63225

Photovoltaics for Community Service Facilities

Guidance for Sustainability

Africa Renewable Energy Access Program (AFREA)

The International Bank for Reconstruction
and Development/THE WORLD BANK GROUP
1818 H Street, N.W.
Washington, D.C. 20433, U.S.A.
africaenergyunit@worldbank.org

Manufactured in the United States of America
First printing December 2010

This is a publication by the Africa Renewable Energy Access Program (AFREA), a Trust Fund Grant Program funded by the Kingdom of the Netherlands through the CEIF (Clean Energy Investment Framework) Multi Donor Trust Fund (MDTF) recipient executed and technical assistance window established by the Energy Management Assistance Program (ESMAP).

Photo Credits
Pages 2 and 5: Photo: ©IT Power Ltd., 2001
Page 3: Photo: ©Anil Cabraal, 2009
Page 10: Photo: ©Jim Finucane, 2009

Designer
Studio Grafik

Production
Marjorie K. Araya

Photovoltaics for Community Service Facilities

Guidance for Sustainability

Africa Renewable Energy Access Program (AFREA)

THE WORLD BANK

ESMAP
Energy Sector Management Assistance Program

Contents

The complete list of Annexes is accessible online at: http://www.worldbank.org/afr/energy/afrea

Boxes

Figures

Tables

Note: All dollar amounts used in this report are current U.S. dollars unless otherwise specified. As a result of rounding, numbers in tables may not add to totals and percentages in figures may not add to 100.

Foreword

Meeting the Millennium Development Goals by 2015 cannot be achieved without providing essential health, education, and clean water services to the over 1.6 billion people living in unelectrified areas. With grid electricity services or diesel electricity generation prohibitively expensive in remote areas, the attributes of solar photovoltaics (PV) seemed ideally suited to providing energy services in areas where electricity supply by conventional means is difficult and expensive. While solar PVs have been deployed across the remote and rural areas in developing countries to meet essential service needs of communities, its long-term sustainability has been below par, in part due to lack of attention to proper design and provision of long-term maintenance services. Drawing on experiences and good practices from throughout the world, the *Photovoltaics for Community Service Facilities: Guidance for Sustainability* fills the knowledge gap and offers a guide to practitioners beginning with the process of selecting a solar photovoltaic system to planning for its long-term operation and maintenance.

This report is part of AFREA[1] and ESMAP's commitment to enhancing sustainability of solar PV systems to meet community electricity needs.

Our hope is that it will improve the function, and therefore, the benefits derived from electricity in rural community facilities. We understand that it is impossible to determine the best practice in all cases and hope the Toolkit will be used as a reference to help users understand the key decision points that can affect the outcome of a project.

Tjaarda P. Storm van Leeuwen
Program Manager
Africa Renewable Energy Access
Program (AFREA)

1 The AFREA Program Manager is also the Adviser to the World Bank Group Africa Energy Unit (AFTEG).

Acknowledgements

The Toolkit was prepared principally by Jim Finucane and Christopher Purcell, with guidance and assistance from a World Bank project team consisting of Anil Cabraal (World Bank Senior Consultant), Kate Steel and Maria Hilda Rivera (The World Bank Africa Energy Unit, AFTEG) and Bipulendu "Bipul" Singh (The World Bank, Energy Sector Management Assistance Program, ESMAP). The preparation of the Toolkit was managed by Anil Cabraal and Kate Steel.

The authors gratefully acknowledge the financial and technical support from the World Bank Energy Anchor, a part of the Sustainable Energy Department, particularly for its early support to the development of the project concept. Special thanks to Norma Adams (Consultant), and Marjorie K. Araya (AFTEG, now ESMAP) for their contributions in the areas of editing and final production of this report. Also, the team benefited from numerous consultations with practitioners in Africa and elsewhere, including a workshop held in Tanzania with local experts in May 2010. Participants from programs in Ethiopia, Kenya, Mozambique, Rwanda, Sudan, Tanzania, the Philippines, and Uganda provided expert advice based on their experiences.

Funding for the Toolkit was provided by the Africa Renewable Energy Access Grants Program. The AFREA Program is funded by the Kingdom of the Netherlands through the CEIF (Clean Energy Investment Framework) Multi Donor Trust Fund (MDTF) recipient executed and technical assistance window established by the Energy Management Assistance Program (ESMAP). These funds are earmarked to support The World Bank Africa Energy Unit (AFTEG) - execute analytical and advisory activities and also to provide recipient-executed technical assistance and pre-investment grants that would help accelerate deployment of renewable energy systems.

The AFREA Program is supporting activities under Pillar 1 of the CEIF which is meeting the energy needs of developing countries and widening access to energy services for their citizens in an environmentally responsible way. All activities supported by AFREA are designed to complement and support AFTEG's mission, aiming specifically at activities that directly support and/or create enabling conditions for increased renewable energy investments and expanding access to modern energy services in Sub-Saharan Africa (SSA), as well as recipient-executed pre-investment activities that are intended to help accelerate deployment of renewable energy systems based on hydro, wind, geothermal and solar energy resources.

The financial and technical support by the Energy Sector Management Assistance Program (ESMAP) is gratefully acknowledged. ESMAP is a global knowledge and technical assistance trust fund program administered by the World Bank and assists low- and middle-income countries to increase know-how and institutional capacity to achieve environmentally sustainable energy solutions for poverty reduction and economic growth. ESMAP is governed and funded by a Consultative Group (CG) comprised of official bilateral donors and multilateral institutions, representing Australia, Austria, Denmark, Finland, Germany, Iceland, the Netherlands, Norway, Sweden, the United Kingdom, and the World Bank Group.

Executive Summary

In many developing countries with large rural populations and low rural electrification rates, most community health and education facilities lack access to electricity. For facilities in remote areas beyond reach of the national grid, photovoltaics (PV) systems may offer the most practical and least-cost way to access electricity. A PV system uses predictable solar resources and has long been cost competitive with diesel generators and other alternatives. In off-grid rural primary schools and health dispensaries, for example, PV systems oftentimes are an appropriate way to run many low-power, high-value appliances and equipment, from lamps and vaccine refrigerators to water pumps, television sets, and computers. Thus, if the electricity grid is not expected to arrive in the near future or if diesel fuel is unavailable or too expensive, a PV system may offer the least-cost technology for providing electricity service.

Social-sector projects with off-grid community facilities, including health and education, often use solar PV systems to generate the electricity needed for services and staff. But sustaining PV system operations at facilities in poor, remote communities can be problematic. If maintenance and repair services are not provided, many systems become inoperative after 3–5 years. Reliable, long-term operation requires that PV systems be well-designed and installed, using equipment of sound quality. Equally, if not more crucial for systems in community facilities (in contrast to systems owned by private households), are the institutional arrangements that ensure the uninterrupted recurrent funding for maintenance, repairs, component replacements, and spare parts. When any of these elements is missing, done poorly, or done in ways inappropriate to the context, system failures can result.

In past decades, technical reasons have often been cited for PV system failures. In certain cases, donor funds have been used to install multiple PV systems at the same facility. Rather than repair components or replace batteries installed under a previous project, it has sometimes appeared easier to procure and install a new system under a new project. But such an approach, which can only be sustained for as long as the chain of donor projects lasts, is ultimately wasteful. In such cases, rehabilitating older systems should be considered, along with putting in place viable long-term maintenance and funding arrangements.

As the PV technology has matured, the confounding issues have increasingly centered on the institutional factors that are pivotal to project success or failure of projects for community facilities. In practice, this means that, during project formulation, greater attention must be paid to the organizational frameworks and operational details for the post-project period, along with the usual attention given to project budgets, procurement, launchings, and disbursements. Such issues have long been dealt with in the case of vaccine refrigerators. Though not without problems, their operation has enjoyed a better sustainability track record than that of other PV systems in off-grid facilities. Indeed, without robust institutional arrangements, the technical problems that inevitably arise with off-grid PV systems, as with any other power source, cannot be adequately addressed.

Facility managers seeking PV solutions to fit their local contexts face similar questions: What technical and institutional requirements are the most critical? What are the key options to consider? What are the major pitfalls to avoid? The key aim should be sustainability —the reliable, cost-effective operation of a system over its design lifetime. Any PV system presented at the design stage as the least-cost solution for powering a school or health clinic will only succeed as least cost if it operates over the long term.

The observations and guidance presented in this toolkit are based on the operational experience of the authors and other team members with PV projects in more than 20 countries over the past 15 years in the Africa, Latin America and Asia regions. They also draw on the reviews of a May 2010 Dar es Salaam workshop of PV experts and project specialists, as well as from the July 2010 peer-review carried out by a group of World Bank renewable energy specialists. The findings suggested by this significant experience base will be of operational interest to all those with key roles in the development of sustainable PV investments in off-grid community facilities.

The target audiences are project developers, managers and practitioners working with organizations that fund or operate projects with PV systems at multiple-site facilities (e.g., sector organizations, such as health and education ministries, rural electrification agencies, local governments, non-governmental organizations and community-based associations). It sets out an approach to project development and implementation and provides the basic guidance on key risks and mitigating measures, which can serve as a checklist for discussions with PV and other experts. For the specialists, the toolkit provides many of the details and references for current best practices.

To date, the preparation of projects to electrify multiple off-grid community facilities with PV systems has generally followed a linear process: (i) identification of a need (e.g., electrify 100 primary schools) based on abbreviated assessments; (ii) quick decision to use solar PV; (iii) setting a budget based on the most approximate assumptions; (iv) system sizing and specification by a single "expert" working without independent professional technical review; (v) adoption of the contracting method that fits the practices and interests of the lead organization or donor; and (vi) protracted system procurement, delivery, and installation.

