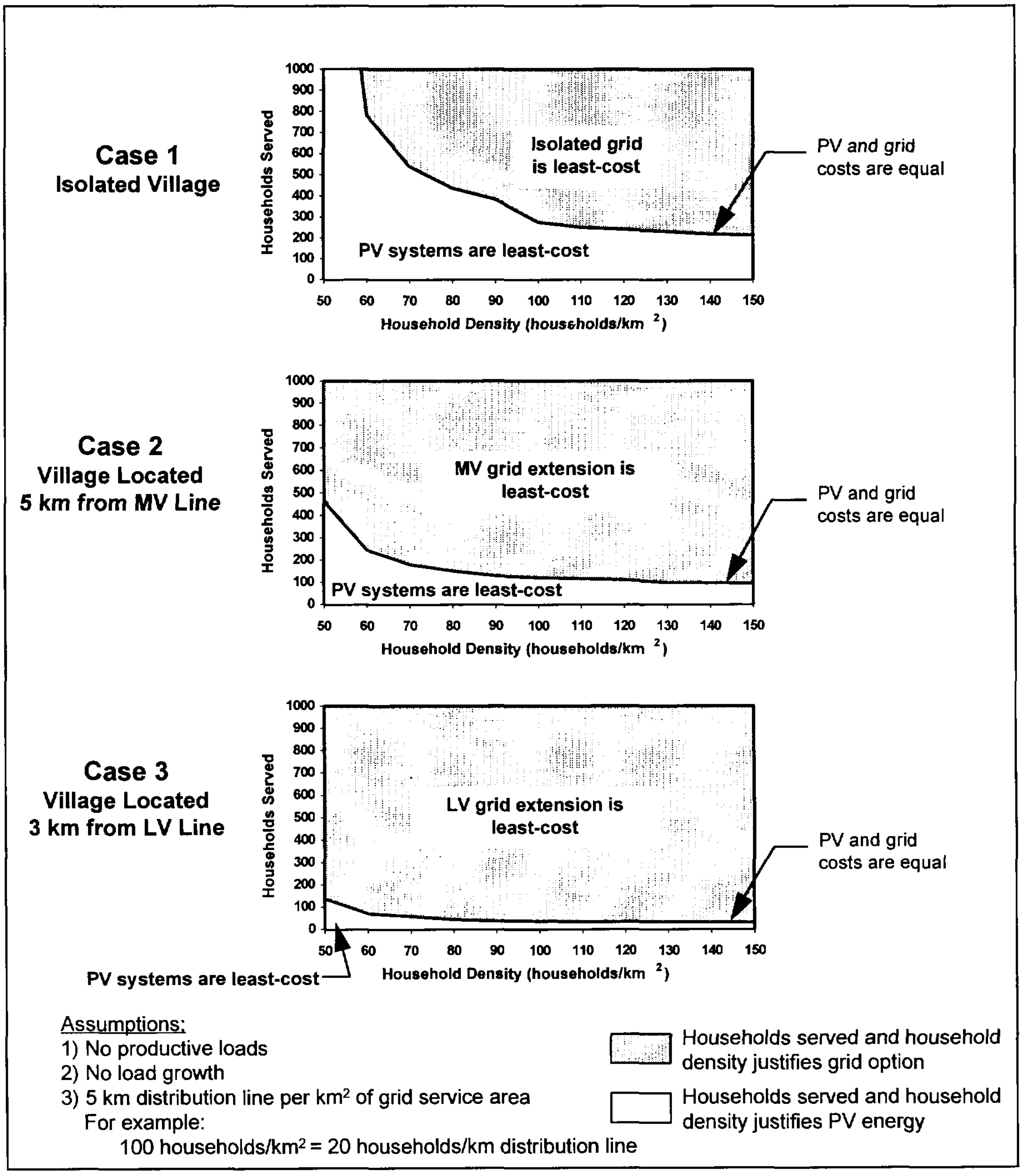
3.11 The break-even curve in each graph traces the line along which the levelized costs are the same for either PV household systems or grid-based power, given specific combinations of load (household connections) and load density (household connections per km^2). PV electrification is the least-cost 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.

4

BARRIERS TO AFFORDABILITY

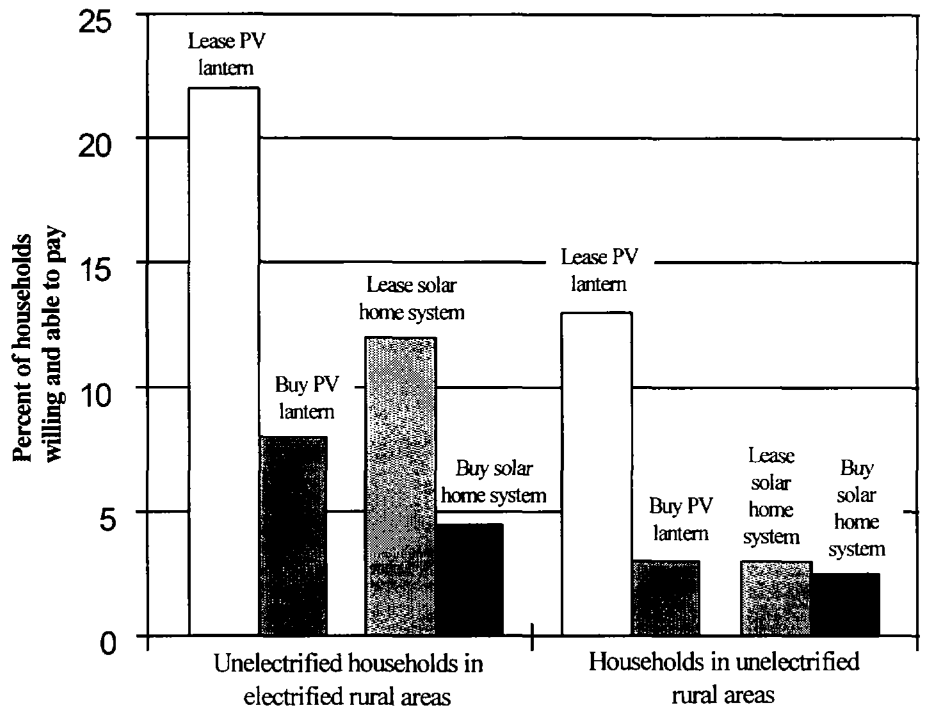
4.1 The previous Chapter outlined the conditions under which solar home systems are the least-cost option for rural lighting and power supply. However, from the point of view of the potential user, the key issue is the affordability of the PV system in relation to its perceived value. While many beneficiaries of rural electrification benefit from subsidies, PV users are generally expected to pay for most of the costs of their systems. This Chapter examines barriers that constrain the purchase of solar home systems. These include:

- ***High capital costs*** and lack of access to credit make solar home systems too expensive for many rural households;
- ***High transactions costs*** arise in purchase or servicing of solar home systems due to limited supply, sales outlets, technicians and financing infrastructure in rural areas;
- ***Market distortions*** often increase the price of solar home systems relative to alternatives. These include:
  - import duties, tariffs, and taxes; and
  - subsidies for kerosene and grid-based service to rural consumers.

FIRST COST BARRIERS

4.2 Solar home systems use renewable energy and are self-contained generation and distribution systems. They consequently have low operating and maintenance costs in comparison to fossil fuel alternatives. Thus, the initial capital cost of a solar home system is very high in proportion to its total life-cycle costs (typically more than 75 percent). As noted in Chapter 2, the actual purchase price of solar home systems range from $100 (10 Wp, China) to $1,400 (53 Wp, Kenya). For many low- and middle-income rural households, the purchase price of a solar home system represents almost one year's income (Foley 1994). The price of solar home systems is one of the greatest barriers to ownership among rural populations, especially given the virtual absence of credit. Figure 4-1 demonstrates the relation of cash-only purchases with leasing and rental options in the market for solar lanterns and solar home systems. It indicates that relatively few Indian households are willing to pay cash for the systems when credit purchases are available (Admar Services 1994). Although outright cash purchase of solar home systems does occur, only the wealthiest of rural consumers have this option. In the Philippines, it is estimated that only 10 percent of potential purchasers can pay cash, while 20-60 percent could afford to buy a system on credit, depending on payment conditions and terms (ASTAE 1995c).

Figure 4-1. Demand for PV Systems in Rural India, by Type of Financing



Source: Admar Services, 1994.

4.3 Term credit for the purchase of PV systems is unavailable in most countries. In general, banks extend credit to rural customers for productive purposes only. Since solar home systems are considered consumer goods, they are excluded from such credit options. Where commercial financing or leasing schemes are available, a down payment of 25–30 percent is often required. Interest rates on bank loans generally range from 18–25 percent, while dealer financing may carry interest rates of over 30 percent.[1] The loan repayment periods for commercial loans are generally short (from 2–3 years). The combination of high interest rates and short maturities increases the size of monthly payments and thus reduces the number of households that can buy on credit. A number of options are available to overcome the problem of limited credit access (see Box 4-1).

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[1] Terms specified in local currency. See also Table 6-2.

Box 4-1
Increasing Credit Availability for PV Systems

The limited credit availability or stringent loan terms to PV enterprises and purchasers constricts the rural market for PV systems. Reasons are: unfamiliarity of the lenders with the technology; high transaction costs relative to the size of loans; inadequate collateral; and borrowers with no credit history, limited or lumpy cash flows (de Lucia and IFREE, September 1995). Some approaches to increase rural credit for PV are:

- ***Seed Capital Fund*** – Funds provided by philanthropic organizations or development aid agencies create a revolving fund that is used to purchase PV systems. This approach is often used in the early stages of a solar home system program. Examples include: Enersol NGO in the Dominican Republic; Solanka NGO in Sri Lanka; and the BANPRES project in Indonesia.
- ***Equity Investments and/or Debt Financing by the Government*** – As with grid-based rural electrification, the government finances the initial capital equipment of a PV project through an equity contribution or loan. This approach is used in Mexico.
- ***Asset-based Lending*** – A solar home systems enterprise obtains a loan by mortgaging its assets. Unfortunately, many solar home system enterprises have limited assets and therefore the amount they can borrow is restricted. In lieu of fixed assets a bank could ask for other forms of security (e.g., post-dated checks, personal guarantees, bank guarantees). A bank may accept the PV system as partial collateral, but this is rare because banks perceive PV systems as difficult to repossess.
- ***Non- or Limited-recourse Financing*** – A lender agrees to financing credit for a solar home systems enterprise, based primarily on the project cash flows. At present, this option is rarely used as the enterprises do not have sufficient operations experience. The solar home systems program executed by the RECs in the Philippines did receive such financing from the National Electrification Administration.
- ***Consumer Financing*** – A bank gives a personal loan to a consumer for the purchase of a solar home system. The bank may require that the consumer pledge other assets to cover the loan or attach a portion of their salary to ensure repayment. Examples are the solar home system loans provided by the Peoples Bank and Hatton Bank in Sri Lanka.
- ***Supplier Credits*** – Some PV module suppliers offer credit to their dealers or PV systems integrators. The length of the credit terms is likely to be short (six months), but such credit can improve cash flows. PV companies in Indonesia have received these supplier credits.

4.4 Financing costs may increase the life-cycle costs of PV systems but they make the systems more widely affordable. For example, in the Dominican Republic, a $700 solar home system can be purchased for a 25 percent down payment and 24 monthly payments of $30. In contrast, combined household expenditures on kerosene, dry cells, and automobile batteries for lighting and power can reach $35 per month. Moreover, the householder's monthly outlay for the solar home system will end after two years, with the exception of battery replacement. Data from a dozen countries indicate that current monthly expenditures by families in the highest income group in unelectrified areas average $17.60, including $7.90 for kerosene, $4.10 for candles and dry cell batteries, $2.50 for automotive battery recharging, and $3.10 for battery amortization (Meunier 1993). Monthly expenditures for lower-income groups ranged from $2.30 to $3.80 for kerosene and candles to $8.30 for kerosene lamps, candles, and dry-cell batteries.

An Enersol customer in the Dominican Republic signs a solar home systems loan agreement.
Source: Enersol Associates, Inc.

4.5 The affordability of solar home systems can be extended to a greater number of consumers if an energy service company (ESCO), such as the local electric utility or distribution company, offers electricity services using solar home systems, rather than grid extensions (Box 4-2). The ESCO retains ownership of the equipment and recovers its costs over a long period of time. If an ESCO can obtain long-term credit at relatively low interest rates, this option can be an effective way of lowering household monthly payments. As discussed in Chapters 5 and 6, a number of pioneering initiatives are successfully demonstrating this approach.

4.6 Unless subsidies comparable to "lifeline rates" for grid electricity are offered, the market for PV systems will remain limited to middle- and upper-income rural households. Purchases of PV systems can be expected to follow patterns similar to those found in traditional rural electrification projects. In Indonesia, for instance, studies show that the poorest 25–50 percent of the population is unable to afford electricity service even if the connections are financed through power company loans. Direct observation tends to support this supposition for most countries with per capita incomes of less than $200 per year (World Bank 1994b).

Box 4-2
Idaho Power Company and Southern California Edison Programs for Solar Photovoltaic Service

Two US electric utilities have pilot programs that offer PV electricity services to eligible customers. Eligibility is determined through a comparison of PV systems and grid extension costs. Remoteness of site, accessibility, load size, load profile, solar resources, solar impediments, and suitability are taken into consideration in determining eligibility.

A minimum PV system size of 1-kWp is required per customer. The maximum the utility will pay per installation is $50,000 net of the down payment made by the customer. An initial fee of 5 percent of the installed cost is charged as a down payment. The balance of the net installed costs and all replacement, repair, and maintenance costs are recovered at 1.6 percent of the net installed cost per month.* A minimum 15-year agreement is required; at the end of this period, the customer assumes ownership of the system. The customer can also purchase the system at any time at its depreciated value.

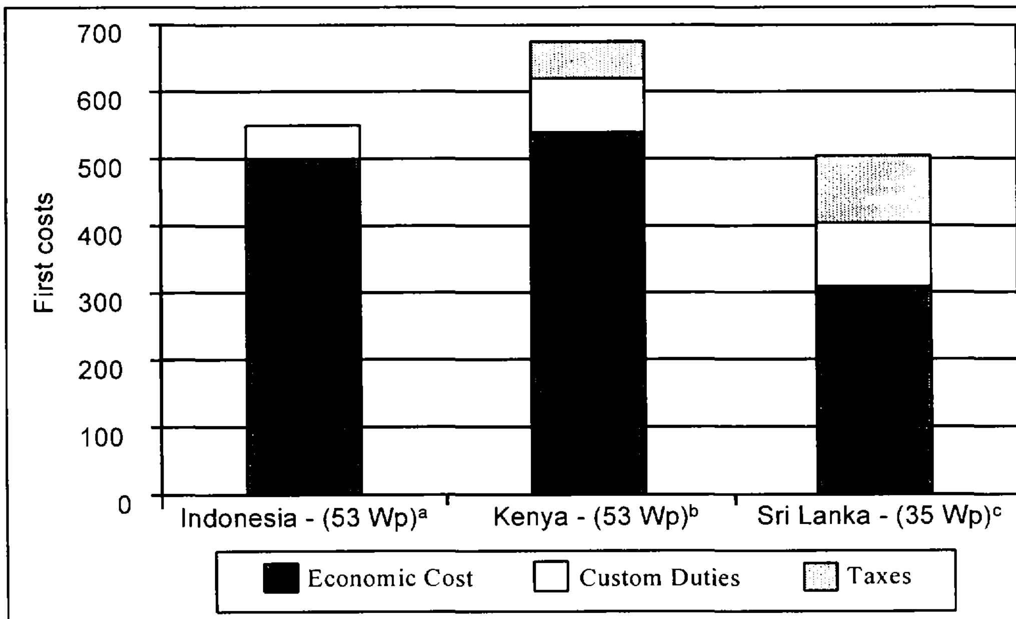
The system is installed and maintained by licensed independent contractors on request. The utilities will also offer a back-up generator for a customer. The customer is responsible for providing fuel and fuel storage for the generator.

* Under these payment terms, a 50-Wp, $500 system requires a $25 down payment and $7.60/month inclusive of battery replacement, repairs, and maintenance, for 15 years. In contrast, a repayment scheme for a similarly priced PV system in Indonesia requires a $114 down payment and $9.10/month for 36 months, exclusive of battery replacement, repairs or maintenance charges (April 1, 1994 rate of Pt. Sudimara Energi Surya, Jakarta, Indonesia).

HIGH TRANSACTION COSTS

4.7 The PV home system industry is relatively new. Markets are small and still developing in many countries. In the early stages of market development, it is difficult for sales and service networks to reach the economies of scale that would allow for price reductions. The Indonesia experience clearly illustrates how economies of scale can affect the production, sales, and servicing of PV systems. A solar home system in West Java (where annual sales are in the thousands) is 50 percent cheaper than in Lampung, Sumatra (where sales are in the hundreds). The combined effect on prices of a small market and limited competition is also seen in Kenya, where the total installed price of a 53-Wp system is $1,378, compared with an estimated financial cost of $670, based on competitive prices plus taxes and duties (see Figure 4-2).