By contrast, a more sustainable approach would, during project preparation, comprehensively address both technical and institutional requirements, including post-project maintenance and recurrent funding. Early on and throughout the planning process, internal loopbacks would be incorporated to consider trade-offs and facilitate the inputs of communities, PV experts, procurement specialists, and other stakeholders. In addition, consultations would be held with independent specialists to take advantage of a wider body of experience and expertise.

Also essential at every operational stage are supervisory and contract capacities in installation and maintenance that are robust, timely, intensive, independent, and professional. These include technical support for vetting equipment and installations and regular, repeated, in-the-field monitoring and reviews of performance, whether done under contracts or via various types of in-house maintenance arrangements.

Robust maintenance arrangements are the sine qua non of sustainability. These include securing funding for battery replacements and other recurrent costs, clearly identifying ownership responsibilities, building necessary capacities, and installing a reporting and tracking system to provide data to monitor maintenance and performance and anticipate problems.

The authors of this guidance document have proposed that these three elements—comprehensive preparation, sound supervision, and robust maintenance arrangements—be incorporated into project development that is phased in four equally important stages: (i) rapid assessment, (ii) development of the PV implementation plan, (iii) procurements and contract management, and (iv) long-term operation.

The rapid assessment of the project scope determines whether PV is the most cost-effective solution and the implementation models available. This initial phase involves five key steps. The first assesses why PV systems are being considered. The second decides on which facilities to cover, where they are located, and how many there are. The third determines the energy requirements and PV system sizes, and then estimates PV system costs and the least-cost option.

Finally, the initial implementation model for supply, installation, and operation is decided on with key stakeholders. This phase could be done largely by the task team leader and would result in a tentative project concept and preparation plan for the stakeholders to consider. The required time for this phase ranges from a week to a month.

If this rapid assessment determines that PV is a viable option, it results in a brief concept for a possible project and the plan for its preparation. The project concept is discussed with stakeholders and independent specialists, including off-grid renewable energy specialists, and is adjusted as appropriate. The plan for project preparation takes into account an assessment of available information and activities to be undertaken during preparation to fill gaps and generate additional and improved data.

The second phase of project development is the preparation of the PV implementation plan. This is accomplished with the assistance of several specialists, including a PV technical specialist, and involves working closely with lead organization managers and specialists, broad-based stakeholder consultations, and multiple iterations. The time required for plan preparation, estimated at 1–3 months, depends mainly on the quality of existing data and how much new information must be generated from the field on facility site characteristics and energy requirements. Although many of the same questions raised during the rapid assessment are revisited, this phase addresses them at a deeper, more detailed level.

The third phase of project development, procurements and contract management, involves securing firm financing commitments (including those for post-project recurrent costs), developing tender packages, tendering and contracting, and contract management. It also covers PV system installations; maintenance; and performance tracking, monitoring, and supervision. To avoid the common pitfalls of many off-grid PV projects, a viable strategy for off-grid PV procurement must be developed. Guidance is given on choice of procurement method and process, timely promotion and publicity, appropriate phasing and scheduling and bidder criteria, and contract negotiations.

Good practice guidance is provided on the key technical requirements for viable PV contracts. These range from reasonable lot sizes and cost estimates, PV system packages, and locations of installation sites and facilities to practical completion of installations, commissioning and acceptance, and system handover from the contractor to the implementing agency or beneficiary entity; they additionally include payment structures, warranties, and guarantees; reporting and communication channels; and maintenance and performance tracking. Also covered are the conditions for effective contract management and the appropriate supervisory support required during transaction and rollout periods and over the longer term.

The fourth phase, long-term operation, is where too many projects fail. The key to success is maintenance continuity, and the basic rule is “you get what you pay for.” While it is imperative that good maintenance capacities and practices be put in place together with viable institutional arrangements for funding post-project maintenance (including component replacements), the choice of approach depends largely on assessments of the local context.

In summary, this toolkit is, at a minimum, a checklist of key issues to address in developing an institutional PV project. While it is not a technical manual, nor a substitute for using professional PV specialists to size, configure, and specify system and maintenance requirements, it offers practical operational guidance to assess, develop, and implement projects with PV systems in ways that enhance cost-effective supply and sustainable post-project operations. The guidance offered herein demonstrates that the opportunities for effectively addressing the issues to establish the basis for sustainability are many.

Part 1. **Introduction**

Access to electricity is vital to community service facilities in rural areas. In rural health clinics and schools, electric lighting provides public security and allows facilities to remain open in the evenings. Housing facilities with an electricity connection often attract the most qualified staff members. Beyond lighting, electricity is used to power an array of appliances, such as vaccine refrigerators, and other specialized equipment; pump water; and run a host of communication devices—from radios and television sets to computers and videocassette players—linking rural people to information, markets, and urban centers. Community service facilities without a connection to the national or local electricity grid must rely on alternative energy sources (e.g., independent diesel generators, solar photovoltaic (PV) systems, liquefied petroleum gas (LPG) or kerosene), or do without.

In many developing countries with large rural populations, rural electrification rates are low, and most community health and education facilities lack access to electricity. Uganda is a typical example. In rural areas, where more than 80 percent of the country's more than 30 million people live, most health and education facilities are small and lack electricity. Among lower-level health facilities, which represent 90 percent of all health facilities in the country, half lack access to the national grid, mini-grids, or stand-alone diesel or PV systems (Table 1). Among education facilities for young and school-age children, most of which are located in remote rural communities, about four-fifths lack electricity access (Table 2).

TABLE 1: ELECTRICITY ACCESS OF UGANDA HEALTH FACILITIES

		Access status (%)		
Facility type	**% of total**	**Grid or permanent mini-grid**	**Stand-alone diesel or solar system**	**No access**
Urban hospital	2	100 (except for a few district hospitals)	A few district hospitals	
Rural hospital (HC IV)	7	27–43 (NGO ones have higher access rates)	57–73	
Rural health center (HC III)	27	14	52	34
Rural dispensary (HC II)	65	6	29	65

Source: Uganda Indicative Rural Electrification Plan, 2008.

TABLE 2: ELECTRICITY ACCESS OF UGANDA EDUCATION FACILITIES

		Facility location (%)			Access status (%)		
Facility type	**% of total**	**Urban**	**Peri-urban**	**Deep rural**	**Less than 1 km**	**Connected**	**No access**
Tertiary and training	1.5	100			85	85	15
Secondary	17	17	29	54	46	27	54
Pre-primary, primary, and post-primary	82	6	12	82	21	5	79

Source: Uganda Indicative Rural Electrification Master Plan, 2008.

ADVANTAGES OF PV FOR OFF-GRID FACILITIES

For many community service facilities in remote areas beyond reach of the national grid, PV systems may offer the most practical and least-cost way to access electricity. A PV system, which uses predictable solar resources, has long been cost competitive with diesel generators and other alternatives. A PV system is simpler than diesel to operate, can be deployed quickly, and has low operating costs. It requires minimal service, making it suitable for hard-to-reach communities, and has a low environmental impact. Moreover, the PV technology is mature, making it possible to standardize modular components and systems.

For rural schools in remote areas, PV systems may offer the least-cost solution for electricity access. Eastern Cape Province, South Africa.

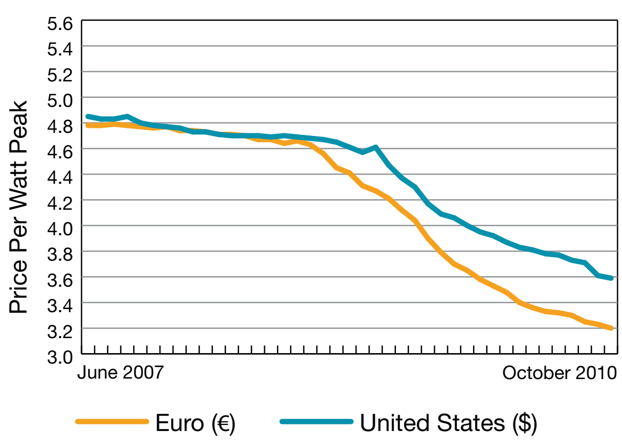
In off-grid facilities, such as primary schools or rural health dispensaries, PV systems offer an appropriate way to run many low-power, high-value appliances and equipment for facility services and staff housing: lamps, vaccine refrigerators, water pumps, television sets, computers, and phones. Thus, if the electricity grid is not expected to arrive in the near future and if diesel fuel is unavailable or too costly, a PV system may be the least-cost technology for providing electricity service.

Declining costs and strong growth

Two encouraging market trends are the: (i) resumption of declining costs of PV modules, following several years of price increases caused by a short-term shortage of polysilicon semi-conductor materials (Figure 1); and (ii) rising international PV production (33 percent compound annual growth) (Figure 2). These key trends, both of which are expected to continue over the medium term, reflect growth in major grid-based markets and advances in technology, sales volume, and competition driven by policy-based incentives for low carbon growth efforts and consumer interests in the same markets.

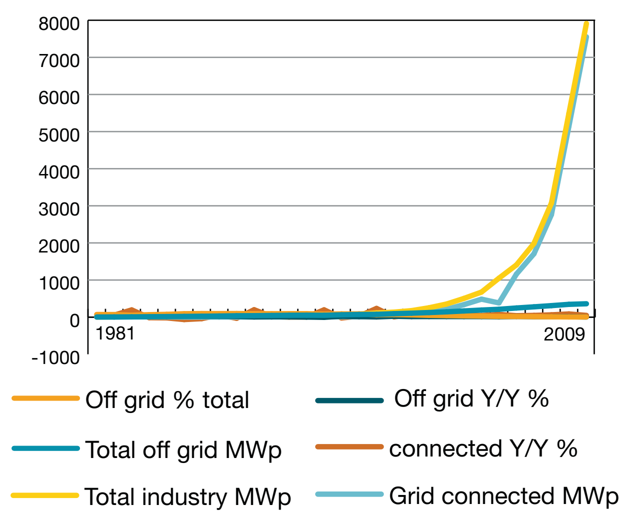
Though representing a steadily declining and now small fraction of the international market, the off-grid market benefits from the industry's price declines and production advances. [2] At the same time, the costs of running a diesel generator—the most common alternative supply option for many off-grid facilities—continue to rise along with increases in the price of fossil fuel.

FIGURE 1: DECLINING COSTS OF PV MODULES



Source: www.solarbuzz.com/Moduleprices.htm

FIGURE 2: PV INDUSTRY GROWTH SHOWING MWP SALES, 1981-2009



Source: Paula Mints, Navigant Solar Services Program, 2010. See footnote 2 for details.

2 The off-grid market share of global MWp sales declined from 25 percent in 1999 to 2.5 percent a decade later; see data from Paula Mints, (www.navigantconsulting.com/downloads/FinalSupplyNums2009.pdf) and *Photovoltaics World*, Vol. 2010, Issue 2 (March) (www.electroiq.com/index/photovoltaics.html).

Increasing supply of energy-efficient lights and appliances

International markets also have a growing supply of energy-efficient lights and appliances. By allowing smaller-size PV systems to support the same level of demand, energy-efficient devices can increase the competitiveness of PV systems as the option of choice for small off-grid facilities. Using low-wattage lights, laptops, television sets, DVD players, and other appliances reduces the required PV system size, lowering the costs of investment, maintenance, and replacement without affecting the level or quality of service.

PV SYSTEM COMPONENTS AND CONFIGURATIONS

Solar PV systems installed under the World Bank/GEF funded Rural Power Project using SSMP business model. Panobolon Village, Guimaras, the Philippines.

In off-grid facilities, PV systems are either stand-alone or centralized configurations that serve multiple units. The systems deliver either direct current (DC) or alternating current (AC). The main system components are the PV panel, battery, and charge controller; in addition, an inverter is used in systems that deliver AC electricity.

PV Panel. The PV panel or module consists of cells of thin semi-conductor material that convert radiation from the sun into DC electricity. The panel is covered with a transparent material that is sealed for waterproofing and framed for easy mounting. Panels are mounted in a sunny location (shade decreases performance) at a tilt, with the angle equivalent to the site's latitude, but not less than 15 degrees to facilitate run-off of rain and dust. Monocrystalline and polycrystalline silicon and amorphous silicon (thin film) panels certified to international standards with up to 25-year manufacturer warranties are generally a safe choice, although when companies go out of business or multiple mergers and sales occur, the practical viability of their warranties may come into question.

A good supply of monocrystalline and polycrystalline panels is available; at the initial power level, they have a longer life span and are more efficient than amorphous silicon panels, thus requiring less space and possibly a lower balance of system cost per watt. The long-term trends of declining costs and increasing conversion efficiencies for PV panels are projected to continue. Panel costs now represent 35–40 percent of initial installed system costs.

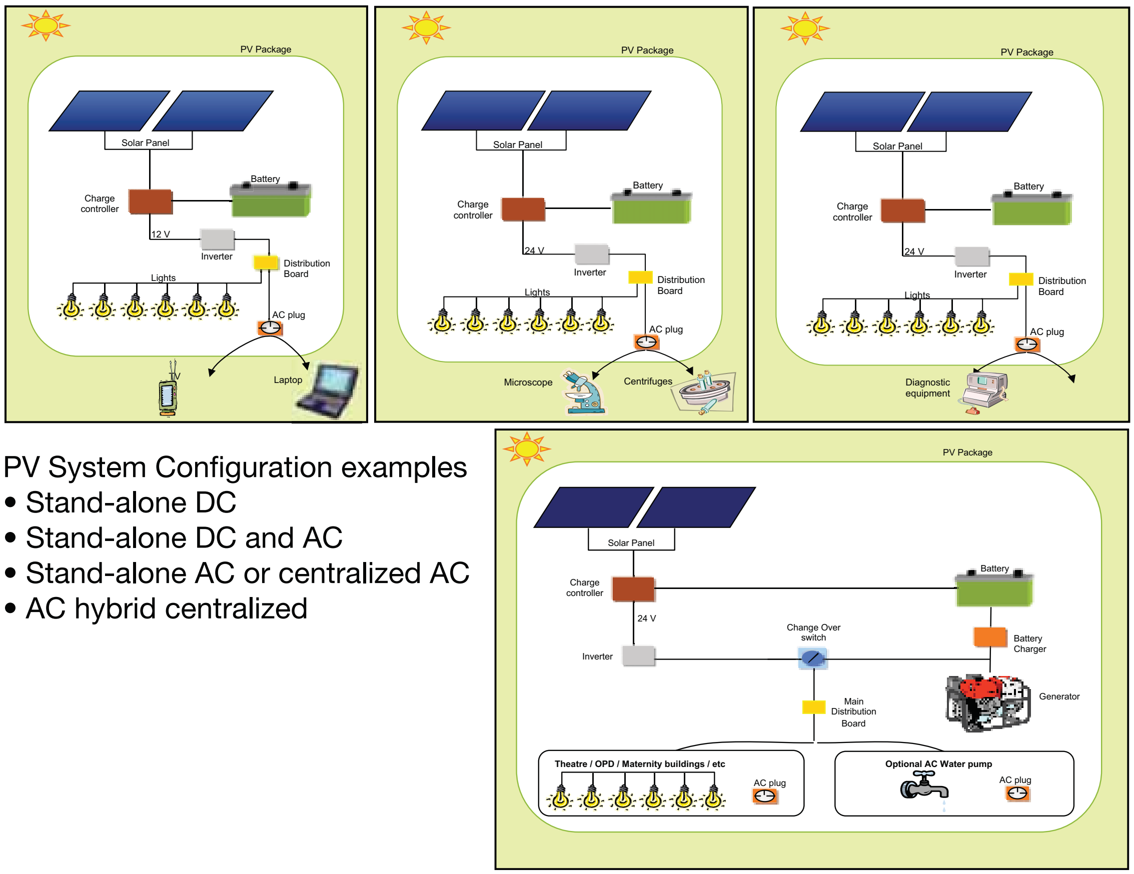
Battery. PV batteries, which store the energy generated by the panels, are easily the most problematic component of the off-grid PV system. They are also the most expensive component on a life-cycle basis. Deep-cycle, lead-acid batteries, with a life span of 5–10 years, are well-suited to PV systems, although they often are not available locally, which is an issue at the time of replacement. Modified car batteries are lower priced and may be locally available; however, they need to be replaced every two or three years. The cost of periodic replacement may well be a concern for budget-constrained organizations. Thus, deciding how to handle battery replacements should be tenaciously addressed during project preparation.

Charge Controller. The charge controller protects the system investment and can lower life-cycle battery costs. It regulates the power from the panel to the battery, stops the charging when the battery is fully charged, and cuts off the power from the battery to the loads when the battery is depleted below a safe level. Robust charge controllers with established track records that can optimize usable power delivered by the PV system are available.

Inverter. The inverter converts the battery's low-voltage DC electricity into standard AC voltage output, permitting the connection of a wide range of electrical appliances. If the system is used to power DC loads exclusively, an inverter is not needed.

Choice of configuration depends largely on the level of energy required and the physical layout of the off-grid facility. For smaller community service facilities, stand-alone PV systems may be the most cost-effective solution to meet electricity-service and reliability requirements. For facilities across multiple buildings, whose energy demand is greater, one or more centralized or hybrid systems may be more cost-effective, depending on the site layout and distances between buildings. At sites with diesel generators already in use, a PV/diesel hybrid system may be the best option. If wind resources are plentiful, a wind/PV/diesel hybrid may be the answer (Figure 3).

FIGURE 3: TYPICAL CONFIGURATIONS OF OFF-GRID PV SYSTEMS



Source: Uganda ERT Health Component 2006 report, IT Power Ltd.

REVERSING PATTERNS OF LOW SUSTAINABILITY

Social-sector projects with off-grid community facilities often use solar PV systems to generate the electricity needed for services and staff. But sustaining PV system operation at facilities in poor, remote communities can be problematic. Without providing repair and maintenance, many systems become inoperative after 3–5 years. Reliable, long-term operation requires that PV systems be well-designed and installed, using equipment of sound quality. Equally, if not more, critical are the institutional arrangements to ensure uninterrupted recurrent funding for maintenance, repairs, component replacements, and spare parts. When any of these elements is missing, done poorly, or done in ways inappropriate to the context, system failures can result.

In the past, technical reasons have often been cited for system failures. In some cases, it has appeared easier to procure and install new systems rather than rehabilitate older ones. But such an approach, whose sustainability has depended on the chain of donor projects, is ultimately wasteful. As the PV technology has matured, the confounding issues have increasingly centered on institutional factors, which are pivotal to project success or failure. In practice, this means that, during project formulation, greater attention must be paid to institutional frameworks and operational details for the post-project period (e.g., the minutiae of running costs, ownership, maintenance, and user controls), along with the usual attention given to project budgets, procurement, launchings, and disbursements.

Such issues have long been dealt with in the case of PV vaccine refrigerators. The World Health Organization (WHO) reports that more than 5,000 such refrigerators were operative by 1996.[3] Though not problem free, their operation has enjoyed a better sustainability track record than other PV systems in off-grid community facilities (Box 1).

3 For details, visit http://apps. who.int/inf-fs/en/fact132.html

Low sustainability has been a challenge in remote communities. Eastern Cape Province, South Africa.