Figure 4-2. The Impact of Duties and Taxes on the Initial Cost of a Solar Home System in Indonesia, Kenya, and Sri Lanka (in 1993 dollars)



Note: Costs assume the existence of a mature sales and service system. Base CIF price is adjusted by applicable local transport, sales, and installation margins in each country.

[a] Maximum import duty of 5 percent; 10 percent VAT; 17 percent distribution, installation, and retail margin.

[b] Import duties of 15 percent; 13 percent taxes; 33 percent margin.

[c] Import duties of $2.50/Wp; effective business and sales tax of 32 percent; 17 percent margin.

Source: ASTAE (1994b); ASTAE (1994d); UNDP/ESMAP (1994).

4.8 The costs of solar home systems should fall as markets mature, sales and support networks develop, and competition grows. Using existing durable goods, sales, and service outlets could help reduce these overhead costs. However, as experience in Sri Lanka shows, unless the margins offered to such rural outlets are sufficiently high – they will not have much incentive to support solar home system sales. It is difficult for a new and somewhat marginal PV home system industry to make substantial investments in retail and service networks. Support from government and donor agencies can help build the necessary infrastructure to accelerate development. Such assistance can include:

- Supporting and conducting least-cost rural energy planning that includes PV home system options;
- Making investment capital available for solar home system programs;
- Encouraging the commercial banking sector and financing agencies to finance PV home systems on reasonable terms by offering support mechanisms refinancing arrangements;
- Supporting promotional campaigns for PV household systems among rural households;
- Removing regulatory barriers that limit competition among energy service providers; and
- Offering training and technical assistance to help establish retail and service networks.

These issues are discussed more fully in Chapter 5.

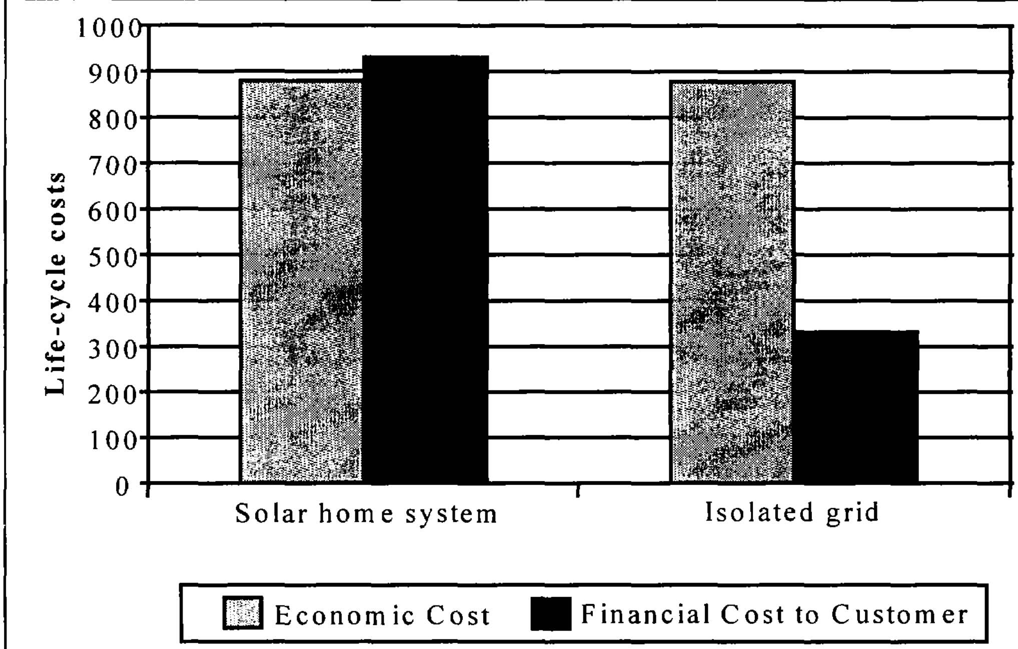
MARKET DISTORTIONS

4.9 **Import duties.** As a relatively new and evolving technology in developing countries, PV systems often require imported components, which can account for virtually all equipment costs. Several countries impose high tariffs on PV components, driving prices prohibitively high. Often protective tariffs are set to encourage local manufacture (Figure 4-2). In Kenya, for example, import duties and value-added tax (VAT) for PV system components effectively add 16 percent to the CIF cost of PV modules and as much as 89 percent to the cost of batteries. As a result, the wholesale price of a solar home system is nearly 40 percent more than the CIF price. In Sri Lanka, import duties added about $2.50/Wp to the cost of a PV module in 1993/94. In 1994, India levied import duties of 45 percent on PV equipment and as much as 300 percent on solar lanterns. Duties on electronic components are particularly harmful to the PV system market, since suppliers are tempted to substitute locally-made inadequate or poor-quality battery charge controllers or to dispense with controllers altogether (World Bank 1994a).

4.10 **Subsidies for Other Rural Energy Options.** While duties and taxes on PV system components <u>raise</u> the financial costs of PV systems, subsidies for rural grid service and kerosene often <u>lower</u> the cost of these energy options to well below their economic value. A recent study of six rural electrification programs using grid-based electricity revealed that the costs to consumers were well below the full economic costs in all cases. The actual costs of residential use, which coincides with the peak system use, were estimated at $0.31/kWh for Maharashtra (India) and Java-Bali (Indonesia), while average tariffs were $0.027/kWh and $0.055/kWh, respectively (World Bank 1995). While subsidies may be justified on social or developmental grounds, unfortunately, they reduce the costs of grid service to levels well below those of PV systems, even when solar home systems are the least-cost economic option.

4.11 Figure 4-3 illustrates the effect of these market distortions in Indonesia, which levies a 10 percent VAT on all goods and imposes import duties on PV modules, while subsidizing rural grid service. While the economic life-cycle costs of PV home systems are lower than they are for service from a remote grid, the actual life-cycle costs paid by rural households are much higher for PV than for subsidized grid service. Therefore, the strong customer preference for grid service is not surprising.

Figure 4-3. Comparison of the Economic and Financial Costs of PV- and Grid-Based Service in Indonesia (in 1993 dollars)



Note: The villages involved comprise approximately 250 households, the load 100 households/km^2 (20 hh/km distribution line). The household service level is set at 8 hours area lighting, 6 hours task lighting, and 60 Wh/day for appliances. See Annex 2 for a discussion of the methodology used.

4.12 As PV home systems become accepted as a complement to grid extension, manufacturing and marketing networks will mature and costs will fall. To support this process, governments can help develop larger sales and service networks to capture the advantages of economies of scale. Governments can also rationalize the fiscal treatment of PV systems and conventional rural energy in more open trading policies and market pricing of rural energy services.

5

INSTITUTIONAL MODELS

5.1 This Chapter examines institutional structures for implementing household PV programs and discusses the roles governments and donor agencies can play in supporting such programs. PV systems programs have been implemented with various institutional arrangements. These range from electric utilities or rural electric cooperatives to private sector leasing and direct sale programs. No single institutional design is applicable in all countries; rather, successful programs are based on local conditions, capabilities, and consumer needs. The experiences of Indonesia, Sri Lanka, and the Philippines demonstrate that effective and sustainable programs have made use of existing institutions, rather than new organizational structures.[1] While this approach avoids the problems of creating and staffing new institutions, the capabilities of existing institutions may have to be strengthened through staff training and, occasionally, through expansion. Also, existing institutions may require specific incentives to accept additional responsibilities.[2] When it is not possible to utilize existing organization, new dedicated solar electrification organizations can be established. In the Pacific Islands, the Tuvalu Solar Electric Cooperative Society was set up after several attempts to use the local utility failed.

5.2 This following section discusses four models for household PV programs: energy service companies (ESCOs), leasing or installment arrangements, consumer financing through dealers and commercial banks, and cash sales. It also discusses ownership arrangements, financing mechanisms, and the flows of products, services, and money. The institutional models described apply to newly created solar electrification organizations as well as existing institutions. Table 5-1 summarizes the main features of each model.

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1 In Sri Lanka, Solanka used existing Death Benefit Cooperative Societies as the basis for forming the Solanka Sun Societies. In the Philippines, five rural electric cooperatives that were already providing electricity services to their grid-connected customers were enlisted to implement household PV programs.

2 In Indonesia, the BANPRES Project used local cooperative (Koperasi Unit Desa) for field implementation. Their incentive for participation was the potential to increase their membership pool.

Table 5-1. PV Program Structures

Structure	*Ownership*	*Financing*	*Product flows*	*Service flows*	*Money flows*	*Examples*
ESCO	Module and controller owned by company; other components may be owned by customer or company	Provided by ESCO through service agreement	Bulk purchase of systems or components; installation by ESCO or by supplier under contract to ESCO	Provided by ESCO as part of ESCO agreement	Monthly consumer payments to ESCO; ESCO pays equipment suppliers, service and admin. staff, and bank loans	Utility: Idaho Power Company (USA) Coop: Rural Electricity Coops (Philippines), Tuvalu Solar Electric Cooperative Society (Pacific Islands) Private: SOLUZ, Inc. (Dominican Republic)
Leasing	Module and controller owned by intermediary; other components usually owned by customer	Provided from intermediary through lease agreement	Bulk purchase of systems or components; installation by intermediary or supplier under contract to intermediary	Provided by intermediary or private vendor under contract to intermediary; may be included as part of leasing agreement	Monthly consumer payments to intermediary. Intermediary pays equipment suppliers, admin. staff, and bank loans. Service technicians may be paid by consumer or intermediary.	NGO: Gansu Solar Electric Light Fund (China) NGO-led, Coop-run: Solanka Sun Society, Sarvodaya (Sri Lanka); Enersol (Dominican Republic) Govt-led, Coop-run: BANPRES (Indonesia)
Consumer Financing	All components owned by customer; module can be used as loan collateral, although other loan security may be needed.	Provided from commercial bank, coop, or vendor	Individual purchase of system; installation by private sector or NGO	Provided by private vendor, generally on a fee-for-service basis, through service contracts	Proceeds of loan used for lump-sum consumer payment for equipment. Monthly consumer loan repayment. Servicing paid by consumer at time of service.	Dealers: ADESOL, ADEPE, ADESJO, SSID (Dominican Republic); Pt. Sudimara, Pt. Kyocindo; (Indonesia); Solar Power & Light Company (Sri Lanka), Electricidad del Sol, Industrias Electricas (Dominican Republic) Banks: Bank of Ceylon, Hatton Bank (Sri Lanka)
Cash Sales	All components owned by customer	Not applicable	Individual purchase of system, installation by private sector or consumer	Provided by private vendor, generally on a fee-for-service basis, through service contracts	Lump-sum payment to vendor. Servicing paid by consumer at time of service.	Dealers: Pt. Sudimara, Pt. Kyocindo (Indonesia); Solar Power & Light Company (Sri Lanka), Electricidad del Sol, Industrias Electricas (Dominican Republic); all companies in Kenya

ENERGY SERVICE COMPANY (ESCO)

5.3 An ESCO sells energy services but retains ownership of the system that provides them—that is, the hardware is neither sold nor leased. An electric utility is, by definition, an ESCO. Cooperatives, NGOs, and private companies can also function as ESCOs. Working examples of such ESCOs include the Tuvalu Solar Electric Cooperative Society in the Pacific Islands and SOLUZ in the Dominican Republic (see Box 5-1). Typically, an ESCO procures solar home systems in bulk from regional distributors or on the international market, installs the system and services the power-generating components (which, at a minimum, include the PV module and support structure). The ESCO is also responsible for financial management and administration. ESCOs may also retain ownership of controllers, inverters, and batteries, so that customers pay only for energy service.

5.4 The ESCO model has several advantages. First, the monthly cost to the consumer can be reduced by spreading the cost of the solar home system over a period comparable to its physical life (ten years or more).[3] The smaller monthly payment makes the system more affordable, allows the ESCO to serve a larger population within its service territory, and creates a "critical mass" of demand. A large consumer base can help the ESCO provide cost-effective maintenance and administrative service and reduced equipment costs, through standardization and high-volume purchasing.[4]

5.5 By aggregating demand, the ESCO can obtain favorable financing terms that are not generally available to individual consumers. ESCOs are often eligible for low-interest loans or grants from private or public sources and are generally considered to be better risks and more creditworthy than individual rural customers. In addition, the transaction costs associated with one large loan are lower than they are for a large number of small consumer loans. The favorable terms can then be passed on to customers in the form of lower service fees.

5.6 The ESCO is a useful model for delivering least-cost rural energy services in areas where off-grid household PV initiatives can be coordinated with conventional electrification efforts by electric utilities.

5.7 Despite its attractive features, the ESCO model does present some disadvantages. First, an ESCO generally requires an existing organization, since setting up a new ESCO is difficult and expensive. Second, a sustainable ESCO model will need a broad base of

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3 This method is similar to amortizing investments (in generation, transmission, and distribution) associated with grid-based rural electrification schemes over periods comparable to the physical life of the equipment.

4 Prices are determined by annual sales volume, which does not necessarily imply bulk buying. Smaller, just-in-time shipments allow feedback on product quality, reduce storage and capital costs, and can even out manufacturers' production schedules.

local support. A handful of temporary personnel, no matter how qualified, will not be able to guarantee strong institutional capability. Third, a full cost-recovery mechanism must be in place in order to ensure the program's sustainability. Programs that rely on grant funds for initial capital investment, must, at a minimum, secure payment to cover recurrent costs. Fourth, since customers do not own their PV systems, the product may be misused.

5.8 Operation of an ESCO also requires a broad range of technical and business capabilities within a single organization, as well as a long-term view of debt servicing that may involve repayment schedules of ten years or more. The decades of experience with grid-based rural electrification programs provide some key lessons for ESCOs.

- The ESCO must be operated as a business with gross income greater than gross expenses.
- ESCO users should participate in capital formation, either through cooperatives or

  through significant contributions to the initial costs of the system. This will instill a sense of ownership in participants and reduce dependence on outside financing.
- While it is preferable for user or participant fees to include all costs, including capital recovery, at a minimum they must cover the operating costs of the service and be collected regularly.
- The staff must be proficient in business management, photovoltaic systems installation, trouble-shooting and repair, and routine maintenance.
- The ESCO must adopt technical and operating standards to ensure that good quality components are procured, maintenance and repair procedures are simple, and the cost of stocking spare parts is minimized.
- The ESCO staff must have access to information, technical assistance, and continued training in order to maintain their technical and managerial effectiveness.
- Fiscal and technical oversight is required to maintain financial "due diligence" and to detect and correct problems with service resulting from poor management or technical error (Waddle 1994).

Incorporating these features in the design of ESCO programs increases the likelihood that customers will receive efficient, effective services.

5.9 Since ESCO administration can impose significant overhead costs on a household PV program, a critical mass of customers is required for a sustainable program. If there are not enough participants, the administrative cost burden will overwhelm the program and make the systems unaffordable. In a small 600-household program proposed by

Sarvodaya in the Southern Province of Sri Lanka, levelized administrative costs are estimated at Rs. 1,750/year per system ($35), which is equivalent to 12 percent of the initial installed cost.[5] This sum covers the costs of collecting fees, administration, service technicians (one per 60 systems), fuel for transporting components, motorcycles and bicycles, office supplies, tool kits, and training. It approximates the 10 percent administrative charge levied by the Rural Electric Cooperatives in the Philippines for their relatively small household PV programs. Instead, in parts of Indonesia, where many more solar home systems are deployed, consumers are only charged a shipping and handling fee of Rp. 25,000 ($12.50) at the time of installation and a bill collection fee of Rp. 6,000/year per system (less than $3, or about 0.5 percent of the installed cost). Maintenance costs are borne directly by the customer.

Box 5-1
Examples of Solar Home System Projects Implemented by ESCO

SOLUZ Inc., a private US company working with Industrias Electricas bella Vista in the Dominican Republic, operates as a commercial, for-profit venture (Hansen 1994). Within months of its creation in early 1994, SOLUZ was providing PV systems services to 100 customers in the Dominican Republic. The company expects a ten-fold increase in customers by the end of 1995.

Five rural electric cooperatives in the Philippines serve as ESCOs for solar home systems. The cooperatives own the PV modules, the supports, and the controllers; consumers own the remaining components and pay a fixed monthly fee to cover loan repayments plus administrative and maintenance costs.

The ESCO approach is also used by the Tuvalu Solar Electric Cooperative Society and in other PV systems projects in the Pacific Islands. Consumers pay a $40 connection fee, plus a monthly fee of $5 for a one-panel system ($6.10 for a two-panel system) to cover administrative and service expenses; the ESCOs absorb the cost of the PV module. These programs depend on government or donor start-up funds and therefore are not financially self-supporting.

Two US utilities, Southern California Edison and Idaho Power, have pilot programs that offer their customers grid-quality electricity, using relatively large PV systems (the minimum system size is 1 kWp). The utility owns the PV system and provides installation and maintenance. The consumers pay a 5 percent connection fee and 1.6 percent of the net installed cost per month.

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[5] Computed from data in: Fernando 1994.