Indeed, without robust institutional arrangements, the technical problems that inevitably arise with off-grid PV systems, as with any other power source, cannot be adequately addressed (Box 2).

The range of potential technical and institutional combinations available for any community facility depends much on the local context (though obviously, some imperatives flow from the technology). At the same time, there is a paucity of relevant time series data on the comparative operation of PV systems installed using various technical and institutional approaches. Facility managers seeking PV solutions to fit their local contexts face similar questions: What technical and institutional requirements are most essential? What are the key options to consider? What are the major pitfalls to avoid?

The key aim should be sustainability, which at the minimum is the reliable, cost-effective operation of a system over its design lifetime. Any PV system presented at the design stage as the least-cost solution for powering a school or clinic will only succeed as least cost if it operates over the long term. Table 3 offers basic guidance on sound practices for mitigating the risks of developing and implementing PV projects in rural community service facilities.

PREPARING A SUSTAINABLE PROJECT

The preparation of PV system projects for multiple community facilities has too often followed a linear process: (i) identification of a need (e.g., electrify 100 primary schools) based on abbreviated assessments; (ii) quick decision to use solar PV; (iii) setting a budget based on the most approximate of assumptions; (iv) system sizing and specification by a single "expert" working without independent professional technical review; (v) adoption of the contracting method that fits the practices and interests of the lead organization or donor; and (vi) protracted system procurement, delivery, and installation. Iterations or loopbacks in the institutional and technical design process—often responses to budget limitations, political imperatives, or procurement procedure concerns—are generally seen as troublesome bumps hindering the pace of implementation. Once system installations and disbursements are completed, implementation, from the funder's perspective, is ended.

By contrast, a more sustainable approach would:

- address comprehensively both technical and institutional requirements, including post-project maintenance and recurrent funding;
- incorporate internal loopbacks during the planning process to consider trade-offs and facilitate inputs of communities, PV experts, procurement specialists, and other stakeholders early and persistently throughout the process; and
- include consultations with independent specialists to take advantage of a wider body of technical and institutional experience and expertise.

BOX 1: SUSTAINABILITY OF PV VACCINE REFRIGERATORS

Key factors that have contributed to the sustainability of PV vaccine refrigerators are:

- robust equipment,
- system designs and standards with high reliability requirements,
- international system for qualifying equipment,
- stand-alone-operation (not integrated in a system with other applications),
- periodic training of users and technicians,
- good maintenance discipline,
- enforcement of use rules,
- reliable tracking of system performance,
- sustained recurrent funding, and
- community support (in some cases).

Source: Data on the 2007 shift of WHO and UNICEF to improved methods for setting performance standards and testing and qualifying equipment is available at http://technet21.org/Tools_and_resources/pqsdocs.htm

BOX 2: LESSONS FROM THE ZAMBIA SOCIAL INVESTMENT FUND

In 2000–05, the Zambia Social Investment Fund (ZAMSIF) disbursed US$6 million under the first phase of a World Bank–supported project for PV system supply, installation, and initial 6 months of maintenance (Table 7). These disbursements made ZAMSIF the dominant buyer in Zambia's PV market. Anecdotal evidence indicates that system quality and installations improved over the 5-year period; yet sustainability remained a major issue. There is no database of systems installed and performance, a necessary tool for accurate tracking and managing of sustainability.

Vague Specifications and Difficult Bid Evaluations. Initially, bidders proposed various system configurations, sizes, components, and quantities, which made bid evaluations and verifications of the quality supplied problematic. Later, using the World Bank's Standard Bidding Document (SBD) for Goods, ZAMSIF specified the systems (with specifications prepared by a consultant), yet bid evaluations remained a major hurdle. Indeed, the second time the SBD for Goods was used, the Zambia National Tender Board (ZNTB), which had cleared the bid documents and procedures, rejected ZAMSIF's technical evaluation. The bid documents, including specifications for sizing and batteries, were revised and then used successfully in two procurements.

Weak Bidder Qualifications and Performance. The bidder qualification requirements allowed firms with no experience in PV system supply, installation, and maintenance to win contracts. Lacking quality-assurance controls, the suppliers subcontracted installations to smaller firms. ZAMSIF officials considered inadequate on-site supervision by the relevant ministry staff, rather than supplier practices or capabilities, as the major concern, and developed improved on-site preparation, verification, and supervision procedures; trained additional ministry staff; and later contracted consultants to carry out quality assurance on a sample basis.

Lack of Standardized Systems. Systems for staff houses were not standard solar home systems (SHS); rather, a wide range of systems was used to meet the varying building designs and staff levels of the various sectors. This complicated supervision of installations and training and later management and control of spare parts and maintenance.

No Provision for Continuity of Maintenance. Beyond the supplier's initial 6 months of maintenance and the defects liability period, specifications on handling maintenance tasks were insufficiently defined. The health and education ministries retained system ownership, even though they lacked the procedures, capacities, and budgets for supporting them. ZAMSIF preferred that the ministries contract local firms for maintenance services, but this was seldom done. Over time, trained staff moved on, manuals were lost, components were not repaired or replaced, and stolen panels were not recovered or replaced.

Weak Institutional Context. ZAMSIF's approach was in line with the government policy aim of decentralization. But management, financial, and technical capabilities at district, sub-district, and community levels were weak. ZNTB lacked the capacity to evaluate PV tenders; and ZAMSIF's location in the Ministry of Finance and National Planning was itself an issue.

Organizational Silos. While ZAMSIF was conducting PV procurements, a rural electrification master plan was being prepared, regulatory arrangements for grid and off-grid electrification were being introduced, a rural electrification agency was being established, and three PV system-based energy services companies (ESCOs) were being piloted. Not being organizationally linked to the energy sector, ZAMSIF operated independently of these parallel efforts. This compartmentalization was mirrored on the World Bank side. While ZAMSIF's initial model was based on a World Bank bid document from a China project, consultations with the Bank's energy-sector specialists did not occur until 2004, when the team preparing a project with off-grid PV systems reviewed ZAMSIF's practices as part of its assessments of the PV sector. The reviews resulted in recommendations for introducing a range of best practices, including increased use of DC (rather than AC) lights and appliances, sizing, standards, standardization, warranties and guaranties, supplier quality assurance, spare parts, and maintenance.

Source: Authors' observations and information provided by Wedex Ilunga, 2010.

TABLE 3: BASIC GUIDANCE TO MITIGATE RISKS OF PV PROJECTS IN COMMUNITY FACILITIES	
Risk	**Guidance**
Wrong technology choice, (trading current low costs of diesel generator against high future costs). Sudden, unexpected grid extension and energization.	Compare life-cycle costs (not only initial capital costs) of alternatives. Determine whether communities can receive electricity from the grid. Rural electrification plans are famously uncertain (e.g., when communities are connected, they may be subject to local and national politics or decisions of external donors). Bringing a "connection" is not synonymous with "bringing electricity."
Procurement and implementation rollout delays.	Involve/build PV procurement capacities of lead organization and funder early on and persist throughout the design and preparation stages. Design contracts with detailed technical specifications and strong certification, warranty, and commissioning conditions. Standardize to as few "building blocks" as possible. Closely supervise equipment supply and installations.
Poor-quality, inefficient designs and equipment. Over- or under-investment in wrongly-sized systems of too high or low quality.	Ensure technical system design by well-qualified PV specialists aware of current best practices and not linked to potential suppliers. Consult with off-grid PV specialists and seek independent review. Design PV systems via an iterative process, considering: • current and near-term energy use (the introduction of electricity may result in such unanticipated demands as extended TV viewing or cell-phone charging); • best available solar resource data from vicinity or databases that extrapolate resources; • energy-efficient lights and appliances (but do not set the number of lights or lighting quantity or quality too low); • good-quality components, using international or equivalent standards for panels, batteries, controllers, and energy-saving lights (don't skimp); • budget capacities to meet the recurrent costs of maintenance, repairs, and component replacements; and • local O&M capacities, including suppliers and maintenance providers at central, regional, and local levels.
Lack of funds for battery replacements result in system shutdown. Misuse, poor maintenance, and lack of maintenance or troubleshooting skills. "Sudden" failures due to lack of system performance tracking and supervision.	Include community participation in preparation. Establish system ownership. Secure firm commitments for recurrent budgets for maintenance and component replacements. Consider beneficiary participation in funding O&M. Decide on in-house or outsourcing maintenance, and build local-service capabilities accordingly. Fix and enforce rules for system use and maintenance. Be clear on the limitations of PV systems (e.g., they are not for ironing, cooking, or heating). Ensure user training in appropriate use and load-management practices. Track PV system maintenance and performance to anticipate and address problems before failures occur. Closely supervise contract implementation, maintenance, and performance.
Adverse environmental impacts. Theft and vandalism.	Arrange recycling or disposal of light bulbs (e.g., CFLs or fluorescent tubes that use mercury) and lead-acid batteries. Identify any security risks and mitigating measures. Consult and create strong awareness to align community and staff expectations with sustainability of PV systems.

Source: Authors' observations, 2010.

These preparation elements should be incorporated into a four-phase process:

1) **Rapid assessment (time required: 1 week–1 month).** The rapid assessment of the project scope determines whether PV is the most cost-effective solution and the implementation models available; this could be done largely by the task team leader and would result in a tentative project concept and preparation plan for main stakeholders to consider.
2) **Preparation of the PV implementation plan (time required: 1–3 months).** This second phase would be accomplished with the assistance of several specialists, including a PV technical specialist, and would involve working closely with lead organization managers and specialists, wide stakeholder consultations, and multiple iterations.
3) **Procurements and contract management (time required: 1 year for contracting and start of installations).** This phase would involve securing firm financing commitments (including those for recurrent costs); developing the tender packages; tendering and contracting; installations; maintenance; and PV system performance tracking, monitoring, and supervision.
4) **Long-term operation (time required: 20 or more years).** The final phase is the maintenance and operation, including the financing of component replacements, over the expected lifetime of the PV systems.