LEASING ARRANGEMENTS

5.10 Under a leasing or hire-purchase arrangement, the intermediary retains ownership of the solar home system or some of its components until the cost is recovered. The solar home system is used to secure the lease agreement. Most leasing programs to date have been set up with grants or low- or zero-interest loans from donors and governments and have used NGOs as intermediaries. In Indonesia, Sri Lanka, and the Philippines these grants have been used to establish revolving funds to buy PV systems. The intermediary serves as the manager and guarantor of the funds if loans need to be repaid, registers qualified participants, makes bulk purchases, provides installation and maintenance services, stocks spares, trains consumers, collects fees, and performs other administrative tasks. The BANPRES Project in Indonesia and the Solanka/Sun Societies and Sarvodaya in Sri Lanka use lease arrangements under which customers make monthly payments to the NGO/intermediary responsible for servicing the debt to the donor agency or government. Once a loan is paid off, ownership transfers to the customer. The principal differences between ESCOs and leasing arrangements are that ESCOs retain ownership of the major solar home system components, while in lease or hire-purchase arrangements, fees are essentially loan repayments. Services such as maintenance must be paid for separately. As an institutional model, lease or hire-purchase arrangements share many of the potential advantages of the ESCO scheme but are often constrained by the scarcity of grant financing to set up revolving funds.

Solanka, a Sri Lankan NGO supported by the Solar Electric Light Fund of Washington, D.C., USA, offers a revolving credit fund and SHS sales through their own village stores. Source: SELF, Washington, D.C.

CONSUMER FINANCING

5.11 Consumer financing is a very common mode for increasing the sale of consumer durable goods in all parts of the world (see Table 5-1). However, direct sales are limited either to those who can obtain financing from dealers or local banks or to high-income consumers who can pay cash. Some consumer financing models involve NGOs; for instance, in the Dominican Republic, ADESOL and ADESJO have addressed the lack of commercial bank financing by providing loans for solar home systems through a national network of qualified independent solar entrepreneurs.

5.12 Credit arrangements in which dealers finance solar home systems resemble those available for other consumer durable goods such as sewing machines, motorcycles, televisions, and refrigerators. Consumers obtain maintenance services through an annual service contract or on an as-needed basis. The dealers, who are part of the community, are familiar with their customers' creditworthiness. Unlike banks, they do not require stringent security guarantees. Dealers have knowledge of and confidence in their products. Their incentive to sell results in faster, more efficient transactions than with commercial bank financing. However, dealers typically offer shorter repayment periods and relatively high interest rates. With access to cheaper funds, dealers could offer their customers more favorable rates.

5.13 Commercial banks rarely finance the purchase of consumer durables in rural areas of developing countries. When bank financing is available, interest rates are high. For example, the KUPADES program of the Bank Rakyat Indonesia has begun lending money to rural customers for consumer goods. Interest rates are around 30 percent per annum, and repayment periods are typically one year, although the bank is allowed to lend for up to three years. The limited ability of rural people to offer acceptable collateral also restricts commercial bank financing to high income-consumers, those with fixed assets or co-guarantors or to salaried borrowers.

5.14 Commercial bank financing can help implement household PV programs if:

- ***The solar home system is considered eligible for bank financing.*** Some banks, which offer loans for "income-producing" investments, use the income stream as partial loan security. However, a solar home system may not qualify as "income-producing". Banks must be encouraged to examine the potential effects of PV systems on household income—for instance, a woman can earn money during the day if she has light by which to perform household tasks at night.
- ***Bank staff are familiar with household PV systems.*** The Sri Lankan experience shows that even if banks are willing to lend money for solar home systems, an awareness program targeted at loan officers is necessary.
- ***Borrowers have convenient access to banks.*** Ideally, the bank (or a branch) should be located close to borrowers. Proximity is particularly important if

more than one visit is needed to secure the loan and if payments must be made in person. Since banks are open only on weekdays, dealers may have to assist customers in arranging financing or, as happens in some rural credit schemes, may need to offer outreach services for rural customers.

- ***Loan application procedures are streamlined.*** Loan forms should be simple to complete and the number of visits required to approve the loans kept to a minimum. Again, it is helpful to have suppliers assist buyers in preparing loan applications and negotiating with banks.
- ***Collateral and security barriers are addressed.*** Rural households without salaried workers may lack the necessary collateral to secure a loan. In some cases, land and dwellings cannot be used as security because there is no clear title. A possible solution is to treat the PV module as collateral and to enlist the help of suppliers in collecting payments or repossessing the module in cases of default.
- ***Repayment schedules are flexible and complement borrowers' income flow.*** Many rural residents have irregular income streams that depend on harvests, sales of animals or seasonal employment. Flexible schemes would, for example, allow farmers to pay after crops are sold rather than on a monthly basis, and take into account informal and intermittent employment. Salaried workers could authorize regular payment deductions from their monthly salary.

5.15 The primary advantage of commercial financing is that it is firmly rooted in the private sector, which has the potential to offer more competitive, efficient services than government-sponsored programs. In addition, commercial financing relies entirely on existing institutions (banks, NGOs, and private vendors) and can be self-sustaining if there is sufficient market demand. However, this model is subject to the "chicken and egg" problem common to the development of all new markets: costs will not decline until there is sufficient demand to create economies of scale, but demand will not increase until costs decline.

CASH SALES

5.16 A significant number of solar home systems are sold directly to high-income customers who pay the full amount in cash. Direct cash sales are common in many countries, including Kenya, where roughly 20,000 units that have been sold, mainly through cash sales. Private vendors receive their products from wholesalers and regional distribution networks. Cash sales represent the simplest financial vehicle and share the advantages (and drawbacks) of commercial financing. Given the limited disposable income of most rural households, direct cash sales of capital-intensive solar home systems cannot sustain a household PV electrification program directed at a sizable proportion of the rural population.

THE ROLE OF GOVERNMENTS AND DONOR AGENCIES

5.17 Providing electricity to rural populations is a complex task. Though the private sector's role in rural electrification is growing, governments must provide the framework for rural electrification activities and donors can accelerate the process.

5.18 **Governments.** The case studies on which this report is based show a range of government involvement in household PV programs. In the Indonesian BANPRES Project, the government acts as the primary implementor, although village cooperative and private sector equipment vendors also play important roles. This contrasts with the passive role of government in the Dominican Republic in PV electrification. While the level of government involvement in household PV projects may vary, these case studies and other experiences indicate that governments can best support programs by focusing on: decentralizing the delivery of rural energy services; developing local and national markets; and supporting transparent institutional and regulatory frameworks.

5.19 **A Multimodal Approach to Delivering Rural Energy.** Many rural electrification programs are run by a single institution, usually the state-owned electric utility which supplies power to both urban and rural areas. The utility, which seeks to provide all customers with similar levels of service, is responsible for planning all rural electrification programs. In urban areas, this model has worked well. In rural areas, however, it is often unworkable (see Chapter 2) because most rural electrification programs center on grid extension, which is only one option among many that can meet the energy needs of rural populations. The rural energy planning process needs to incorporate technologies such as household PV which can complement grid extension when PV is the least-cost economic option and reflects local needs (for lighting, the operation of household appliances, commercial and industrial loads, or other uses) and the ability and willingness of customers to pay (not all customers need or can pay for 24-hour grid power). The rural electrification process should allow delivery of energy services through a range of institutions, both public and private, as well as local cooperatives and NGOs. In regions or markets where the private sector or local organizations can take the lead in project planning and implementation, the government should adopt a facilitating and oversight role. Elsewhere, governments can take a more direct role by including household PV options in rural electrification programs.

5.20 Indonesia is currently incorporating renewable energy options, including household PV systems, into its Rural Electrification Master Plan, partially funded under the World Bank-supported Second Rural Electrification Project (World Bank 1995a). Indonesia is also preparing a World Bank/GEF-assisted project to support private sector installation of 150,000–200,000 solar home systems. In Mexico, the PRONASOL Program has incorporated a solar home system component into its rural electrification efforts. This provides privately installed solar home systems in areas where grid service is unavailable or too costly (Huacuz and Martinez 1994). Approximately 30,000 solar home systems have been installed under the PRONASOL Program (see Box 5-2). In Argentina, some unelectrified areas will be offered household PV systems under a new program for dispersed rural populations (SEN 1995). Private sector companies will compete for concessions to supply electricity using solar home systems and minigrids; the concessions will go to companies requiring the lowest subsidy and meeting other performance criteria. The $314-million program will supply electricity services to 1.4 million inhabitants and 6,000 public services in areas with very low population densities, and where grid extension is unlikely. Beneficiaries will contribute $142 million, subsidies from existing provincial government funds will add $75 million, and the national government will provide $97 million.

5.21 **Market Development.** Most governments are seeking to move away from highly subsidized rural electrification programs to more economically sustainable alternatives. In general, this shift results in a more consumer-oriented, market-based approach to rural energy services for which solar home systems are ideally suited. To promote sustainable household PV electrification, governments should assure the following:

- ***Rationalized import duties and taxes.*** Import taxes and duties on PV components and solar home systems should be avoided since they can increase the costs of solar home systems dramatically, limiting the potential market.

- ***Equal fiscal treatment of rural electrification options.*** Although market-based pricing is the appropriate goal, the poorest households may still require subsidies in order to buy and maintain solar home systems. To reach the poor, PV systems should receive similar financial support as that provided under conventional grid extension or isolated grids in rural areas.

- ***Public investment in PV.*** Public financial assistance should be provided for PV electrification efforts, just as public sector equity financing and long-term loans have flowed to grid-based rural electrification projects, when economically justified. Even if a government is not involved in procuring solar home systems directly, it can play a key advocacy and demonstration role in support of PV systems by using PV equipment in education, health, and other social programs.

Box 5-2
Mexico's PV Rural Electrification Program

In 1989, the Mexican Government launched the National Solidarity Program (PRONASOL), an infrastructure development program, in poor regions and communities. This program included a rural electrification component and provided a special budget for the electric utility, Comision Federal de Electricidad (CFE), and another to provide PV electricity services to remote communities. To date, 40,000 solar home systems (rated at 48 to 100 Wp per system) have been installed; some 29,000 have been supported by PRONASOL.

Implementation: The CFE is responsible for technical aspects of PV electrification. Private contractors and local NGOs disseminate information. Villagers wishing to acquire solar home systems submit applications to the local government and organize themselves into a local electrification committee. The requests are then submitted to PRONASOL for approval. Sites are selected on the basis of remoteness, distance from the grid, and lack of near-term grid connection plans. The CFE then contracts with private companies to install systems. Users must participate in the construction, operation, and maintenance of the system; the CFE is responsible for quality assurance and acceptance testing.

Financing: PRONASOL supports both productive and "quality-of-life improvement" uses. Productive uses of PV (for agro-industrial and related applications) are financed as "soft" loans by Mexican development banks. "Quality-of-life" uses (household lighting and entertainment, public lighting, telephones, and vaccine refrigerators) are supported by the federal government, which has budgeted $10 million annually in grant funds. The federal government pays about 50 percent of the total cost. The remainder is borne by the state government (30 percent) and local governments and the participating communities (20 percent). This includes the users, who can pay with in-kind contributions such as labor, materials, and transportation of equipment. Communities are responsible for setting up fee-collection mechanisms to cover the costs of maintenance, repair, and future expansion of the systems.

Sustainability: The PRONASOL program has identified four key elements of sustainable infrastructure programs: (i) strong, locally based industries that assure a ready supply of quality products; (ii) a clear, comprehensive framework under which industry can operate; (iii) adequate financing; and (iv) local availability of hardware and consulting, engineering, installation, commissioning, and maintenance services. To encourage service quality over sales, the CFE collaborates closely with the solar PV industry to support information dissemination, international technology transfer, trade shows, industry-to-industry interactions, and system design guidance. Technical specifications have been developed collaboratively with the PV industry, which has adopted them voluntarily. The Mexican Government's firm commitment to PV technology as a viable option for rural electrification, its continued collaboration with NGOs and the private sector, and a careful assessment of potential users' attitudes toward electricity have made PRONASOL an effective and sustainable program.

- ***Access to affordable financing.*** Financing mechanisms such as credit lines, loan guarantees, and hire-purchase and leasing schemes expand the PV home systems market. Governments should support innovative financing mechanisms that allow lenders to offer long-term credit on reasonable terms. Investment funds currently provided for such programs include the World Bank-supported India Renewable Resources Development Project (under which IREDA offers eight-year solar home system financing), the GEF-assisted Zimbabwe Solar Home Systems project, the projects in Mexico that will provide credit for private sector sales of solar home systems, as well as the Indonesia and Sri Lanka projects discussed above.

- ***Local participation in rural electrification programs.*** Local cooperatives, NGOs, and grass-roots organizations are better suited than centralized power utilities to provide PV home systems to dispersed rural populations. Government policies and programs should help enable these groups to participate in PV dissemination by offering them training in business practices, installation and servicing, among other things as well as improved access to credit.

5.22 **Institutional and Regulatory Frameworks.** If the private sector and NGOs are to assume greater responsibility for planning and implementing rural electrification projects, they will need a transparent, "enabling" institutional and regulatory framework. Governments should ensure fair and not overly restrictive credit laws and regulations. Governments can also help develop appropriate technical standards, encourage a diversity of rural electricity service providers, assume responsibility for monitoring and oversight, and disseminate information.

- ***Setting technical standards.*** Baseline quality and safety standards can be used by the implementing organizations that procure systems, by the financial institutions that appraise loans, by local equipment suppliers, and by solar home system users in making their purchases. Government institutions can develop these standards themselves, as was done by BPPT in Indonesia and IREDA in India, or they may collaborate with industry, consumers, and other stakeholders to form an independent standards-setting body.

- ***Encouraging a diversity of service providers.*** In some countries, regulations governing rural electrification programs effectively rule out service providers other than the public electrical utility. If a PV market is to develop, such restrictions must be lifted. In Argentina, the government specifically encourages and supports alternative service providers.

- ***Providing monitoring and oversight and information disseminating.*** Monitoring and oversight of PV programs are important to gauge progress and to identify successful practices to replicate elsewhere. Governments should collect and disseminate such information and promote PV technology (but not specific products). These functions are especially important in new markets in which the private sector is weak.

ROLE OF THE WORLD BANK AND OTHER DONORS

5.23 Potential support for household PV programs from multilateral development organizations such as the World Bank, the United Nations, regional development banks, the GEF, bilateral aid and development agencies, and philanthropic organizations, should be integrated into broad rural energy or rural development plans. Donor efforts are most effective when coordinated with governments, local organizations, other donors, and private sector stakeholders. The donor community can facilitate PV electrification programs, provide technical assistance, and help fund both pilot and large-scale projects. Donor roles include:

- ***Promoting policy dialogue.*** Donors can encourage governments to adopt policies and practices that will be most beneficial to rural electrification programs, implementing regulatory reforms, least-cost planning and effective financial mechanisms, and improved fiscal policies.
- ***Providing investment financing.*** Donor funds are often essential for implementation of household PV programs due to the high up-front investment costs of these programs and the limited availability of long-term capital in many developing countries. However, local financial institutions need to participate in projects in order to ensure the commitment of stakeholders.
- ***Technology transfer.*** Donor agencies can help disseminate information on technological innovation, best practices, training, and demonstration projects. Effective donor support can improve project and program design, evaluation procedures, technical designs, standards and specifications, quality assurance, manufacturing methods, installation practices, and operation and maintenance of new technologies.

5.24 The World Bank and other multilateral lending institutions can encourage client countries to recognize PV and other renewable energy options as sustainable rural energy alternatives, complementary to grid extension. While assisting rural development and rural electrification project preparation, World Bank staff should explicitly consider renewable energy technologies and suggest their application where they best match the demand. World Bank/GEF support is particularly critical for up-front infrastructure investments to support the start-up of large-scale household PV programs in rural areas. Two innovative World Bank/GEF-supported operations are presently under preparation in Indonesia and Sri Lanka (see Boxes 5-3 and 5-4). Both rely heavily on implementation of PV household electrification programs through the private sector.

Box 5-3

World Bank/GEF-Assisted Indonesia Solar Home Systems Project

In a project that is presently under preparation, the World Bank and the Global Environment Facility (GEF) are planning to assist the Government of Indonesia in providing electricity services using solar home systems to about 200,000 households in West Java, South Sulawesi and Lampung provinces. The households targeted are in areas where the electric utility (PLN) grid service is not expected for at least three years or where it is uneconomic for PLN to provide such service. The estimated cost of the project is $72.0 million with $26.0 million from the users and suppliers, a $24.0 million grant from the GEF, $20.0 million from the International Bank for Reconstruction and Development (IBRD), and the balance from the Government of Indonesia. GEF cofinancing is based on the potential for the PV systems to displace kerosene and other fossil fuels that produce global warming gases. The project is designed to overcome the principal constraints to solar home system market development: (a) the high initial cost and the limited availability for term financing; (b) lack of information at the household level; and (c) undeveloped supply and service networks.

The project will finance only certified products that meet specified standards. Each 50-Wp or larger system must power at least three fluorescent lights (each providing more than 200 lumens of light), and a black and white 14-inch TV for four hours or more per day, on a day with average solar radiation.

The project will use a commercial approach where dealers sell solar home systems directly to rural customers. It is expected that at least eight dealers will participate in this project. The project will offer loans through commercial banks to dealers for up to five years at market interest rates. Dealers will provide installment payment programs to solar home systems customers. The commercial banks will apply for their standard loan appraisal procedures to decide whether to make loans to the dealers. The Government of Indonesia refinances the commercial bank loans using on-lending arrangements for an IBRD credit. While each dealer will set the payment terms, typically, a customer will make a down payment of about Rp. 200,000 and an installment payment of about Rp. 20,000/month for 42 to 48 months. Each dealer will receive a GEF grant of approximately $90-$125 for each unit sold. This grant helps increase the penetration of sales within the market areas allowing dealers to make the initial investments required to create a sustainable commercial SHS market. In addition, the GEF grant will fund market development activities including promotion, business development, quality assurance, and technical support.

Box 5-4

World Bank/GEF-Assisted Sri Lanka Energy Services Delivery Project

The Sri Lanka Energy Services Delivery (ESD) Project is expected to support the installation of approximately 30,000 solar home systems over a five-year implementation period. Financing for these installations would be available to private sector and NGO developers through an ESD Credit Line established under the Project. In addition to the PV systems, the ESD Credit Line is expected to support development of approximately 20 village microhydro systems and related distribution network and 20 mini-hydro plants (connected to the central electricity grid). An estimated $12 million will be requested for the PV subprojects. Half of this funding would come as commercial credit, supported by World Bank (IDA) funds. Project developers would provide $3 million in equity, and the GEF would provide $3 million in grant cofinancing. The Project is designed to remove the principal obstacles to widespread dissemination of renewable energy technologies. With respect to solar home systems, these obstacles are: (i) a lack of access to term financing; (ii) unfamiliarity of consumers, private sector developers, and the financial community with the technology; and (iii) an underdeveloped sales and distribution infrastructure. GEF grant support under the Climate Change Operational Program will help overcome these obstacles to commercialization of this climate-friendly technology. Once the necessary infrastructure is in place, and a competitive market prevails, solar home system costs will drop, allowing continued sales after the ESD Project is completed.

The ESD Credit Line will provide commercial financing through participating credit institutions for subprojects which meet standard appraisal criteria. All systems sold must conform with equipment standards developed for the Project. It is expected that NGO and private sector developers will utilize the ESD Credit Line to provide term financing to their solar home system customers. During the Project period, developers will receive a GEF grant of $90 to $100 for each 30- to 50-W solar home system sold. To be approved, business plans submitted by project developers in support of their ESD credit application must show financial viability and continued solar home system sales well beyond the Project period. GEF grant funds will also support business development and technical support.

6

ATTAINING FINANCIAL SUSTAINABILITY

6.1 Household PV programs must be financially self-sustaining. This Chapter examines financing terms and conditions, pricing strategies to secure cost recovery, and appropriate roles for grants and subsidies. Strategies for securing repayments, financing battery replacements, and serving low-income consumers are also suggested.

6.2 The relatively small scale and marginal profitability of existing household PV programs limits suppliers' capacity to establish efficient production and assembly facilities, obtain bulk procurement discounts, and set up effective sales and service networks. The high first cost of solar home systems requires financing to make them affordable to rural populations. The financial characteristics of the four models of PV systems delivery discussed in the preceding Chapter are summarized below in Table 6-1.

Table 6-1. Financing Characteristics of PV System Delivery Models

Financing Characteristic	*Solar Home System Delivery Model*			
	ESCO	*Lease/Purchase*	*Consumer*	*Cash Sales*
Affordability	High	Moderate	Low	Low
Interest rate[a]	Low	Medium	High	—
Repayment period	Long	Medium	Short	—
Down payment/Connection fee	Low	Moderate	High	Full cost at purchase
Loan Security/Collateral	System	System	System and/or other collateral	None
Risk to lender	Low	Moderate	High	—
Administrative cost[b]	High	Moderate	Moderate	Low
System Ownership	ESCO owns generation components only, rest by user	User (at end of lease)	User	User

a. Interest charged to the borrower (ESCO or customer). The ESCO passes this financing charge on to the consumer as part of its service fee.

b. Costs borne by implementor/supplier.

TERMS AND CONDITIONS

6.3 The financing terms and conditions of existing household PV programs vary from country to country and depend on the local cost of funds, the degree of risk to the lender, and loan processing and administration costs. Connection costs for ESCO customers and down payments for borrowers range from zero in a government-sponsored program in Sri Lanka to 50 percent under a loan scheme offered by one private supplier in Indonesia. Repayment terms can be lenient—twenty-year, no-interest loans—or stringent—two-year loans with 34 percent interest. Not all programs are sustainable, with a full cost-recovery basis. Table 6-2 compares the financing terms available for solar home systems in the United States and the four country programs reviewed by ASTAE. In general, the high interest rates and short repayment periods under consumer financing are the most onerous to the borrower. Government/donor-sponsored programs and NGO-run initiatives usually have more favorable financial conditions. Government programs may be heavily subsidized (for instance, the BANPRES project in Indonesia and the 1,000 Solar Home System Project in Pansiyagama, Sri Lanka). NGO projects often receive investment capital in the form of an initial grant from local or foreign donors. Examples include the ADESOL and ADESJO projects in the Dominican Republic and the Solar Electric Light Fund (SELF) support for Solanka in Sri Lanka. SELF has also supported local NGOs in China, Vietnam, India and elsewhere. Donor funds are used to seed a revolving fund to facilitate the purchase of PV systems. As participants repay their loans the fund is replenished and additional loans can be made.

PRICING STRATEGIES

6.4 Market surveys provide a useful tool for assessing consumers' willingness to pay for PV electrification services and should be incorporated into program planning. Some government-sponsored household PV programs set very low monthly fees, based on average household expenditures for kerosene. This policy assumes that rural consumers have a very low capacity to pay. Such programs are intrinsically unsustainable because they do not plan for full cost recovery; in addition, they often have difficulty collecting fees. In the Sri Lankan Pansiyagama Project, beneficiaries considered the program a government giveaway (in some ways it was, since funds were lent at zero interest and little attention was initially given to fee collection). Fee collection rates were only 52 percent, even though only a minimum payment of \$1.50–\$2.50/month was required. However, the Pansiyagama repayment rate increased significantly when the modules of several delinquent customers were removed. The BANPRES project in Indonesia also did not give high priority to cost recovery. The average fee collection rate (\$3.75/household/month) was about 60 percent, although it varied from 5–95 percent among participating cooperatives. Several subsidized schemes in the Pacific Islands have also failed, due to financially unsustainable pricing policies.

Table 6-2. Terms for Solar Home System Financing in Selected Countries

Country/ Solar Home Systems Initiative	*Type of Financing*	*Source of Funds*	*Down Payment (Percent of Solar Home Systems Cost)*	*Annual Interest Rate (Percent)*[a]	*Repayment Period (Years)*	*Prime/One-Year T-Bill Rate (%)*[e]
Indonesia						
BANPRES	Leasing	Gov't	5	0	10	
Dealer	Consumer	Supplier[b]	30	18	3	
Dealer	Consumer	Supplier[b]	50	18	2	18.0/10.0
Sri Lanka						
Gov't	Leasing	Donor/Gov't	0	0	20	
Dealer	Consumer	Dealer	25	30–34	2	
Cooperative	Leasing	Donor	15	7	8	
NGO	Leasing	Donor	10	10	10	
Dealer	Consumer	Bank	20	22	5	17.1/13.9
Philippines						
RECs	ESCO	Gov't/Donor	18	22[c]	10	15.1/12.9
Dominican Republic						
Dealer	Consumer	Dealer/ Supplier	50	0–50	0.5	
NGO	Consumer	Donor/Bank	25	20–36	1–2	29.0/18.0
USA						
Utilities	ESCO	Utility	5	1.6% month[d]	15-year minimum	7.75/6.0

Notes: The majority of sales in the Dominican Republic, Indonesia, and Sri Lanka have been cash sales, owing to the lack of credit facilities.

a. May include service and administrative fees.

b. Suppliers use working capital loans or lines of credit from commercial banks to finance sales through dealers.

c. Includes a 10 percent margin for administration. Consumers do not pay this cost, so this rate should not be compared with consumer loans.

d. The fee for service is given as a percent of net installed cost. It includes capital recovery as well as PV systems servicing and maintenance costs.

e. Indonesia: rate as of mid-August '94 (Indonesia does not have a one-year T-Bill; rate given is 90-day bank CD rate). Sri Lanka: rate as of mid-September '94. Philippines: mid-July '94 rate; United States mid-October '94 rate.

6.5 Consumers are often willing and able to pay more than government programs charge for energy service. Government and bilateral donor-funded PV projects, designed without regard to cost recovery, may also damage private efforts if customers expect to receive subsidized systems. Recent commercial sales in Indonesia demonstrate that consumer willingness and capacity to pay is influenced more by the size of the down payment than by the number or magnitude of monthly payments. Commercial suppliers in Indonesia note that a down payment higher than 30 percent of the cost of an installed system (around $120) severely limited demand. For example, consumers prefer to purchase a solar home system at Rp. 800,000 with a payment scheme that requires a Rp. 250,000 down payment and 36 monthly payments of Rp. 20,000 rather than purchasing the same system with a down payment of Rp. 300,000 and 40 monthly payments of Rp. 16,000 (de Lange 1994). Clearly, not all consumers can pay these fees, and thus sales are limited primarily to wealthier consumers in these rural areas.

6.6 Full recovery of the capital investment, borrowing and operating costs is crucial for financial sustainability. In an ESCO, these costs will include: debt servicing, staff salaries, administrative expenses (for instance, account, billing and collections, disconnections and reconnections, consumer education, and staff training), expenditures for facilities, maintenance costs (battery replacement and recycling, spare parts, and consumables), allowances for defaults and losses, and transportation expenses—and of course profits. In a sales scheme, costs will include purchases of materials, debt servicing, staff salaries, dealer margins and other sales expenses, general administrative expenses, and expenditures for such essentials as facilities, consumables, and transport, as well as profits.

6.7 Ideally, repayment periods for consumer loans should be short, for example, less than the average life of the battery (three years) as in the Dominican Republic programs and in commercial ventures in Sri Lanka and Indonesia. In this way, borrowers will have repaid all or most of their loan by the time the battery has to be replaced and will have the necessary funds to replace the battery. Shorter repayment periods also reduce lender risks. While they increase the monthly payment, short loans are less sensitive to interest rates. For example, a 25 percent rise in interest rates increases monthly payments by only 6 percent in a three-year payment scheme, while the monthly payment increases 15 percent with a ten-year repayment period.

6.8 The down payment should ideally cover a significant portion of the system cost, if it is to serve as the primary security for the loan. A reasonably large down payment is a useful mechanism for screening consumers and establishing creditworthiness. At a minimum, the down payment should cover the sunk costs of transport, labor, wiring, and fixtures, allowing for full recovery in case of default. Alternatively, the down payment can equal the cost of the battery, to select out those customers capable of meeting battery replacement costs. The most sizable down payment would equal the cost of the module, typically 50 percent of the total system cost. While a large down payment provides additional loan security and reduces monthly payments, it does limit the number of households that can afford the system. Energy planners, financiers, system suppliers, and others involved in household PV programs must strike a balance between program goals and participants' ability to pay.

6.9 **Serving Customers with Limited Ability to Pay.** To increase the number of households able to pay for solar home systems, pricing strategies can include flexible repayment, fee schedules that match customers' income streams, or extending this repayment period (with due regard to the additional risk this entails). Farmers, for example, may prefer a semiannual or quarterly payment plan, while salaried workers may find it easier to pay monthly or authorize payment deductions. Defaults can be avoided if users make a deposit before the system is installed—a scheme similar to the "lay-away" programs offered by US retailers. Payment due dates can also be extended on a case-by-case basis.

This Sri Lankan family was able to afford an 18 Wp solar home system, with three tubelights.
Source: SELF, Washington, D.C.

GRANTS AND SUBSIDIES

6.10 Governments and donors have provided grants or subsidies for technology promotion and demonstration, regional development, poverty alleviation, environmental and other reasons. Grants and subsidies should only be used for market-conditioning activities, or under the right conditions, as limited injections of equity to buy down the capital cost of a project. Such subsidies should not be used to demonstrate untested technologies on unwary consumers. Market-conditioning activities include training, promotion, project design, feasibility studies, setting and enforcing quality standards, monitoring, and establishment of infrastructure. If the capital investments are to be subsidized, a strong case must be made, based on need and an assessment of beneficiaries' capacity to pay. The amount of capital cost buy-down should preferably be limited to defraying the higher costs associated with the start-up of a new solar home systems program. The buy-down amount should be calculated, taking into account the price to the consumer in an established program serving a larger group of consumers.

6.11 The grants or subsidies must be very transparent and targeted, bearing in mind that, as in any subsidized program, the benefits may not go to the most deserving. Before subsidies are introduced, their impact on the development of a broader PV market should be assessed. A subsidized program may produce a quick injection of PV equipment, but potential consumers may form unrealistic expectations about obtaining systems at below-market rates. This can damage long-term, larger scale PV diffusion. A donor-subsidized program which "dumps" PV equipment will result in unstable market conditions as local project implementors gear up to meet a short-term demand. It could also hurt local commercial suppliers as they cannot compete with the subsidized goods[1] (Covell and Hansen, 1995).

6.12 Grants and subsidies must not be used to cover recurring operating costs. While governments or donors may initially agree to cover some of the operating costs of a household PV program, changes in policies may reduce or eliminate such funding. If a program depends on ongoing subsidies, any reduction can jeopardize its long-term sustainability.

ENFORCING REPAYMENTS

6.13 Disconnects for extended nonpayment of fees can be an effective tool for cost recovery. Even though the need for a strong disconnect policy is recognized in theory, in practice, it is difficult to disconnect households in arrears, unless an external agency takes responsibility for such an unpopular action. The ADESOL program in the Dominican Republic has yielded a high loan recovery rate since its loan fees are collected by local representatives and societal pressures to honor one's debt are high. Societal pressures might not always function this way, and local solar home systems organizations might not always be the most effective fee collectors. In the Philippines, an impartial outside organization had to be hired for fee collection tasks, while the local solar home systems company continued to provide solar home systems service and maintenance. In Tuvalu, fee collection was undertaken by a national organization to avoid problems due to patronage and family ties[2] (Conway and Wade, 1994). The Pansiyagama Project in Sri Lanka originally had no local organization for fee collection. This was a major issue until the government agency contracted with a private company to provide maintenance services and collect fees.

FINANCING BATTERY REPLACEMENTS

6.14 Batteries are a major replacement cost in solar home systems. Customers unable to afford new replacement batteries purchase poor-quality or reconditioned substitutes instead.[1] If these components do not function well, users are likely to become dissatisfied and leave the program, jeopardizing its sustainability. Where users' ability to buy replacement batteries is a concern, an arrangement to finance battery replacements should be considered. An Indonesian supplier operates a successful three-year battery replacement plan for its customers.

6.15 Setting up a battery replacement fund is worth considering under ESCO or leasing models. The scheme can include a small monthly charge, held in escrow, to pay for replacement batteries. For example, placing $1.50/month in an escrow account for three years will generate the $50 necessary to purchase a new battery. Should the battery need to be replaced in less than three years, the consumer can pay the difference; if the life of the battery exceeds three years, the consumer can receive a rebate. This approach offers several advantages: it finances only high-quality batteries; it allows for volume discounts from suppliers; and it facilitates care of batteries and battery recycling.

6.16 Increased affordability should never be based on cost reductions achieved by lowering the quality of the equipment or decreasing support services. Instead, smaller high-quality units can be offered. For example, a 10-Wp solar lighting kit provides lighting equivalent to that of a kerosene mantle lantern and can be offered instead of a 50-Wp solar home system. Customer satisfaction, and hence loan repayment, requires that users be aware of the lower level or service they will receive from smaller systems, and that they have the option to obtain larger systems in the future.

6.17 In summary, the financial sustainability of household PV programs requires:

- Selecting qualified customers (those with the ability and willingness to pay);
- Offering high-quality products and responsive service (see Chapter 7);
- Matching consumer expectations with the level of energy service the program will provide;
- Establishing a pricing strategy that covers all costs and insures judicious use of any grants or subsidies; and
- Creating simplified administrative procedures for financing, fee collection, and disconnecting customers in case of non-payment.

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1 In some countries, old batteries are reconditioned by replacing defective cells. While the reconditioned battery is low cost, its quality is very poor. On a life-cycle basis, the purchaser might spend more on reconditioned batteries than if new high-quality batteries were purchased.

7

TECHNICAL REQUIREMENTS

7.1 Customer satisfaction is the primary goal for a solar home system initiative. Users play a larger role in PV household electrification than in traditional grid-based rural electrification programs. When satisfied with the service they receive, users are more willing to forgive occasional lapses in the power supply and to make payments promptly. The project is consequently more likely to meet its financial goals. Providing satisfactory service requires high-quality products and responsive, ongoing maintenance and support services.