TOOLKIT BASIS, AUDIENCE, FOCUS AND ORGANIZATION

The observations and guidance presented in this toolkit are based on the first hand, on-the-ground experience of the authors and other team members with the development and supervision of PV projects and activities in more than 20 countries over the past 15 years in the Africa, Latin America and Asia regions. They also draw on the reviews of a May 2010 Dar es Salaam workshop of PV experts and project specialists, as well as from the July 2010 peer-review carried out by a group of World Bank renewable energy specialists. While there is no comprehensive compilation of projects with PV systems in community facilities, nor any randomized testing, the findings suggested by this significant experience base will be of operational interest to those with key roles in the development of sustainable off-grid PV investments. The target audiences are project developers, managers and practitioners working with organizations that fund or operate projects with PV systems at multiple-site facilities (e.g., sector organizations, such as health and education ministries, rural electrification agencies, local governments, non-governmental organizations and community-based associations). For the non-energy specialists, it sets out an approach to project development and implementation and provides the basic guidance on key risks and mitigating measures, which can serve as a checklist for discussions with PV and other experts. For the specialists, the toolkit provides many of the details and references for current best practices.

The toolkit is neither a manual for PV system design, installation, and maintenance nor a substitute for using professional PV specialists to size, configure, and specify system and maintenance requirements. Rather, the aim is to offer practical guidance for assessing, developing, and implementing projects with PV systems in ways that enhance cost-effective supply and sustainable operations. The assumption is that organizational budgets are constrained and that reliable system performance over 10 or more years is mission critical.

The organization of this toolkit reflects the four-phase project approach set forth above. Thus, Part 2 presents the rapid assessment, Part 3 details preparation of the PV implementation plan, Part 4 covers procurements and contract management, and Part 5 addresses long-term operation. Part 6 concludes, and annexes provide added information and links to tools and resources to assist managers and practitioners in building their knowledge of the issues to better inform their decisions.

Part 2. Rapid Assessment

The rapid assessment determines whether PV off-grid electrification is a possible option. During this initial phase, information is gathered via discussions with lead-organization management and technical staff, energy-sector specialists, and representatives of nongovernmental organization (NGOs), firms, and other organizations and specialists with recent experience in the use of PV systems in off-grid community facilities. This work is done in collaboration with the organization that will eventually own and operate the systems. The five key steps in the rapid assessment process, summarized below (Box 3), are discussed in the sections that follow.

ASSESS WHY PV SYSTEMS ARE BEING CONSIDERED

It is useful to clarify the multiple reasons for considering PV systems for community service facilities since these will inform stakeholder expectations, as well as the project timeline and budget. Some common reasons are to:

- Electrify existing off-grid facilities that currently lack access.
- Electrify new facilities to be constructed.
- Save money by replacing or combining systems with diesel generators.

BOX 3: SUMMARY OF KEY STEPS IN THE RAPID ASSESSMENT

1. **Assess why PV systems are being considered.** Are there existing facilities without electricity access, new facilities yet to be constructed, high costs of operating existing diesel generators, new services that require electricity to be introduced, or difficulties in recruiting and retaining staff without electricity?
2. **Determine which, where, and how many facilities and which services to cover.** Develop concept and initial scope based on discussions with main stakeholders and reviews of readily available data. Assess quality of information and identify data gaps. If water pumping services are considered, separately estimate their requirements, costs, and possible implementation models.
3. **Determine the energy requirements and PV system sizes.** Estimate energy demand using country and international norms for main strata of facilities. Assess available information on country experience. Source solar-resource data from websites or maps; use month of least sunlight as the design month. Estimate system sizes using basic conversion ratios and estimating factors.
4. **Estimate PV system costs and least-cost option.** Calculate investment costs using broad ranges (e.g., US$14–19 per Wp) based on recent national or regional procurements. Estimate operating costs as a fixed proportion of investment costs. Determine the least-cost solution, comparing life-cycle costs per kilowatt hour (kWh) of PV systems against grid extension and diesel generators, using standard cost curves.
5. **Decide on implementation model and institutional and technical details.** Identify initial implementation options for supply, installation, and operation with key stakeholders. Estimate total costs by applying margin to estimated investment costs. Agree on project preparation strategy, responsibilities, requirements, and timing. Consult with independent specialists, including off-grid renewable energy specialists.

Source: Authors' observations, 2010.

- Use funds that are available for renewable energy systems (with PV being the one that can be deployed most quickly).
- Support specific services (e.g., computer-based distance education or the vaccine cold chain).
- Respond to community requests.
- Recruit or retain staff in remote areas.

In certain cases, it may appear easier to procure and install a new system under a new project rather than repair or replace the batteries of a system installed under a previous one. But such an approach, which can only be sustained for as long as the chain of donor projects lasts, is ultimately wasteful.[4] In such cases, rehabilitating older systems should be considered, along with putting in place viable long-term maintenance and funding arrangements (Part 5).

New system installed alongside non-working system. Panobolon Village, Guimaras, the Philippines.

DETERMINE WHICH, WHERE, AND HOW MANY FACILITIES AND WHICH SERVICES

A first estimate of the types of facilities, the numbers of each type, and their locations can usually be done using information from organizations on their rural facilities, services, and electricity-access status. In doing this, the data gaps and quality and scope of available information will become clear. In some cases, GIS mapping will have been done; for others, the only available information will be uncertain and outdated, requiring considerable effort to generate basic data during the planning process. Indeed, in many cases, information on whether facilities already have PV systems or whether existing systems are functional may be unavailable and will have to be collected later.

In terms of services, the aim at this stage is to clarify the main ones to cover, those considered high priority and those not likely to be covered. For example, classroom computers and lighting might be covered, while color-television viewing using satellite receivers for staff housing may not. In some cases, service levels will have already been determined; for example, the education ministry may have established standards for lighting and other services for various levels of school. In short, this is a first iteration in balancing expectations, levels of service, and costs.

DETERMINE ENERGY REQUIREMENTS AND PV SYSTEM SIZES

If information is available on the service requirements of each type of facility, an initial estimate of their energy requirements can be built up (Annex 1).[5] This can be done in daily watt hours, adding a margin for near-term growth, as well as for any underestimation of requirements. The wattage of the lights and appliances to be used in each type of facility is multiplied by the number of hours they would be used each day. If this information is not available, it is possible to do a quick estimate using national or international norms for the various types of facilities (Annex 2).

Identify solar resources

The PV system size needed to meet the energy requirements depends on a site's solar resources, which are calculated in daily peak sun hours (PSH). PSH levels can vary significantly within a country and by season of the year. It is good practice to use the month of lowest solar radiation on a tilted plane in each region as the design month for sizing systems. For most locations, monthly PSH on a tilted plane are available on the websites of various organizations, including the Photovoltaic Geographical Information System (PVGIS) of the EU Joint Research Council and NASA's Atmospheric Science Data Center.[6]

Calculate the PV system array size

The output of a PV panel is rated in watt peaks (Wp). PV systems can be sized by calculating the Wp size or array of PV panels necessary to meet the estimated energy requirements, taking into account normal technical losses by each component. In later iterations, the impacts on system size and costs of more or less energy-efficient lights and appliances, higher or lower levels of requirements for service reliability, and other design choices can be assessed. At this stage, however, we are seeking only a first estimate of system sizes.

4 In some cases, donor funds have been used to successively install multiple PV systems at the same facility.
5 Initial estimates can be done using available information on solar resources and basic data and rules of thumb on electricity requirements and costs.
6 http://re.jrc.ec.europa.eu/pvgis/; http://eosweb.larc.nasa.gov/sse/

TABLE 4: ESTIMATED DAILY ENERGY REQUIREMENTS AND PV SYSTEM SIZE

Appliance	Units (no.)	Watts (W)	Use (hrs/day)	Wh/ day
Lamp	4	11	3	132
Laptop	1	40	5	200
Radio	1	15	8	120
TV	1	50	3	150
Other	2	30	2	120
Subtotal (Wh)				**722**
Margin near-term growth			0.2	144
Energy demand (per day)				866
Margin technical losses			0.4	347
Gross energy use (Wh/day)				1,213
PSH (hrs/day)			5	
PV system array size (rounded up) (Wp)				250

Source: Authors' calculations, 2010.

With the estimates of the energy requirements and solar resources, the system size in Wp required for each facility can be estimated. This is done by dividing the total requirements in daily watt hours (Wh) by the number of PSH, and then adding a margin, say 40 percent, for technical losses (Table 4).

ESTIMATE PV SYSTEM COSTS AND LEAST-COST OPTION

Initial estimates of system investment costs can be done using broad unit costs based on information gathered locally and from recent local and regional procurements. In late 2009, total costs for communities in East Africa were US$14–19 per Wp for the supply and installation of off-grid PV systems (including lights, wiring, and some capacity building); vaccine refrigerator systems (vaccine refrigerators and solar water pumps are usually supplied as a single integrated package) cost US$16–19 per Wp (Table 5).

Most community facilities in off-grid communities that are candidates for PV systems are health clinics and primary schools. The installed costs per facility currently range from US$4,500 to $40,000 on average, depending on the size and whether appliances are included in the PV supply contract (Table 6).

Choosing the least-cost technology. The technology options for facility electrification depend on a range of factors. Key among them are distance from the electricity grid, plans for rural extension of the national grid, site-specific renewable resources (e.g., solar, wind, and hydropower), diesel prices, issues of access and logistics, and resources and requirements of funding sources. Assessing the least-cost option and the types of PV systems and configurations to consider can be done fairly quickly with information on facility locations and their energy demands, availability of and potential for grid connection, and diesel-fuel affordability and reliability of supply (Figure 4).

Plans for grid extension are a major consideration. Unfortunately, rural electrification decisions and timing are typically subject to strong political and other pressures, often making it difficult to foresee when particular communities will be connected. If a rural community is likely to receive a grid connection within five years, its facilities are not likely PV system candidates. A key aspect to consider, however, is whether and when a grid extension will be energized.

TABLE 5: PV SYSTEM COMPONENT COSTS

Cost component	Cost	Comments
System supply and installation	US$14–19/Wp	Major costs are PV panels (36%) and batteries (25%, depending on battery type and quality).
Maintenance, repairs, and replacement of battery and other components	10–15% of initial investment costs/year	Operating costs are about 50% of total life-cycle costs; battery is the most expensive component on a life-cycle basis.
Other		Institutional density, quality of roads, location of service center, and other logistical factors are important determinants of operating costs.

Source: Authors' calculations, 2010.

TABLE 6: TYPICAL PV SYSTEM COSTS FOR SMALL SCHOOLS AND HEALTH CLINICS

Facility type	Electricity requirements (kWh/day)	PV system initial cost (US$)
Health clinic (health centers, dispensaries, and health posts)	1.5–7	4,500–40,000
Small primary school (200–400 students; no boarding facilities)	2–5	7,700–26,000

Source: Authors' calculations, 2010.

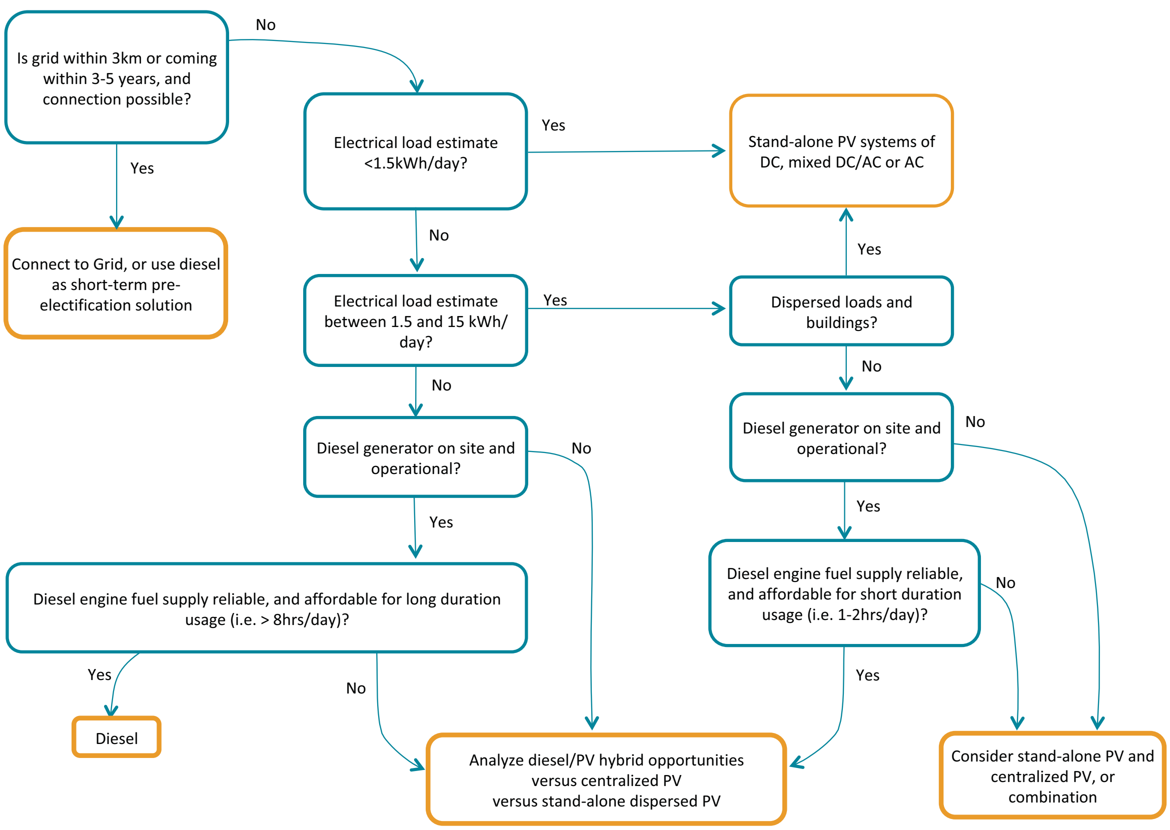
While poles and wires may be installed, thus meeting a narrowly-defined electrification-access target, the grid may not be energized for lack of energy supply or other reasons, meaning that the energy-demand requirements of the community facility will not be met.

Interim or alternative options. For communities that will not be grid connected in the near term (or for whom a grid connection may not be energized in the near term), a diesel generator may be the preferred interim, pre-electrification option (Figure 4). Other alternatives may include LPG or kerosene lighting and refrigeration. However, for lighting, there is a significant qualitative difference between kerosene and electricity. Also, the risk of fuel-price increases, coupled with the inability of ministries or agencies to assure an adequate and timely supply of fuel, must be taken into consideration.

Life-cycle costs of energy comparisons. The initial cost of supplying and installing PV systems is too often the most prominent cost metric during project preparation, which can contribute to distorted investment decisions. The cost effectiveness of PV systems and other options should be compared in terms of their life-cycle costs of energy (LCOE) in dollars per kilowatt hour ($ per kWh) and, because of its practical importance for any budget-constrained organization, their operating costs. The LCOE is calculated in present-value terms, discounting both the costs and benefits (kWh) over the typical 20 years used in appraisals of PV investments. The cost is the initial investment plus the present value of all future costs of component replacements, O&M expenses, and any other costs over the lifetime of the investment. The kWh benefit is the present value of daily usable energy production of the system over the same period.[7]

To compare the costs of a grid extension, a diesel generator set, a diesel-PV hybrid, and a stand-alone PV system, cost curves have been developed. At a discount rate of 6 percent over 20 years, PV systems will be the most cost-effective solution for: (i) small schools, health posts, and other facilities located more than 1 km from the grid with daily energy requirements less than 3 kWh; and (ii) institutions farther than 3 km from the grid with daily energy requirements of up to 15 kWh. Though LCOE estimates are sensitive to the discount rate, with diesel generators becoming comparatively more

FIGURE 4: DECISION TREE FOR LEAST-COST TECHNOLOGY CHOICE



Source: Authors' schematics, 2010.

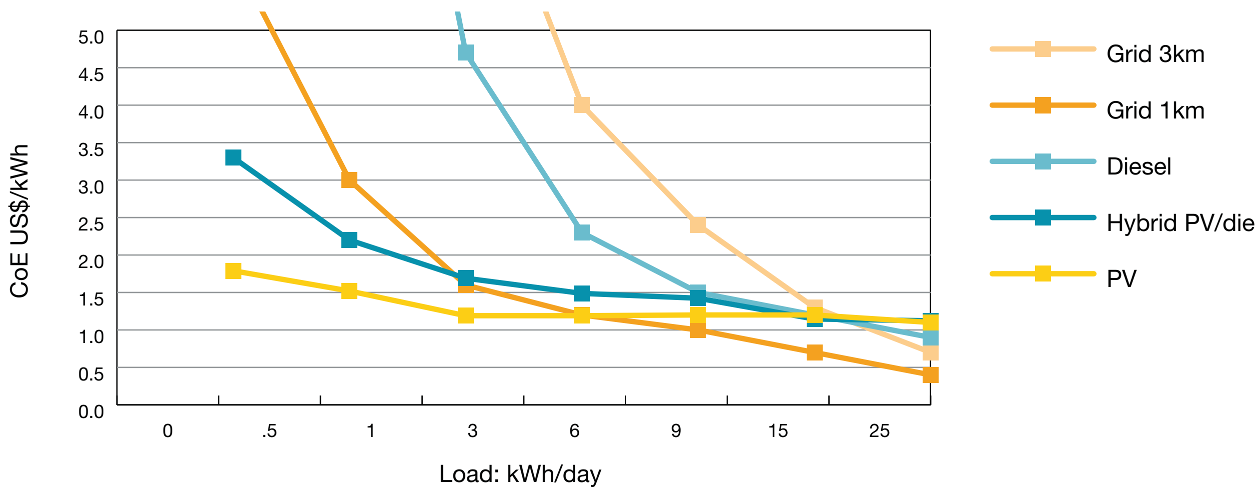
7 Web-based tools for sizing and configuring PV systems and comparing life-cycle costs of PV systems, grid extensions, diesel generator sets, diesel-PV hybrids, and other options are publicly available free of charge; these include RETScreen (www.retscreen.net/) and HOMER (www.homerenergy.com). Even if not used in initial preparation, they are useful as a due-diligence cross-check of both technical design and costs. NASA's renewable energy website provides data on solar insolation and links to RETScreen and HOMER (http://eosweb.larc.nasa.gov/sse/).

cost-effective as the discount rate rises, the relative rankings of cost effectiveness of the technology options for small facilities remain unchanged as the discount rate is raised to 12 percent (Figure 5).

Annual operating costs. Compared with diesel generator sets, PV systems offer significantly lower operating costs (Figure 6). With no fuel expenses, the running costs of PV systems are mainly for periodic component replacements and maintenance. For organizations with difficulties meeting recurrent budgets, the attractiveness of PV systems is often that of avoiding the high recurrent costs and hassles of purchasing, transporting, storing, and controlling diesel fuel.