7.2 Solar home systems need to be designed to meet customers' expectations at a cost that matches customers' capacity and willingness to pay. A well-designed and constructed system should be reliable, easy to use and maintain, and require minimal care to keep working properly. Users will want to be able to upgrade their systems as their income allows. Systems should be designed to accommodate such expansion. Ultimately, however, users will be happy with their systems *only* if they fully understand how the units work and accept their limitations.

HARDWARE DESIGN

7.3 All system components should be of the highest quality. This refers to modules, controllers, lights, wiring, switches, batteries, connectors, and module supports. Design budgets should be treated as guidelines, not as a project's highest priority. High-quality systems will out-perform cheaper ones and help ensure the project's sustainability. An appropriate indicator is the life-cycle cost of the project, which takes into account the cost of warranty and maintenance services and the effect of possible nonpayment of fees. For example, in remote sites where service costs are high, it may be more cost-effective to provide an overdesigned system with high-quality batteries instead of a system designed with tighter performance margins. Where affordability is an issue, users can be offered several system sizes and made aware of the trade-offs between system capabilities and costs. Users can then make an informed choice from a range of system sizes, based on their own requirements and their ability to pay. Systems can be designed to allow for future upgrades. For example, one supplier in Indonesia offers a PV module support structure that can accommodate two modules, although the base system has only one. The controller is capable of handling the power output from two modules, and the distribution panel also allows for adding more outlets and lighting circuits.

7.4 Future household PV initiatives can learn from the successes and problems encountered in similar programs to date and improve procurement specifications and technical infrastructure. Specific technical requirements for solar home system components are discussed below.

7.5 **Modules.** The PV module is generally the most reliable component of the system. In all four country programs reviewed, module failures or even breakages were rare. Preference should be given to modules that meet JRC 503 or equivalent specifications and to suppliers offering at least ten-year performance warranties.[1] Countries such as Sri Lanka and India, with local module manufacturers that do not meet such specifications, may have import barriers that limit the availability or raise the cost of modules meeting JRC 503 or equivalent performance specifications. In such cases, if removing the trade barrier is not a feasible option, local suppliers must make sure their products meet specifications and offer enforceable ten-year warranties.

7.6 Crystalline cell modules with 36 cells should be used instead of 32-cell "self-regulating" modules. The benefits from improved performance, particularly in hotter climates, more than outweigh the added cost of the charge controller required for the 36-cell module. All modules currently being installed in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic are the 36-cell type. In the initial stages of PV dissemination in Sri Lanka, 32-cell modules were used to avoid the cost of a controller. The suppliers soon realized that the benefits of using 36-cell modules outweighed the added cost of the controller, and installations now use the 36-cell module.

7.7 Module terminals should include lock washers, nylock nuts, or other devices to assure that the terminals do not loosen during the life of the module. Preferably, only modules with a single-junction box should be used. In the Philippines' household PV program, some modules with two junction boxes were supplied. As a result, the cable had to be stripped to separate the two leads, exposing them to the weather and possible corrosion.

7.8 **Module Support Structure.** The PV module support structure should be corrosion resistant (galvanized or rustproof steel or aluminum) and electrolytically compatible with materials used in the module frame, fasteners, nuts, and bolts. The design of the module should allow for proper orientation, tilt, and, as has been noted, easy expansion of the system's capacity. Roof mounting may be preferable to ground or pole mounting, since it requires less wiring and reduces the possibility of module shading. The module support should be firmly attached to the roof beams and not loosely attached

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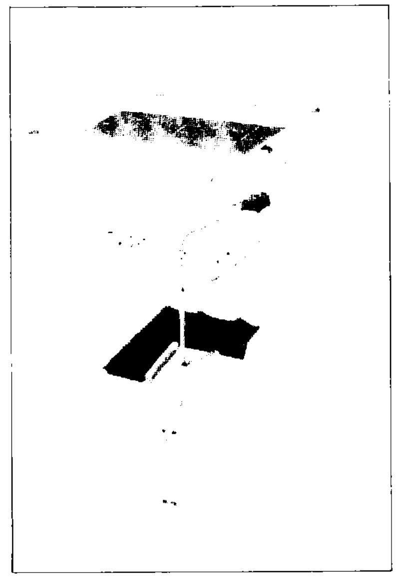
[1] Some tests are more important than others. These include visual inspection, performance at standard test conditions, insulation, measurement of temperature coefficient, measurement of nominal operating cell temperature (NOCT), performance at NOCT, performance at low radiance, outdoor exposure, thermal cycling, humidity freeze, damp heat, and robustness of termination. A similar specification for flat-plate, thin-film modules are US National Renewable Energy Laboratory (NREL) document no. NREL/TP-213-3624 (1993) or JRC Specification No. 701 (1990).

to the roof tiles. The module or array should not be placed on the roof but kept 10–50 cm above the surface itself, to allow cooler and more efficient operating conditions. If the module is mounted on a pole, the pole should be set firmly in the ground and secured with guy wires to increase rigidity. Pole-mounted modules should be accessible for cleaning but high enough above the ground to discourage tampering.



Roof-mounted module support structure in use in Indonesia. Source: PT. Sudimara Energi Surya.

7.9 **Charge and Load Controller.** The charge and load controller prevents system overload or overcharging. In the past, some programs have not paid adequate attention to the controller. Unsuccessful attempts were made in Sri Lanka to operate solar home systems without a controller or with only a simple charge indicator (a simple controller that provides a low-voltage disconnect (LVD) and charge indication has since been added). Poor-quality controllers have also caused problems. In the Philippines, for example, problems caused by low-quality, locally manufactured controllers were resolved when the controllers were replaced with high-quality, imported components. To operate reliably, the controller design should include:

- A low-voltage disconnect (LVD);
- A high-voltage disconnect (HVD) which should be temperature-compensated if wide variations in temperature are expected in the battery compartment. Temperature compensation is especially important if sealed lead-acid batteries are used;
- System safeguards to protect against reverse polarity connections in the DC circuits (reverse energy flows through the PV module(s) short circuits in the input or output terminals) and lightning-induced surges or over-voltage transients; and
- A case or covering that shuts out insects, moisture, and extremes of temperature.

To enhance the solar home system's maintainability and usability, the controller should:

- Indicate the battery charge level with a simple LED display and/or inexpensive expanded scale analog meter. Three indicators are recommended: green for a fully charged battery, yellow for a dangerously low charge level (pending disconnect), and red for a "dead" or discharged battery;
- Be capable of supporting added modules to increase the system's capacity;

- Be capable of supporting more and bigger terminal strips so that additional circuits and larger wire sizes can be added as needed (this is necessary to ensure that new appliances are properly installed); and
- Have a fail-safe mechanism that shuts the system down in case of an emergency and allows the user to restart the unit.

7.10 Field surveys suggest that most controllers have some (but not all) of these characteristics. However, even highly sophisticated controllers must be tested and proven in the field. A sophisticated new controller that was used in the Pansiyagma project in Sri Lanka created problems which led to user dissatisfaction, poor cost recovery, and serious skepticism regarding PV programs elsewhere in the country.

7.11 **Battery.** The battery that is most often used in solar home systems is a lead-acid battery of the type used in automobiles, sized to operate for up to three cloudy days. Automotive batteries are often used because they are relatively inexpensive and available locally. Ideally, solar home systems should use deep-cycle lead-acid batteries, which have thicker plates and more electrolyte reserves than automotive batteries and allow for deep discharge without seriously reducing the life of or damaging the battery. In a well-designed solar home system, such batteries can last over five years. However, deep-cycle batteries are not usually made locally in developing countries and high duties often increase the price of importing such batteries.

7.12 In Indonesia, a good-quality automotive battery in a well-designed system can last three years or longer, if the battery is well maintained and rarely subjected to deep discharges; the average daily discharge should be limited to about 20 percent of battery capacity. For example, lightly stressed automotive batteries in the Sukatani, Indonesia PV project had exceptionally long life -- 75% of the batteries last nearly five years (Panggabean, 1993). Field investigations in Sri Lanka reveal that poor-quality materials and questionable workmanship have led to random cell failures in some locally-made automotive batteries and shortened battery life to about two years. Solanka has introduced an extended warranty program that guarantees the performance of the entire system (including the battery and light bulbs) for two years for a fee of Rs 500 ($10).[2]

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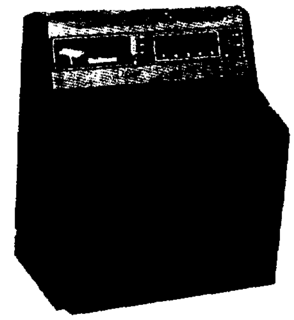
[2] Priyantha Wijesooriya, Solanka Associates, personal communication, Colombo, Sri Lanka, October 1994.

7.13 **Battery Mounting.** Batteries are sometimes left exposed on the ground and accessible to children. The potential dangers (burns from battery acids, shorts, and explosions) highlight the need for a well-designed battery enclosure to maximize safety and minimize maintenance. Such enclosures are being introduced in Indonesia and the Pacific Islands. Made of injection-molded plastic or fiberglass, the enclosure contains the battery, charge controller, charge indicator, and switches. The electronic elements are isolated from the battery, and the battery enclosure has vents to disperse gases and channels to divert any acid overflows. There is no exposed wiring and the battery can be checked and filled easily.



This injection-molded battery box, with controller, switches and outlets is used in Indonesia for 50 Wp and larger systems. Source: PT Sudimara Energi Surya.

7.14 **Lamps, Ballasts, and Fixtures.** The principal reason most householders acquire a solar home system is that it provides brighter, safer, cleaner, and more convenient lighting than kerosene lamps. Users tend to have more "lighting points" after they acquire a system. Field observations show that the additional lights increase satisfaction with and acceptance of the solar home systems. In many cases, householders have subsequently added additional lights to their system while maintaining the overall level of energy consumption (systems with 12 lights have been observed in Indonesia).

7.15 Efficient fluorescent lights (CFL or tube lights) are usually preferable to incandescent lights.[3] However, fluorescent lamps require well-designed ballasts that ensure an operating life of the tubes of more than two years and that do not interfere with radio or television reception.[4] In some programs, such as Bolivia's, fluorescent light ballasts have been the most problematic component of the system.

7.16 Low-watt (1–2 W) incandescent lights may be preferable in cases where low-level area lighting is needed for short periods (less than 1/2 hour per day) or intermittently (such as in bathrooms or secondary bedrooms). A choice may also need to be made between supplying high-efficiency fluorescent lights (tube lights with preheating elements or CFLs) or locally available low-efficiency tube lights. While the high-

3 Fluorescent light fixtures with efficiencies greater than 35 lumens per watt, inclusive of ballast losses, are available. Incandescent lights have efficiencies of about 12 lumens per watt.

4 Critical design parameters include operating voltages (85-125 percent of nominal), waveform symmetry (within 10 percent), operating frequency (more than 20 kHz), crest factor (less than 2), minimal under (75 mA) current draw under open circuit conditions and protection from short circuit or reverse polarity connection (see Preiser et. al., 1994).

efficiency lights can offer lower lifetime costs, users may become dissatisfied if they are not available locally.[5]

7.17 Fixtures with reflectors are recommended to increase the effectiveness of the lights. Fixtures that use diffusers must be sealed against insects, since the "useful light" output and efficiency of the fixtures with diffusers can be drastically reduced by a buildup of dirt and insects inside.

7.18 **Wiring, Switches, and Outlets.** Solar home systems should have high-quality switches and outlets (preferably rated for DC operation). In Sri Lanka, standard AC surface-mounted wall switches were used along with two-prong AC wall outlets. If the lights and appliances draw little current, these AC switches and outlets are satisfactory substitutes for DC-rated components.

7.19 Undersized wiring is sometimes used in solar home systems, particularly when additional light fixtures are installed. This practice leads to energy losses and unacceptable voltage drops and should be strongly discouraged. All wiring should be stranded copper, sized to keep voltage drops to less than 5 percent between battery and the load. Since DC electricity has a polarity that must be maintained, insulation color conventions or labeled wires should be used (red for positive, black for negative, green or bare wire for the grounding conductor).[6] The four country field surveys uncovered several twisted wire or spring-clip wire connections. These do not provide a good electrical connection and should not be used. Soldered or crimped connections or screwed terminal block connectors are the best choices. Soldered wire connections require a noncorrosive rather than an acid-flux solder, especially in regions where corrosion can be a serious problem. As in any electrified home, the wiring should be neatly and securely attached to the walls, either on the surface, in conduits, or buried inside the walls.

7.20 Solar home systems should also have a distribution panel that allows users to connect additional loads simply and safely, utilizing the circuit protection and LVD features of the controller. In Sri Lanka, the panel is a simple terminal strip or similar connection point that allows secure and reliable connection of multiple loads. The terminal strip is located at the regulator, in a separate distribution box, or in the battery box. The distribution panel must always be used if additional circuits are to be installed. Direct battery connections must not be made.

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5 The user can replace a fluorescent light with a locally available incandescent bulb. An incandescent light uses more current to provide the same level of illumination as a fluorescent light, reducing the service available from a solar home system. In addition, energy losses will be greater and circuit wiring may become dangerously overheated if it is not designed to accept the higher current.

6 Grounding is generally not required if the open circuit voltage is under 50 V.

7.21 **Other Appliances.** Any appliance that operates on electricity can be powered by a solar home system, if the system has sufficient capacity. In the four countries surveyed, the most widely used appliances (other than lights) were black-and-white, 15-inch televisions and radio/cassette players.[7] Users in the Dominican Republic expressed a desire to operate other appliances, such as refrigerators, irons, and VCRs. However, most of the users do not have the capacity to pay for larger systems and the availability of DC-compatible appliances such as color televisions and fans is limited. These users will have to save to buy larger systems. Appliances with high energy requirements, such as irons and air conditioners, cannot be used with small systems, since converting DC to AC electricity involves additional costs and energy losses. Large 1-kWp systems supply 100 kWh/month to customers of Southern California Edison. This is the equivalent of supply grid-quality AC power and is sufficient to operate most of the appliances found in a typical American home.

7.22 **Inverters.** Customers requiring AC electricity will need an inverter to convert the DC electricity from PV systems. It is very unusual for users with systems smaller than 100 Wp to require inverters (none was observed during ASTAE's field investigations). In any case, the cost of an inverter and associated energy losses recommend against its use in small systems. Several types of inverters are available: square wave (the least expensive and least efficient), modified square wave, and pure sine wave (the most expensive and most efficient). If needed, the inverter with lowest life-cycle cost should be selected. Small inverters dedicated to the specific loads that require AC power should be used rather than a centralized inverter for all loads.

STANDARDS AND SPECIFICATIONS

7.23 Government or independent agencies should either set performance standards for solar home systems or, in programs utilizing government funds, should require that the system components meet internationally recognized performance standards for modules, controllers, other electronics, and batteries. These standards need to be effectively enforced, as has been done in the Indonesia BANPRES Project. BPPT, as the executing agency, established system specifications for procuring the solar home systems, based on information obtained from consumer surveys and field tests of several solar home system types. The BPPT Solar Test Center was also used to evaluate various system configurations. Each country need not establish its own standard, but can adopt those established by the international PV community.

7.24 Both prescriptive and performance specifications have been used for procuring solar home systems. *Prescriptive* specifications outline the requirements for each major component. For example, they may specify the size of the PV modules, the battery capacity, the wattage or lumen output of the lamp, the wire sizes, and the controller set

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[7] It is important to ensure that TVs do not have stand-by current draw, or that the set is unplugged when not in use. This means that remote-control TVs are not recommended for use with PV systems.

points and safety features. This approach has been used in the GEF-financed Zimbabwe PV Project and the Indonesia BANPRES Project and is included in the proposed World Bank/GEF-assisted Indonesia Solar Home Systems Project. Prescriptive specifications are easier to implement and make verifying compliance with the requirements relatively simple. *Performance* specifications detail the output or service which the solar home system is expected to provide. They may specify the number and lumen output of the lights, the average hours of lighting needed at each light point, the watt-hours of other appliances, and the loss of load probability or availability. The supplier then determines the system configuration according to site conditions and performance requirements. This approach is used in the World Bank/GEF-assisted India Renewable Resources Development Project. Performance specifications give suppliers greater freedom to optimize the design configuration but can make verifying system performance difficult.

7.25 Enforcing solar home system standards should be easier under ESCO or leasing arrangements that involve bulk or high-volume purchases. Ensuring performance standards is more difficult in a less-structured program that may not provide customers with the information necessary to judge the quality of the system. A PV systems mechanism rating similar to the UL® rating system in the United States and the KEMA-KEUR system in Europe would be a useful guide for consumers.

OTHER TECHNICAL CONSIDERATIONS

7.26 **Spare Parts.** Fuses, light bulbs and other spare parts that need to be replaced frequently should be available locally from a dealer accessible to users. The minimum quantity of spares that should be stocked depends on the number of systems in the area and the location of distributors. Table 7-1 lists the recommended minimum number of spare parts for a local cooperative in Indonesia that serves 200–2,000 consumers.