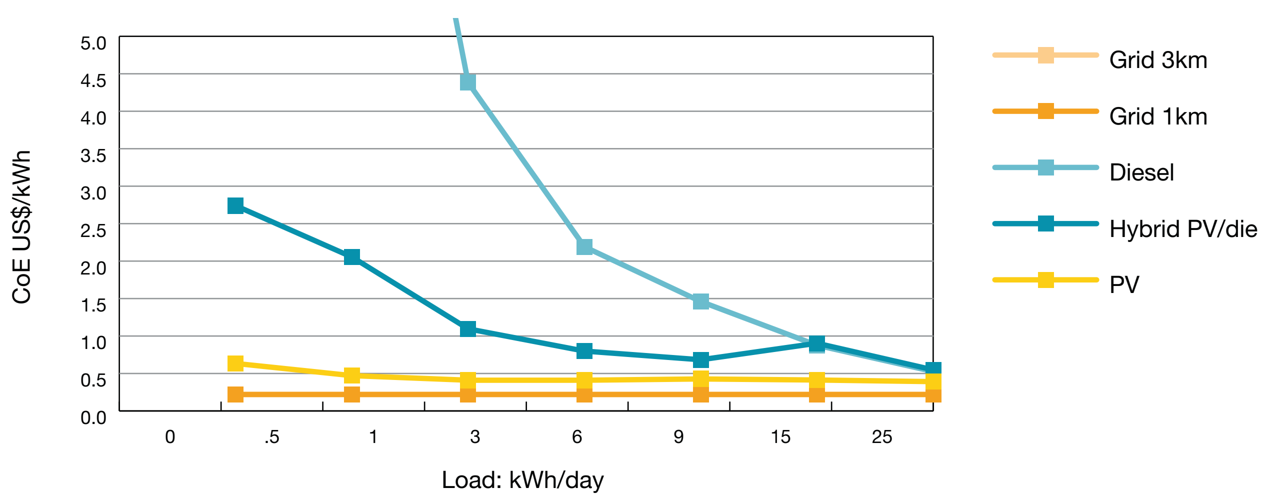
Caution: Battery replacement costs. While low running costs are a feature of PV systems, battery replacements require relatively large, periodic payments that often are not easily accommodated by organizations accustomed to modest or negligible annual budget increases for operating expenses (Figure 7). In these cases, a carefully managed escrow fund could be part of the solution. As a prudent rule of thumb, annualized recurrent costs can be estimated at about 15 percent of the installed cost of stand-alone systems, which would cover periodic replacements of major components, routine maintenance, and repairs. It would also include what is frequently not anticipated: support for essential tracking of system maintenance and performance, higher-level

FIGURE 5: COMPARISON OF LIFE-CYCLE COSTS FOR PV AND OTHER OPTIONS



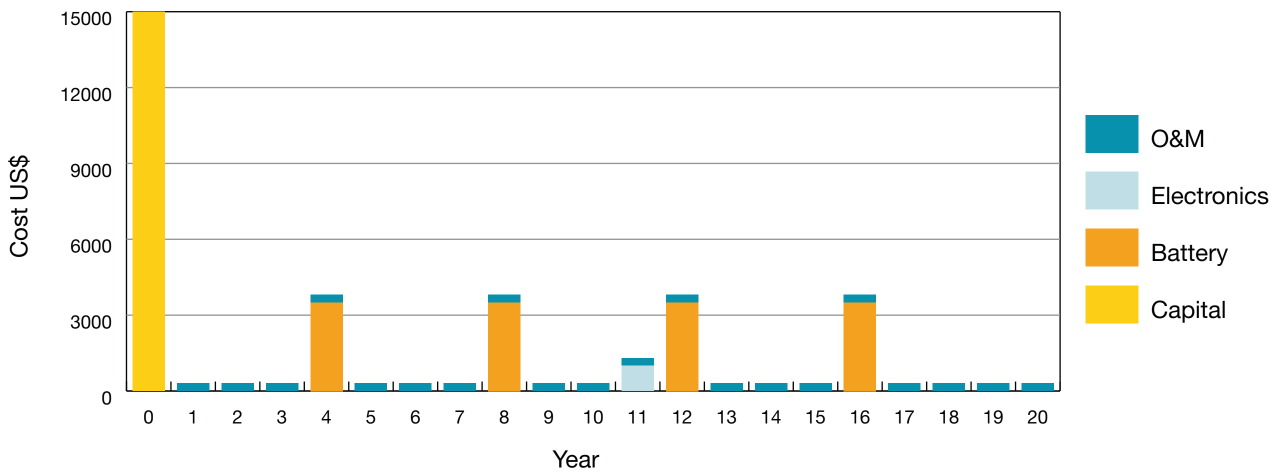
Source: Authors' calculations, 2010.
*6% DR; 20 yer life; diesel US$1.1/litre delivered; grid extension at US$15,000/km; grid elect US$0.22/kWh

FIGURE 6: COMPARISON OF LIFE-CYCLE OPERATING COSTS FOR PV AND OTHER OPTIONS



Source: Authors' calculations, 2010.
*6% DR; 20 yer life; diesel US$1.1/litre delivered; grid extension at US$15,000/km; grid elect US$0.22/kWh

FIGURE 7: ANNUAL COSTS (US$), 800 WP OVER 20 YEARS



Source: Authors' calculations, 2010.

troubleshooting, and supervision. Failure to budget for and fund recurrent costs is often the major factor in system failures.

WHETHER TO INSTALL A PV WATER PUMP

Over a wide range of small- and medium-scale requirements, including the needs of most rural primary schools and health clinics, PV pumps offer a practical, least-cost solution.

Advantages and Potential Drawbacks

For small-scale facilities, solar PV pumps require no batteries; the water tank, typically holding 3–5 days of supply, acts as the storage technology. This avoids most technical losses, the high costs of periodic battery replacement, and other maintenance and management issues commonly associated with PV systems. Compared to diesel generators, PV pumps have minimal operating and maintenance requirements. They automatically turn on and off, and can operate at low flow rates during the day, allowing more hours for the well to recover. Those for most small-scale facilities use DC power from the PV modules, thereby avoiding the cost and technical losses of an inverter. The recent development of pumps that combine a PV array with a variable frequency inverter make it possible to use AC power, further extending the viability of PV water pumping.

Off-grid, community-operated PV water pumps and PV systems for community service facilities confront similar sustainability challenges involving ownership, maintenance, recurrent funding for spare parts and repairs, management and control, and long-term operation after installation and the exit of donor support. An evaluation of the experience in sub-Saharan Africa with hand pumps and the Village Level Operation and Maintenance approach, developed and promoted with World Bank support, concluded that "there are no 'off-the-shelf' solutions...and no simple solutions on the horizon."[8] Because many rural clinics and schools share their water supply with the local community, the water requirements and pump and PV array sizing may go well beyond those of the community service facilities, thereby complicating any decision on whether to install a solar pump. Furthermore, unlike the PV systems for community facilities, which can be standardized to a relatively few models and fairly rapidly deployed, PV water pumps require more customization, time, and engineering input (pumps must be designed and drawn for each unique site and well), and a wider range of installation skills. The required time for procurement and rollout of installations across multiple facilities at multiple sites may not mesh well with those for PV systems for rural schools, health clinics, and other facilities.

Preliminary screening

Whether PV pumps are the most cost-effective solution for a particular organization with multiple-site facilities and a limited time frame for implementation depends on many site-specific factors, including the amount of water required, its availability and at what depth, and the costs of drilling tube wells. A number of questions can be asked and a limited amount of data quickly collected to decide whether PV pumps should be further considered. With the assistance of a PV engineer, an initial assessment can be made on whether solar water pumping is likely the least-cost solution.

8 Jeremy Colin, VLOM for Rural Water Supply: Lessons from Experience, Task No. 162, Task Management and Quality Assurance by Andrew Cotton, London School of Hygiene and Tropical Medicine, WEDC, Loughborough University, March 1999 (www.lboro.ac.uk/well/).

Initial questions

How much daily water is required? National standards for daily water requirements per person are often available. For rural off-grid communities, a typical amount is 20–40 liters per day. Depending on the facility and such factors as who will use the water (e.g., the community or the facility only), the daily water requirement can be estimated.

What is the "head" that the water must be lifted? The total dynamic head that a pump must lift water is a combination of the total height that the water is lifted (measuring the vertical lift from the lowest level where the water is pumped to the intake level of the water tank), plus the effect of extra pressure caused by technical losses as the water flows through the pipes; this extra pressure varies with pipe types and sizes and the flow rate. For this first-screening phase, the total head is assumed to be the total height plus 25 percent.[9]

Is enough water available? The initial answer may be based on the operation of existing wells in the vicinity. In many cases, the interest is to: (i) obtain more water from an existing well by increasing the yield over a hand pump not providing the well's maximum; or (ii) reduce the cost of operating a diesel pump.

How much energy and what size PV array are needed to pump the water? At sea level, 1 kWh is needed to raise 1,000 liters (1 m^3) a total of 367 meters. Thus, if a facility's total daily water requirement were 4 m^3 (e.g., 200 people at 20 liters each) and the water had to be lifted vertically 40 meters (giving a total head of 40 x 1.25 = 50 meters), the hydraulic energy required would be 0.54 kWh per day (4 x 50/367). The "volume head," or the amount of water in metric tons (m^3) multiplied by the total head (expressed in m^4), would be 200 m^4 per day (4 m^3 x 50).