Table 7-1. Suggested Spare Parts List for a Cooperative in Indonesia

Item	*Recommended Quantity of Locally Stocked Spares*
Photovoltaic Module	1 per 250 systems
Charge Regulator	10 per 250 systems
Battery	250 per 250 systems spread out over the 2nd and 3d year after installation
Wire, Connectors, Tape	50m wire and 50 connectors (varies with village ability to purchase additional appliances)
Lamp Ballast	25 per 250 systems

7.27 **Battery Recycling.** High priority should be given to battery recycling in order to minimize environmental contamination and safeguard users. Recycling is most effective in organized programs led by an ESCO or an intermediary. Current battery-recycling programs in the four country solar home system programs reviewed show mixed results. As part of the Solar Energy Program in the Philippines, NEA-GTZ introduced a successful battery-recycling scheme that allowed users to exchange old batteries (for which the manufacturer paid $4.00) through the rural electric cooperative. In West Java, Indonesia, old batteries are collected from each house and recycled by independent operators, who pay householders $2.50 per battery. (However, battery recycling is rare in other parts of Indonesia, where batteries are used less widely and transporting them is difficult.) In Sri Lanka, batteries can be taken to a dealer or a recharging center for recycling, but many users consider the recycling payment, which was about $1.00, too low to warrant returning the old batteries. To increase the volume of battery recycling, the payment was recently doubled. While there is no comprehensive battery-recycling program in the Dominican Republic, it is estimated that about 50 percent of the batteries are recycled.

7.28 **Warranties.** The four country case studies show that ten-year performance warranties for modules are commonly available from many suppliers and should be required in a solar home system program. Warranties for controllers and other electronic components may range from three months to three years and those for batteries from one year (for automotive batteries) to three years (for deep-cycle batteries). Overall system warranties are also offered for up to one year. However, realistic provisions for enforcing warranties must be in place in order to protect consumers.

QUALITY CONTROL

7.29 The solar home system programs in Indonesia, Sri Lanka, the Philippines, and the Dominican Republic demonstrate the importance of quality in manufacturing of systems and their installation. The need for quality assurance extends to component purchase as well as system assembly, testing, and installation. Solar home system installation should always be entrusted to trained technicians.

7.30 Quality assurance directly impacts the profitability of the solar home system business. Experience in China and Sri Lanka clearly shows the link between significant cost savings and high-volume procurement from reputable manufacturers of quality electronic components used in manufacturing controllers, switches and lights. Due to their low volume of production, system assemblers in China and Sri Lanka currently purchase components from local retail stores, where quality is suspect. This necessitates testing every key component (transistor, capacitor, inductor, etc.) for quality before assembly, thus reducing manufacturing productivity. Lower volume procurement from sources where quality is not assured also results in a higher percentage of returns, increased cost of warranty services and general decline in consumer satisfaction.[8]

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8 One supplier in Sri Lanka reported having to replace 100 light fixtures due to overheating caused by a defective and mislabeled transistor.

7.31 Some suppliers provide packaged kits that include all the solar home system components, lengths of wiring, bolts, nuts, terminal strips, wire connectors, and other hardware needed for each system. This prepackaged kit ensures that the installer uses only recommended equipment and will not have to improvise in the field. The installer also needs proper tools, including multimeter, compass, spirit level, hydrometer, and templates for tilt adjustment.

A packaged solar home system kit. Source: BP Solar.

7.32 How well a solar home system is installed is as important as the quality of its components and assembly. Suppliers should develop installation standards and acceptance test procedures and require that these be used. Any "checklist" should include instructions on how to:

- Install the module (orienting it correctly, avoiding shading, minimizing wire runs, ensuring that the module support is securely attached to the roof beams, tightening the connections, and sealing the junction boxes);
- Locate and fasten the controller and battery enclosure properly;
- Attach switches, outlets, fixtures, and wiring (including which wire sizes to use, how to attach components neatly and securely to walls and ceilings, and how to secure electrical connections);
- Boost the battery charge before installation;
- Check all connections and ensure that the system operates properly before it is handed over to the user;
- Teach the user to operate the system safely; and
- Provide the user with the appropriate documentation, including warranty information, and any spare parts, if supplied, such as fuses and distilled water.

MAINTENANCE SERVICES

7.33 While the simple design and dependability of most solar home systems allows a single technician to service a large number of customers, the need for local technical support remains. Users can perform simple maintenance functions. However, field experience shows that very few households can service their system themselves over a long period of time. Solar home system programs are typically used in sparsely populated areas, serviced most effectively by local representatives (preferably from the same village) who can tend to problems in a matter of hours or days, rather than the weeks that might be required with service provided from a central location. The number of technicians required in a service territory depends on the number of systems in use, their quality, and their accessibility (remoteness, road conditions, and available transportation). A rule of thumb in the Dominican Republic is that no system should be more than 50 km from a service center. In Indonesia, both the government-sponsored BANPRES Project and some private dealers use local cooperatives to administer programs, collect fees, and provide maintenance services. The Tuvalu Solar Electric Cooperative Society in the Pacific Islands has local user committees that arbitrate disputes between users and technicians concerning fee collections, disconnections, and poorly functioning systems and keep users informed about the organization's activities. These local networks offer effective support for technicians and help ensure the long-term sustainability of the programs themselves.

7.34 Technicians should be trained in the installation, maintenance, troubleshooting, and repair of systems. Administrative staff must be conversant in program management, accounting, collecting payments, and procedures for disconnecting or removing systems. Well-trained staff are essential for a sustainable solar PV program. Whenever possible, technicians should be used from the villages where the systems are installed. While the simple design and high reliability of solar home systems enables a single technician to cover a large number of customers, it does not eliminate the need for local technical support.

7.35 Solar home system technicians should pass basic certification examinations and also attend periodic refresher courses. Adequate salaries and benefits are required to keep trained technicians on the job in rural areas, and there must be enough business in a service area to support the fixed overhead costs of providing technical services. In Indonesia, service fees from at least 500 systems are needed to pay one technician's monthly salary. (The local cooperative charges a service fee of Rp. 500 per month per system, and the technicians receive a monthly salary of about Rp. 250,000.) The technician may be able to earn extra money by providing other services, such as adding light fixtures to existing systems or new installation. Households should be encouraged to use trained technicians for such procedures. User and technician training should stress the importance of using only approved wiring and connectors.[9]

7.36 **Documentation.** A solar home system program should have documentation, including:

- A technician's manual that describes the system and includes a guide to

[9] "Informal" repairs and modifications made by unqualified technicians or householders can lead to poor performance and dangerous operating conditions. These include bypassing the controller and connecting the appliances directly to the battery; use of undersized wiring, twisted wires, or spring clips for new connections or wire extensions; repairing broken switches with safety pins or two wires twisted together; replacing failed fluorescent lights with incandescent lamps; or not using distilled water or clean rain water to top off the battery.

procedures, maintenance, and troubleshooting. The manual should also contain graphics such as functional block diagrams and schematics;

- A recommended lists of tools and spare parts to be stocked at the local level;
- Procedures for receiving and responding to user requests in a timely manner;
- Standardized technicians' logbooks for recording system maintenance and repairs;
- Warranty and loan agreements;
- Tariff structures and payment terms and conditions;
- Organization and management plans; and
- User manuals and consumer education literature in an easy-to-understand booklet in the local language, or in "comic book" style.

EDUCATING USERS

7.37 Customer satisfaction with solar home systems also depends on the user education provided by program administrators, technicians, and suppliers. The education program should cover routine maintenance procedures such as watering batteries (including how to collect clean rainwater if distilled water is not readily available), interpreting control panel information, managing loads, solar access, and replacing fuses and bulbs. Customer education should also make clear the capabilities and limitations of the particular solar home system.

7.38 "Overselling" the capabilities of solar home systems can quickly lead to customer dissatisfaction and poor repayment levels. In the Pansiyagama Project in Sri Lanka, overzealous promoters showed videos of PV-operated sewing machines, pumps, and power tools to prospective customers. The 21-Wp and 52-Wp systems subsequently installed under the project could not run these appliances. This resulted in unhappy customers and service problems in collecting fees. Educating users about recurring system costs, particularly the need to replace automotive batteries every two to three years, is also important.

7.39 In Sri Lanka, regular visits from technicians during the first year helped train families to use their systems properly and to learn effective load management practices. User education should be directed at the persons in the households responsible for the routine maintenance. These are generally older children or women. Women and children typically derive greater benefits than men do from the solar home systems. They are willing and interested in taking a proportionate share in caring for their systems. In many countries, children from the ages of 11–15 are also those household members most interested in the technical aspects of the solar home system and are therefore more likely to understand the load management principles. To increase involvement of women and children, training should take place in the home whenever possible, preferably with the installation team or technician providing information based on materials and guidelines supplied by the vendor. Solar home system programs also afford excellent opportunities to train women for both administrative and technical positions.

7.40 In summary, technical performance is key to the long-term sustainability of a PV household electrification program. Consumers need well-designed, properly assembled, and correctly installed products that are affordable and fit their budgets. Overselling must be avoided. Spare parts should be easily available as well as local, appropriately trained technicians to provide maintenance and repair services. User education should target those members of the household most affected by the system and best able to perform routine maintenance tasks.

8

BEST PRACTICES: CONCLUSIONS AND RECOMMENDATIONS

8.1 Although the technical, financial, and institutional aspects of solar home system programs vary significantly, successful initiatives must overcome the high first cost of solar home systems, establish sustainable infrastructure, provide quality products and service, and ensure appropriate support from governments and donors.

OVERCOME THE FIRST COST BARRIER

8.2 The preceding Chapters have identified financing arrangements, pricing and cost-recovery strategies, areas for use of grants and subsidies, and the need to rationalize or eliminate discriminatory import taxes and duties.

8.3 ***Financing.*** Given the first initial cost of solar home systems, some form of term financing is essential and can be accessed through ESCOs, hire-purchase and leasing arrangements or financing through dealers or the banking system. Consumer loans which feature high down payments (to minimize defaults) and short maturities (three or four years) limit solar home system purchases to high-income groups. ESCOs that can obtain relatively low-interest, long-term loans and reduce equipment costs by purchasing in bulk may greatly increase the affordability of solar home systems. Any long-term leasing or ESCO financing arrangement should incorporate provisions for battery replacement, since batteries are a significant cost over the lifetime of the system. To increase rural customers' access to financing, solar home system program design should include streamlined loan application procedures and flexible arrangements for securing and repaying loans. Loan officers must be familiar with the PV system in order to facilitate and accelerate loan processing. Finally, banking facilities or outreach efforts will stand a better chance of success if they are conveniently located to users who need to make regular loan payments.

8.4 ***Pricing Strategies and Cost-Recovery Mechanisms.*** Solar home system pricing and repayment arrangements should reflect consumers' willingness and ability to pay. In government-sponsored programs, payments have often been set too low (at the same level as expenditures for kerosene), even though consumers (recognizing the improved quality of PV systems services) are often willing to pay more. Prices and fee structures should be low enough to attract customers but high enough to cover capital, financing, servicing, equipment replacement, and administrative costs, as well as possible defaults. The size of the down payment appears to affect the ability and willingness to pay for a solar home system more than the number or the size of the monthly payments. Rural households with irregular income streams may require seasonal rather than monthly payment schedules. Fee collection and enforcement are best handled by appropriate local and/or national organizations.

8.5 ***Grants and Subsidies.*** Judicious use of grants and subsidies may help catalyze a PV program but should be limited to market-conditioning activities or (under the appropriate conditions) limited injections of equity to buy down capital costs. Since there is no guarantee that subsidies and grant money will continue indefinitely, these funds should not be used to finance operating costs.

8.6 ***Rationalize or Eliminate Tax and Duty Structures.*** High import duties, particularly on PV modules, artificially inflate PV pricing and hinder development of large-scale, commercially viable, market-driven solar home system programs. A reduced market raises the cost of maintenance and other support services. This in turn decreases user satisfaction. The resulting market distortions may also induce local suppliers to use poor quality components that make systems less reliable.

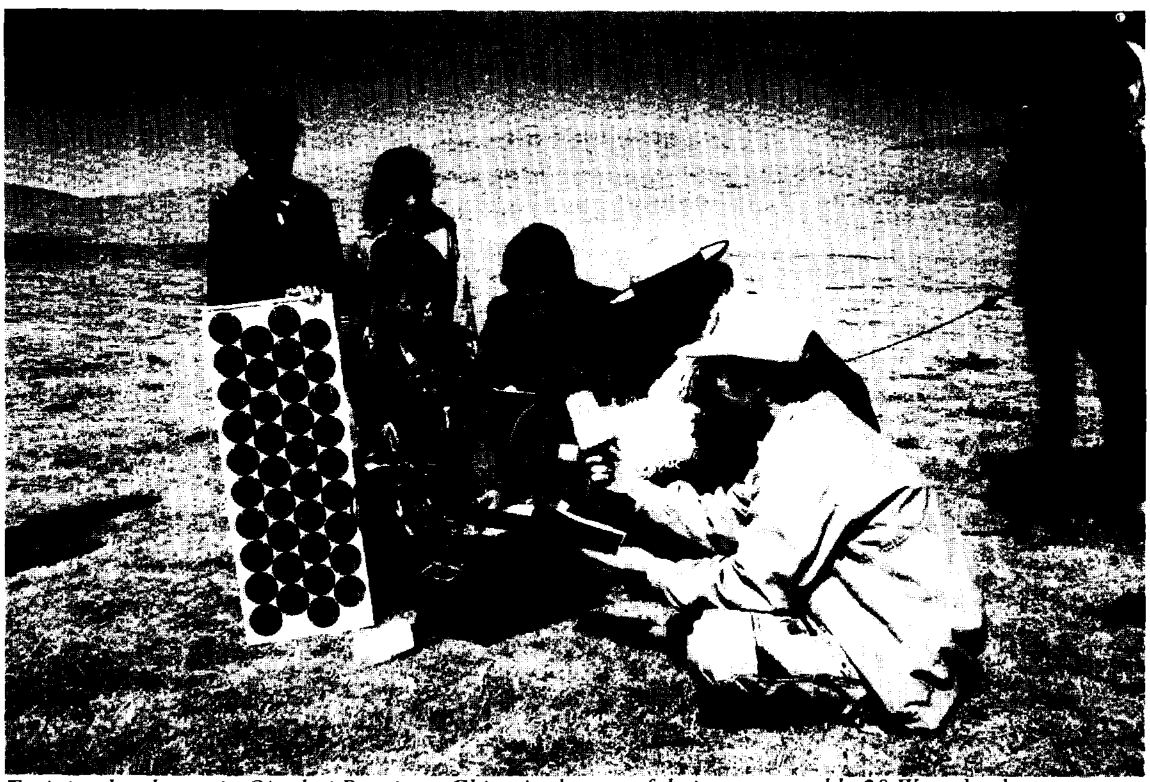
ESTABLISH A SUSTAINABLE INFRASTRUCTURE

8.7 The start-up phase of solar home system marketing requires special attention to sustainable infrastructure development. This requires careful market niche identification, reliance on local capabilities for implementation, and appropriate training programs for technicians and users.

8.8 ***Target Specific Areas.*** The economic niche for solar home systems covers remote or isolated areas where loads and load densities are low. Rural electrification programs should explicitly consider solar home systems as part of a portfolio of technologies that can provide least-cost electricity services. Careful market research should identify which type of service is best suited to each community. Targeting helps solar home system programs serve appropriate rural concentrations and facilitates cost-effective energy service delivery.

8.9 ***Use Local Organizations.*** Local grass-roots organizations are best equipped to implement solar home system programs in sparsely populated areas. A community organization, NGO, or locally-based private firm knows its potential customers and understands local traditions, customs, and constraints. This eases troubleshooting and problem solving. Local organizations can respond to calls in a matter of hours or days rather than the weeks that might be required with a central agency. A suitable local organization can serve as an ESCO. A new organization should be created only as a last resort and requires the full support of the government and community. It is better to build on existing marketing and retail networks or to use leasing, consumer financing, or cash sales arrangements to deliver PV services than to create a new organization.

8.10 ***Ensure Training Technicians.*** Rapid, responsive service will satisfy customers and satisfied customers are important marketing agents. For this reason, well-trained technicians are needed to install, maintain, and repair solar home systems. While some users can perform simple maintenance procedures, trained technicians are still required after installation since experience has shown that, in the long term, reliance on users for maintenance can impair the performance of solar home systems. When systems fail, users are less likely to pay fees regularly. This affects a program's financial sustainability. To avoid unexpected "down-time" in service, technicians should be available locally and equipped with adequate tools and spare parts. Follow-up training is also important after a program has been under way for a number of years. Equipment will require more frequent care, new technicians must be trained, and existing staff will need to upgrade their skills.



Training herdsmen in Qinghai Province, China in the use of their new portable 20 Wp solar home system.
Source: Qinghai New Energy Research Institute.

QUALITY PRODUCTS AND SERVICES

8.11 Sustainable PV household electrification requires satisfactory performance, guaranteed by quality products, uniform standards as well as attention to battery replacement/recycling and customer education.

8.12 ***PV Standards.*** Governments and standard-setting agencies should establish performance standards for solar home systems or require that modules, controllers, other electronic components, and batteries meet internationally recognized performance standards. All standards should be consistent with the level of reliability and performance users expect, and all should be strictly enforced.

8.13 ***Quality Control.*** Solar home systems should be designed to meet customers' expectations (subject to ability to pay) and use only quality components. Assembly and installation procedures need to be standardized and modifications and additions made only by qualified technicians. Performance warranties for modules, controllers, other electronic components, batteries, and, if possible, the system itself so as to ensure optimum performance. If consumers in solar home system programs have limited capacities to pay, technical quality should not be compromised in the interest of reducing costs. These customers should be offered small but high-quality systems.

8.14 ***Battery Recycling.*** PV modules and deep-cycle or automotive batteries are the most costly components of the solar home system. While the average life of a module is more than ten years, automotive batteries may fail within three. Battery recycling both reduces costs and is environmentally sound. However, unless appropriate arrangements or incentives are in place to collect used batteries, consumers are unlikely to assume individual responsibility for battery recycling.

8.15 ***Consumer Education.*** Users must understand and be prepared to accept the level of service a given solar home system will provide. This understanding is the key to effective solar home system programs. Customer satisfaction is a prerequisite for effective cost recovery and increased sales.

GOVERNMENT SUPPORT

8.16 Despite the various initiatives of the private sector, NGOs, and donors in dissemination of solar home systems, governments still have a major role to play in PV market development. Governments can best support the deployment of solar home systems by focusing on:

8.17 ***A Demand-Driven Approach to Rural Energy Planning.*** Solar home systems are only one of many options that complement traditional central grid extension and meet the energy needs of rural populations. The choice of system should be based on the technology's ability to provide the most economical service consistent with energy needs such as lighting or power in household appliances or meeting commercial and industrial loads. The choice should also reflect the willingness of customers to pay for services.

The process should also allow rural energy services to be delivered through a range of institutions, including public and private sector agencies, local cooperatives, and NGOs. Governments that invest directly in PV equipment for education, health, and other social programs can encourage further use of solar energy through visible demonstration of the technology's benefits. Governments can also facilitate access to credit lines, loan guarantees, and other financing mechanisms.

8.18 ***Institutional and Regulatory Frameworks.*** Governments should ensure a transparent, supportive institutional and regulatory framework to encourage market expansion. This can be done by rationalizing import duties and taxes, as well as incentive or subsidy programs, so as to put PV equipment on an equal footing with other means of supplying power. Governments should also ensure technical standards for PV components and systems; encourage a diversity of service providers, such as NGOs, the private sector, and local communities; participate in program implementation; provide monitoring and oversight services; and disseminate information on PV technologies as well as on the performance of solar home system initiatives.

DONOR SUPPORT

8.19 Donor assistance is most effective when integrated into a broader rural energy or rural development plan. Donors should coordinate their support with those of governments, local organizations, other donors, and private sector stakeholders. Donor help is needed for investment financing and technology transfer. Isolated "demonstration" programs should be avoided unless they have adequate long-term support and the prospects for replication are strong. The World Bank and other multilateral banks can actively help governments develop solar and other renewable energy options, where these options meet economic, technical, and institutional needs. Donors can encourage governments to reduce or remove barriers to the economic use of solar home systems. Donors should also strengthen their own ability to identify and assess rural energy options, and make financial resources available through their bilateral and multilateral aid programs to help prepare and implement household PV projects.

ANNEX 1

ASTAE CASE STUDIES IN PV HOUSEHOLD ELECTRIFICATION

1. The Asia Alternative Energy Unit (ASTAE) commissioned four case studies of solar PV program experience, in order to review the experience and performance of solar PV rural electrification in selected countries and provide guidance for future solar PV programs. Field investigations were conducted to: (a) determine the technical performance of installed residential PV systems; (b) examine the management systems and field performance of the organizations responsible for these installations and their capacity to implement expanded programs; (c) assess credit programs and revolving funds to finance solar PV purchases; and (d) evaluate the sociocultural benefits of the affected households and communities.

2. This Annex and Table 1 summarize these case study reports of Indonesia, Sri Lanka, the Philippines, and the Dominican Republic. PV programs in these countries ranged from government-sponsored programs, such as the BANPRES Project in Indonesia, to virtually no government involvement in promoting solar home systems, as in the Dominican Republic. Despite different implementation approaches, a number of common themes emerged. Each country has a large rural population without electricity service and a utility that lacks the financial and institutional resources to serve many of these rural communities. The solar PV programs have involved a rural organization such as a rural cooperative or grassroots NGO, government agencies or private firms. These organizations offered access to credit, supplied products and provided maintenance and support services. Credit shortages were listed as one of the major constraints to a broader use of PV in most of the programs. Affordability was limited as loans, when available, carried high interest rates and/or short repayment periods. While government-sponsored programs offered subsidized credit, funds were limited and cost recovery was poor. All of the programs incorporated training and maintenance support, but there were deficiencies. Typical PV module sizes of solar home systems ranged from 15-Wp to about 50-Wp and systems were mainly used to supply lighting and power for a radio or TV.

Table 1A. Summary Evaluation of Experiences in ASTAE Case Study Countries
Institutional Evaluation

Criteria	*Dominican Republic*	*Indonesia*	*Sri Lanka*	*Philippines*
Organizational structure	ADESOL is an effective umbrella organization for manufacturers, technicians and entrepreneurs; good communication among solar home system organizations.	Key agencies including cooperatives, technology development, planning, energy, banking, etc.; participated in BANPRES project. Multiple agencies made communication difficult at times.	Solar home systems disseminated independently by private sector, NGOs and government agencies.	Bilateral program administered effectively; worked with local NGOs and Rural Electrification Cooperatives (RECs).
Market strategy	Solar PV market independent of rural electrification programs.	Site identification based on electric utility 5-year grid-extension plans. Longer range grid-extension plan not available at that time, but is currently available.	Customer selection was not formally coordinated with the electric utility. Private and NGO marketing used information from regional utility offices.	Strategy was to offer minimum power supply in unelectrified clusters, increasing the demand for electricity and area covered, until grid extension became viable economic alternative.
Information dissemination	ADESOL promotes PV technologies in rural areas; solar home system installers train consumers in load management/ maintenance.	PV technology promoted on the village level by cooperatives.	Private sector conducts own information dissemination programs. Government and NGO programs organized village demonstrations to educate potential users of PV technology.	Solar PV marketed as a "pre-electrification" option.
Sustainability of institutional structure	ADESOL is dependent on donor funds to seed the revolving funds. Private sector receives training from ADESOL.	Program dependent on government assistance for institutional support and to seed revolving fund.	Private sector depends on commercial sales. NGOs require seed funding their revolving funds. Gov't programs used public & bilateral funds.	Programs were dependent on bilateral financial and technical support, but administering agencies were existing institutions.

INDONESIA

3. The Presidential Assistance Project (BANPRES), funded by a presidential grant through the Development Budget (DIP) was used to set up a revolving fund. BANPRES has resulted in the installation of more than 3,300 solar home systems since 1991. The goal of the project is to test the technical and social viability of photovoltaics for large-scale household electrification programs as a means of providing cost-effective electricity services to a portion of the approximately 20 million rural Indonesian households that are unlikely to receive grid electricity for at least ten years. As a result of the positive BANPRES Project experiences, commercially-oriented solar home system initiatives and other programs sponsored by the government have ledto nearly 20,000 solar home systems installed to date. The government intended the BANPRES project to be a precursor to a one million household, 50-MWp solar PV program.

4. The Government of Indonesia places a high priority on electrification and is committed to supporting geographically balanced development of rural areas by increasing the welfare of the people and stimulating the growth of economic activities. The BANPRES Project, with project sites in 13 provinces, was designed to make effective use of existing rural structures and capabilities. The Project is led by the Agency for the Assessment and Application of Technology (BPPT). The BPPT is also responsible for all technical aspects including specifying and qualifying products, and field testing and monitoring. With the assistance of local governments, participating villages are selected based on their desire for electricity, location relative to the administrative area of a qualifying village cooperative (KUD), grid electrification plans, and capacity of householders to pay the downpayment and monthly installments. The KUDs administer the project at the village level. They are responsible for fee collection, maintenance services and enforcing disconnections for payment defaults. The Ministry of Cooperatives (MOC) interfaces between the government and the KUDs. Bank Rakyat Indonesia (BRI) is part of the institutional structure primarily because of its widespread presence in rural areas and fees collected by the KUDs are deposited at the BRI village branch. The implementation of the project is overseen by a Steering Committee. The committee is chaired by BPPT and is composed of key government agencies including the Directorate General for Electricity and Energy Development, PLN (public utility), Bank Indonesia, BRI, MOC and Ministry for Transmigration.

5. Once a village is selected as a project site, residents are chosen to receive BANPRES systems based on their ability to pay and whether or not they are active KUD members. Potential consumers must become full KUD members, if they are not already, and must be willing to sign a lease-purchase agreement with the implementing KUD. The agreement includes a Rp. 1,000 stamp duty. The KUD then contracts a private solar home system supplier to install the system that meets BPPT specifications. KUDs collect the downpayments and subsequent monthly payments. The KUDs retains Rp. 500 per month per solar home system to cover their costs and transfer the remainder to the

BANPRES revolving fund account at BRI. Each KUD employs two maintenance and repair technicians. The user is responsible for battery replacement.

6. The solar home system consists of a 45- to 48-Wp PV panel, support structure, two fluorescent tube lights, switches, a 12-VDC outlet, wiring, an automotive battery, and a battery control unit. The system could generate 145 Wh/day with 6 hours of bright sunshine and is capable of providing 7-8 hours of lighting when operating both lights, or 5 hours of lighting and 5 hours of television. There are no major technical problems with the PV system or its major components or with users load management practices. BPPT assists local enterprises in designing and manufacturing all balance-of-system (BOS) components. Locally produced components are generally well designed and of adequate quality. Where deficiencies existed, BPPT works with the manufacturers to correct them. BPPT, MOC, and private enterprises did a thorough job of research and development, and project design throughout the pilot stage of solar PV project development. Warranty service is provided by equipment suppliers, and the suppliers are making an effort to abide by warranty terms and ensure that defective equipment is promptly replaced. Nevertheless, because the KUDs have not kept adequate spares, users have had to ask them to contact suppliers to send replacement parts, resulting in long lead times in the more remote areas.

7. Users pay a Rp. 50,000 downpayment, and Rp. 7,500 per month for 10 years for the PV system. The monthly fee for the solar home system was less than the PLN electricity service cost from a 450-W connection (about Rp. 4,000 per month for 30 kWh). The solar home system down payment and monthly fee does not allow for full cost recovery if the cost of money (about 18-20% per annum) is included in the monthly fee. Yet recipients often requested that the down payment be financed over several months. In contrast, other private sector solar home system sales targeted to more affluent households in rural Indonesia have down payment requirements of about Rp. 200,000 and monthly fees of about Rp. 20,000 per month.

8. In 1993, the fee collection rate in the BANPRES Project was about 60 percent. KUD officials attributed inadequate fee recovery to seasonal income patterns, short-term financial problems and families realizing they were unable to meet the solar home system financial obligations. In addition, the limited business management capability of some KUDs exacerbate the cost recovery problems. In many cases, the KUDs could not force users to comply with their agreements, since many KUDs did not always adhere to their contractual obligations. Despite strict penalties for late payments as specified in BANPRES guidelines, most KUDs have been handling disconnects for nonpayment differently. KUD staff responsible for disconnecting service are often not given the authority to impose the necessary sanctions, particularly when it is the "power elite" who default. Once users learn that disconnects are not really going to be carried out, payment rates fall and the financial recovery worsens.

Table 1B. Summary Evaluation of Experiences in ASTAE Case Study Countries Financial Evaluation

Criteria	*Dominican Republic*	*Indonesia*	*Sri Lanka*	*Philippines*
Credit supply	Limited credit provided by NGO revolving funds; no commercial bank loans made; NGO loans offer below-market interest rates, will result in eventual depletion of funds.	Credit is supplied by the government-supported revolving fund; consumers pay a down payment and monthly installments for ten years at zero interest.	Very limited access to long-term credit. Bank credit offered at market rates, NGOs rely on revolving funds on-lent at concessional rates. Gov't programs require modest monthly payment.	Project established revolving fund to finance systems. Financing provided to RECs through National Electrification Administration.
Financial sustainability	Payments were generally good.	Full cost recovery was not an objective. Monthly payments comparable to basic utility services. Cooperatives had many inconsistencies in bookkeeping and collection practices. 60% average collection rate, despite low monthly installments.	High payment default rate for government programs until strict disconnect policy was enforced. Private sector and NGO programs had good cost recovery.	Full-cost recovery pricing strategy used except for initial seeding of revolving fund.
System pricing	Pricing could be reduced with greater competition.	Competition helped keep prices low.	High unit costs due to low volume sales and import tariffs. Unit costs were particularly high in gov't tied-aid program.	Program purchased solar home systems in bulk to lower prices.
Tax/subsidy structures	No duty on modules, 100% duty on deep-cycle batteries; import restrictions on solar PV components affected cost to customers.	No import tariff barriers. Fees exclude interest charges. Other organizational overhead costs absorbed by participating government agencies.	High import tariffs. Government program subsidized due to zero-interest financing.	Exempt from import taxes and VAT.

Table 1C. Summary Evaluation of Experiences in ASTAE Case Study Countries Technical Evaluation

Criteria	*Dominican Republic*	*Indonesia*	*Sri Lanka*	*Philippines*
System size selection	System sizes range from 25 to 48 Wp	Based on field tests. Mostly 45- to 48-Wp systems.	Systems sizes included 18, 35, and 50 Wp	Used 53-Wp systems
System quality	Good performance No official standards set. Warranties honored by PV enterprises. Local auto batteries used.	Systems performed well. Warranty services offered by suppliers. System specification based on field tests. Local auto batteries performed well.	Private/NGO systems provided adequate service; No formal standards and specifications set. Local battery quality highly variable. Reliability problems plagued Gov't program.	Generally good when using imported components. Locally manufactured parts performed poorly.
Installation/ repair quality	Good installation and servicing skills.	Good installation procedures. Repairs usually involve part replacement rather than careful assessment of why the system failed.	Private sector/NGOs provided adequate installation and service. Gov't program lacked after sales service after first year, but improved after giving 5-year maintenance contract to private company.	REC technicians provided responsive and effective installation, repair and maintenance services.
Training/ maintenance	Enersol/ADESOL have effective program, which include training courses for technicians and entrepreneurs and monthly membership meetings.	No formal standards for maintaining systems. Had good consumer education program.	Private sector and NGOs had trained technicians and good consumer education programs. Poor communication led to user dissatisfaction with gov't program.	Effective training provided to NGOs. "Comic book" style user manuals proved effective.
Availability of spare parts	Available locally	Cooperatives did not stock many spare parts, led to long lead times for repair.	Spare parts not always available at local level.	Spare parts always available.
Battery recycling	No formal battery-recycling program.	No battery-recycling program was incorporated. But commercial battery recyclers operate in W. Java.	No formal recycling program. Current buy-back rates paid by battery recyclers too low.	Successful battery-recycling program was part of program.

SRI LANKA

9. Approaches used to disseminate solar home systems include sales through the private sector and NGOs, and government-sponsored programs (often with international donor financing). Three firms are active in the private sector: Solar Power & Light Company (SPLC), Sunpower Systems Ltd., and Vidya Silpa. Two NGOs have undertaken solar home system initiatives: SoLanka Associates, modeled after Enersol in the Dominican Republic; and Sarvodaya Jathika Sangamaya. Three government-sponsored programs have taken place in Sri Lanka, the first in 1983, and subsequently the Pansiyagama and the Mahiyangana projects. The latter two projects are administered by the National Housing Development Agency and executed by private firms. The Pansiyagama project is a 1,000-household solar PV project while the Mahiyangana project provides PV systems for health care and water supply applications. There have been about 4,500 solar home systems installed in Sri Lanka, a small fraction of the 2 million households, or 63% of Sri Lanka's population, that does not have access to grid electricity service.

10. The private sector sells PV systems directly to individual consumers, NGOs, local village cooperatives and government programs. SPLC is the sole domestic manufacturer of PV modules, importing the PV cells and fabricating them into finished panels. Other solar PV firms, NGOs and government programs purchase these modules at wholesale prices. All the solar PV suppliers offered warranties competitive with solar PV markets in other countries. Adequate spare parts were stocked by the company or local technician for system repairs. Battery replacement is the responsibility of the user.

11. The SPLC has a comprehensive after-sales service arrangement. The program consists of regionally-based trained technicians, scheduled household visits and reports, and brochures summarizing proper maintenance techniques and system use. SPLC devotes an unusually high percentage of its revenue to marketing, which involves provincial dealers, radio and TV advertisements, demonstration and training programs, and after-sales service. This program addresses issues overlooked by other distributors, but has problems with lead times for maintenance calls. SPLC is finding that providing these support services are difficult and costly due to limited sales.

12. The NGOs have adopted a more informal approach, relying on village-based technicians who work on commission. The NGOs offer maintenance and support services at the village level and promote the manufacturing of some components at the village level to supplement the income of their technical field staff. NGO projects are characterized by active local participation in project design, maintenance, and collection of loan payments. Such close ties with the local communities has allowed for good communication between program organizers and solar home system users.

13. The government-sponsored Pansiyagama solar PV project initially made no provisions for system maintenance. Later due to poor technical performance and fee

recovery problems, a private firm was contracted for one year to make monthly service and fee-collection visits to each household. The firm conducted routine system performance tests and educates users on operation and maintenance. The Pansiyagama project also suffered from inadequate communication and coordination with the electric utilities, NGOs, local credit institutions and potential solar home system users. Based on the success of the one-year contract, a five-year system maintenance contract has been issued to provide continued maintenance and support services.

14. Typical solar home systems consist of a PV module (18-, 35-, or 50-Wp), support structure, wiring, a lead-acid automotive battery, a battery-control unit, a 12V outlet, and 3 to 6 fluorescent tube lights. The cost of a small 18-Wp system in Sri Lanka is Rs. 13,322-15,500. Overall, the systems were reliable, of reasonable quality, and provided adequate service. However, the poor quality of locally-made batteries has led to unreliable performance. Some of the systems at Pansiyagama used untested, poorly designed or defective components which contributed to a significant failure in initial installations.

15. Private sector sales are financed by cash, bank credit, or hire-purchase agreements. However due to limited access to affordable credit, 80% of sales have been cash sales. Bank credit at market interest rates (22%) with a 5-year loan period is available but few households have accessed these lines of credit due burdensome security guarantees and limited promotion by the banks. NGO programs rely on revolving funds with concessional rates and extended loan periods, but funds are limited. Such loans typically have 8-10 year payback periods, with 7-10% interest rates. Systems sold under the Pansiyagama PV project required no down payment, modest monthly installments, no interest charges and a 20-year payback period. The government program resulted in a high default rate due in part to poor technical performance leading to user dissatisfaction. The repayment problems were compounded by the perception that government loans need not be repaid.

16. Due to limited availability of credit, most of the households that obtained PV systems were the rural upper and middle classes. The more affluent households self-selected themselves by their ability to pay for the systems. NGOs and government programs were designed to reach the poorer classes by offering easier access to credit. Nevertheless, the lowest income households in these rural areas would not be able to purchase PV systems in the absence of large subsidies.

17. Monthly payments for the 3-light solar home systems are Rs. 320 when financed at a 22 percent interest rate. It is higher than the monthly payment for grid service (Rs. 245) or battery and kerosene use (Rs. 275). While the government has removed the subsidy on kerosene, making solar home systems more financially attractive, there are still major subsidies for grid electrification. The battery replacement cost of Rs. 2,000 may be difficult for rural households without some means for regular savings towards this purchase.

THE PHILIPPINES

18. The Philippines has had 20 years of experience with PV technology, yet such applications are still perceived as a means of "pre-electrification" rather than a permanent rural energy solution. Solar home system dissemination has been dominated by two rural PV electrification programs implemented under a bilateral agreement between the Government of the Philippines and the German Government. Besides government programs which have disseminated about 500 systems to date, about 10 local private companies supply solar home systems, selling 100-150 units annually to help bring electricity to a few of the more than 6 million Filipino families not connected to the grid.

19. In 1982, the Philippine-German Solar Energy Project (PGSEP) installed a 13-kWp PV plant, which was later found to be uneconomical due to its high capital investment. The project began to focus on solar home systems and communal battery-charging stations. Demand grew more than PGSEP could accommodate, leading to the Special Energy Program (SEP), initiated in 1987. The strategy of SEP is to distribute small solar home systems in clustered sites, gradually increasing the demand for electricity and area covered, until grid extension becomes an economic alternative. The SEP has developed site-selection criteria, which include: rural areas not included in near-term electrification plans; an approved Rural Electrification Cooperative (REC) to ensure quality servicing and fee collection; selection of adjacent RECs to facilitate program monitoring and servicing; at least 20 users in clusters within one day's travel time; an assessment of the ability and willingness to pay the down payment and monthly fees; and a local NGO or Barangay Power Association (BAPA) that can assume responsibility for collections, maintenance, monitoring, and safe, unrestricted access with regard to weather and political environment.

20. The SEP procures solar home systems on behalf of the RECs in bulk (50 systems per procurement package) and receives bulk discounted prices. The cooperatives then sell the systems to the users who pay cash for the balance of systems (BOS), except for the battery control unit (BCU), and make monthly payments for the module and controller. This initial payment is considered a connection fee, similar to the fee charged for household grid service connection. Local technicians from the REC respond to system problems and are generally responsible for installation, trouble-shooting and maintenance. New batteries are acquired by users from the RECs in exchange for old ones, which are then recycled.

21. The BAPA staff are responsible for fee collection and system monitoring. The users are trained in routine operation and maintenance practices and in load management. Users receive a manual in a "comic book" style. Service response by the REC technicians was mostly within two days and favorably perceived by the users. Unlike the solar home systems, the communal PV power systems and battery-charging stations established under the SEP had limited success due to the unclear delegation of responsibilities.

22. A typical solar home system has a 53-Wp PV module, a lead-acid automotive battery, a BCU, switches, a DC/DC voltage converter, a junction box, and five lamps. Systems generate 130 to 206 watt-hours (wh) per day, depending on the location and weather conditions. A solar home system supplied on the average about 140 Wh/day, enough energy to operate one fluorescent light for 3 hours, one compact fluorescent light for 4 hours, and one radio for 12 hours. All solar home system components except for the PV panels are manufactured locally. Project experience with these locally made components has been poor. The locally manufactured batteries, BCUs, and fluorescent lamps performed poorly. Most of the failures were due to improper use or poor quality components, i.e., problems of technology application rather than the technology itself. A 12-V lead-acid automotive battery is used in the system, which often leads to problems due to customer abuse. Due to poor quality of the locally made lights and junction boxes, they were later imported. On the positive side, locally available panel support frames, insulated cables and tumbler switches are reliable. As the solar systems are purchased in bulk, spare parts are always available. The SEP has a successful battery-recycling program.

23. The average price of a solar home system is approximately P 23,000 (US $900). The solar home system components are exempt from import duties and value added tax. The financing scheme of the SEP includes financing from the National Electrification Administration to the RECs who then finance solar home system sales to users. The SEP also established revolving funds for the RECs to finance additional solar home system installations. The ability and willingness of users to pay for PV electrification is a significant issue in the Philippines. At most 10 percent of the total households can pay cash for solar home systems and an additional 20 to 60 percent could procure them if suitable financing schemes were available (i.e., 20-30 percent down payment and an amortization period of at least three years for the balance of the amount). The remaining households could not afford a solar home system, but could acquire batteries to be recharged at battery-charging stations.

THE DOMINICAN REPUBLIC

24. About 400,000 rural households in the Dominican Republic lack access to grid electricity. Solar home systems were recognized as an alternative to supplying rural electricity, without the need for government agencies' involvement as they were unable to meet the growing demand for electricity. Thirteen small businesses, members of an NGO, ADESOL, are currently active in solar home system sales. By 1993, these groups had sold over 2,000 solar PV systems. ADESOL promotes solar home systems and other PV applications, finances solar home system sales through a revolving credit fund, and provides technical and management training to small solar businesses and their technicians.

25. The institutional framework of the solar PV program in the Dominican Republic consists of ADESOL, local NGOs which manage credit programs for solar PV purchases, and the entrepreneurs who sell the systems. ADESOL began in 1984 as a credit fund, part of a grassroots effort by a US-based NGO, Enersol Associates. Its charter is to offer solar home systems services to households in unelectrified villages. Enersol, which had previously collaborated with Catholic Relief Service (CRS) and the US Peace Corps on solar PV projects, supported a project in the town of Bella Vista, Sosúa. Enersol efforts led to the formation of ADESOL, and a small PV equipment supply business, which is now Industrias Eléctricas Bella Vista (IEBV). Enersol also promoted the concept of a local credit fund and solar home system supply business to others interested in PV. These efforts led to a solar PV project within the Development Association of San Jose de Ocoa (ADESJO). ADESOL and Enersol were effective in training small entrepreneurs and their technicians. The ongoing association between ADESOL and Enersol for technical assistance is strengthened by Enersol's ability to tap into grants targeted to US organizations.

26. The businesses in the ADESOL network employ 32 people and their resources vary considerably. Some operate in towns, with access to transportation and communication, while others are based in the villages in which they install the systems. IEBV imports all of its panels and purchases the remaining system components locally. Many of the smaller businesses purchase their panels from IEBV, although one company, Solar Luz Cibao, imports some of its own panels.

27. ADESOL board members, consisting of technicians and entrepreneurs, and its general membership, consisting of solar home system technicians, hold a one-day meeting each month to strengthen the solar technician network and perform follow-up training. ADESOL has only two permanent employees. They work with a group of about 10 Dominican and international trainers who conduct the training courses. Trainees who become active in the solar PV business join ADESOL and become part of its technician network. The fact that ADESOL has trained some 40 technicians since 1986 has been instrumental in disseminating PV technology within the country.

28. Currently, four NGOs are providing credit for solar PV purchases: ADESOL, ADEPE, SSID, and ADESJO. ADEPE, which began offering credit for solar home systems in 1991, combines an extensive rural promoter network with a well-established financial capability. SSID, a church-based community service organization, began financing solar home systems in 1992. ADESJO began making loans for solar home systems in 1985. These NGOs receive the initial funding from donor organizations, including Enersol, Peace Corps Partnership, UN 1% Fund, W. Alton Jones Foundation, the Dutch Embassy, and CRS. The NGOs then provide loans directly to consumers to purchase systems from local entrepreneurs.

29. In the Dominican Republic, NGOs with strong financial support tend to have an urban bias, while the most effective rural developers often lack the financial backing.

Only ADEPE has the necessary financing and human resources to handle an expanded program. Businesses involved in the solar PV market face obstacles to expanding their operations, largely due to a lack of training, limited contacts that the rest of the educated business community enjoys, inadequate working capital, limited resources for promotion and advertising, and a lack of physical resources, such as vehicles, communication, warehouses, and workshops. The small businesses generally have not competed with each other for business because their regional markets do not overlap. This is changing in at least one region, where the ADEPE community now has two small entrepreneurs in the ADESOL network.

30. The PV module size of a typical solar home system ranges from 25 to 48 Wp. A solar home system consists of a PV module, one lead-acid automotive battery, a battery charge indicator/load center with a PV module disconnect switch, a fuse and light fixtures. A typical system powers one fluorescent lamp, four 15-W incandescent bulbs, a 14-W black-and-white television, and a small radio/cassette player. The average installed price of a 48-Wp system is about US $700. Many of the systems and installations were adequate for medium-term usage, although some systems did experience technical problems. These problems dealt with improper support structures for modules, missing battery boxes and voltage regulators, overloaded wiring, and owner misuse (bypassing the battery controller to direct-connect appliances to the battery). The PV modules were reliable except for those using thin-film silicon modules. The manufacturers honored warranties in all cases of failure. Users were generally well-informed about load management and technicians were trained in both installation and troubleshooting.

31. The systems are purchased and owned by the user. Monthly installments are about US$30, compared to about US$36 in households using kerosene and batteries. Prices of solar home systems have increased substantially in local terms, largely due to the devaluation of the peso. Customs charges, exchange-rate surcharges, and domestic industrial protection have also adversely affected the solar PV business. SOLUZ, a US firm, has recently been collaborating with IEBV to lease solar home systems, making the systems available to a larger percentage of the rural population. Since 1994, these efforts have resulted in over 100 systems being leased, with service fees sufficient to allow full cost recovery and be commercially profitable.

32. Access to credit is still a major constraint for solar home system sales. This lack of credit, coupled with solar home system promoters targeting the relatively affluent households, result in about 80% of the sales by cash. Commercial banks do not usually offer credit for solar home systems, which they view as consumer durable goods. NGOs offer loans through a revolving credit fund, which typically require a 25% down payment, 18% interest rate, and a 1-2 year payback period. The revolving credit funds are proving effective, but limited, largely due to the dependency on donations for initial funds.

CONCLUSIONS

33. These case studies document several models for implementing solar PV programs. The findings of the ASTAE evaluations are summarized in Table 1. In addition, the solar PV program in Mexico is a good example of a large-scale PV electrification effort that is part of an integrated rural development project implemented by the government. Several papers documenting the Mexican experiences are noted in the "References" section of this report. Although there is no preferred approach to solar PV promotion, local conditions and cultures might make one method more appropriate than another. The individual case study reports contain detailed descriptions of solar PV programs along with country-specific recommendations. These reports can be obtained from ASTAE at the World Bank by writing to: Asia Alternative Energy Unit (ASTAE), The World Bank, 1818 H Street NW, Washington DC 20433, USA.

ANNEX 2

ECONOMIC AND FINANCIAL COMPARISONS 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

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* *Task Lighting*	*Area Lighting*	*Source of Electricity for Appliances*
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

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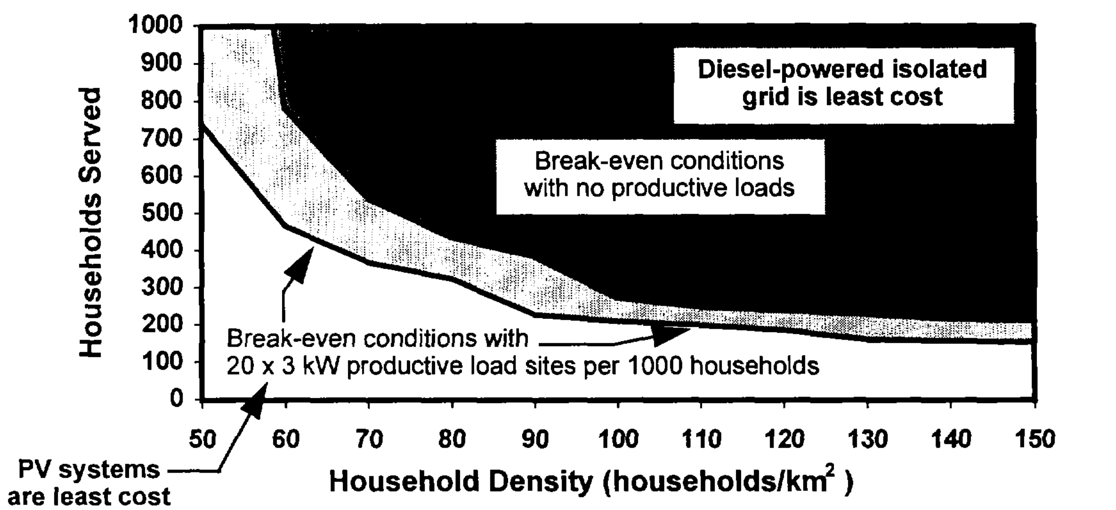
[1] Personal communication with A. Inversin, NRECA, January 1995.

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 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



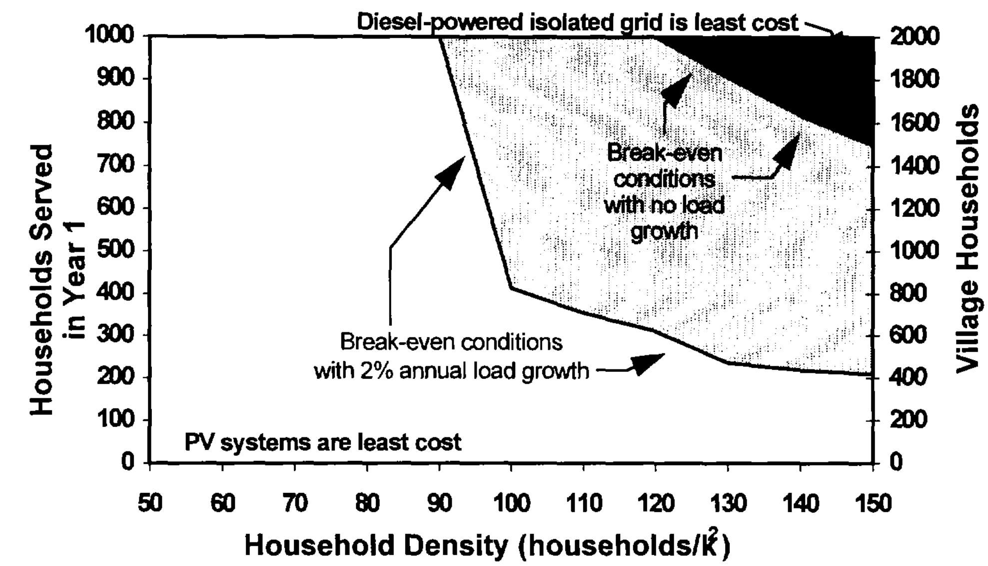
Assumptions:

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.

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