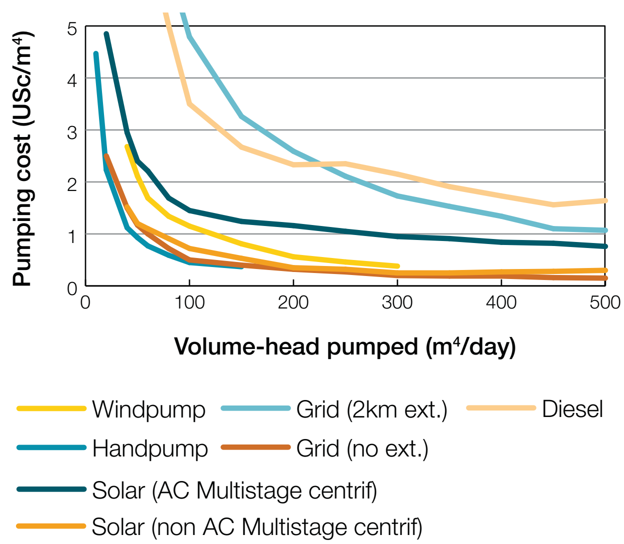
For small-scale applications, DC solar pumps that run directly from the solar panels are 30–60 percent efficient; sometimes called "wire-to-water efficiency," this excludes the solar panel efficiency. These pumps work only during sunlight hours. In this example, achieving 0.54 kWh at a site with 5 PSH per day, assuming panel technical losses of 10 percent and a pump efficiency of 35 percent, would require a PV array of 342 Wp (0.54 kWh per day/35 percent/0.9 percent/5 PSH). This calculation is adequate for a quick approximation, but the actual size will depend on the efficiencies of the pump and array combination.[10]

Answers to the above questions will determine how much water will be needed, whether it is available, and, if so, the volume head per day and a rough estimate of the size of the PV array needed to lift the water, which may assist in the initial cost estimate. It should be noted that this level of investigation must be done separately for each pump site under consideration.

Topics for quick feasibility questions

Life-cycle costs. Screening for the lowest life-cycle costs can be done quickly using several charts and rules of thumb. On the basis of life-cycle costs (using late 2009 figures), solar pumping is more cost-effective than diesel up to 1,000 m^4; at 20 liters per person and a total pumping head of 50 meters, roughly 500 people could be covered (Figure 8). More detailed estimates could be made using a web-based tool made available by the Namibia Ministry of Mines and Energy.[11] If the results indicate potential feasibility, a technical study would then be required to carefully consider pump types, required number of storage days, water tank size, and other key factors.

FIGURE 8: LIFE-CYCLE COSTS OF WATER SUPPLY



Source: Energy & Development Group, Solar Pumping for Communities Technical Guide, prepared for the South African Department of Water Affairs and Forestry (1997). Revised, June 2007.

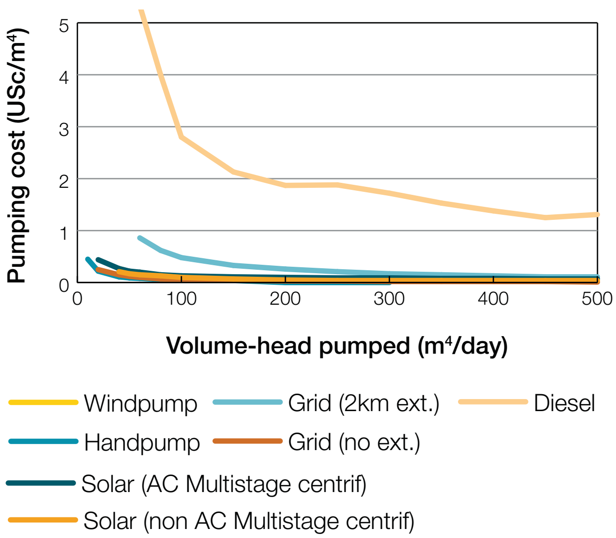
Operating costs. For many facilities, running costs are of more practical importance than life-cycle costs. Our estimates indicate that solar pumping would have lower operating costs over a large range; of course, a grid connection would be cost competitive (Figure 9).

9 Formally, total dynamic head = borehole static water level + borehole drawdown during pumping + lift from the borehole head to the tanks + dynamic pressure losses.

10 The selection of pump type depends on the facility's daily water requirement, depth of water source, and total head at the facility site. The choices are submersible or surface mount and positive or centrifugal displacement There are a number of well-established solar pump manufacturers, each of which provides performance charts for their pumps, indicating which are suitable for a particular facility.

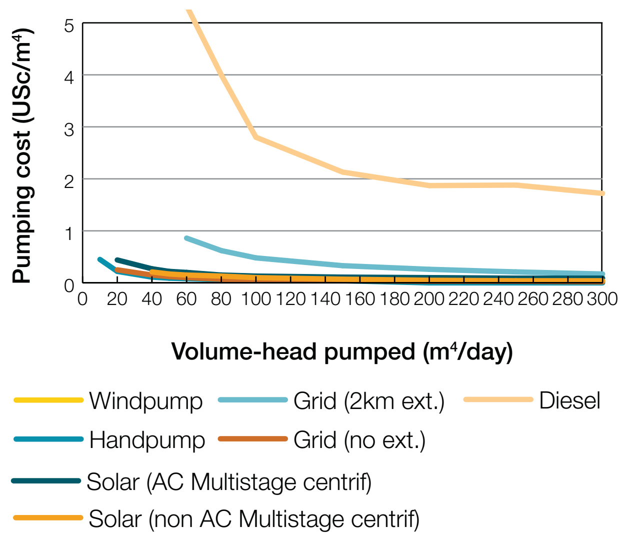
11 For details, visit www.mme.gov.na/energy/pvp.htm

FIGURE 9: RUNNING COSTS OF WATER SUPPLY



Source: Energy & Development Group, Solar Pumping for Communities Technical Guide, prepared for the South African Department of Water Affairs and Forestry (1997). Revised, June 2007.

FIGURE 10: COSTS OF PV AND NON-PV PUMPS



Source: Energy & Development Group, Solar Pumping for Communities Technical Guide, prepared for the South African Department of Water Affairs and Forestry (1997). Revised, June 2007.

Least-cost comparison. PV pumps have long filled a broad niche between hand and diesel pumps as the most cost-effective option.[12] In recent years, as DC pumps have begun to operate at deeper levels and pump more water and as the efficiency and cost of both pumps and PV panels have improved, the niche for PV pumps has steadily grown (Figure 10).[13]

Over a broad range of heads and water volumes, PV pumps will be likely to be a more cost-effective solution than hand pumps or diesel generator sets (Figure 11). For a volume of 40,000 liters per day, for example, solar is the most cost-effective option for heads of 1–50 meters. Hand pumps remain more cost-effective for the smallest scale combinations of liters per day and total head, while diesel generators are not cost-effective in small installations. Thus, over a wide range of small- and medium-scale requirements, solar pumps are more competitive; these could be surface mount pumps for well depths of up to 3 meters, and otherwise more expensive submersible pumps. In parts of Africa, where well drilling costs are high, solar pumps can be more cost-effective than hand pumps, which limit the amount of water that can be extracted from a well, especially when the water table is deep.

Detailed assessment and design

If the outcome of this preliminary screening is positive, a more detailed assessment and design should be undertaken with assistance from PV and water supply specialists and community participation in key aspects. In many ways, the supply and installation and operation of solar water pumps differ markedly from those for PV systems for facility electrification. They may involve civil design and construction work; site-specific sizing to match depths, tank sizes, and distances; control and contamination issues; and various methods of commissioning and backup technical support. The approaches for procurement and bid evaluation also differ. Most solar water pumps are supplied as an integrated package of PV panels, pump, controller, and other components, with a wide range of combinations of panel and pump sizes and types. Suppliers provide performance charts for each of their respective pumps, which show the size and voltage of the solar panels necessary to operate the pumps.

Additional questions

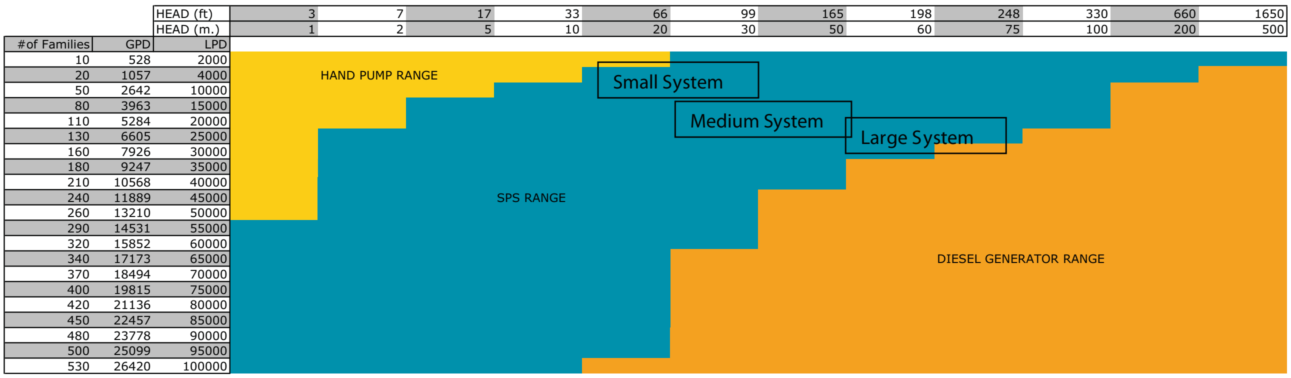
During the detailed design, the community should be surveyed and site data gathered. This process would occur site by site,

12 An assessment conducted in 1987 found that PV pumps were more economical than either hand or diesel pumps in off-grid villages of 300–2,000 people where water-table depths are 20–40 meters; see A. Cabraal, A. Siess, L. Slominski, M. Buresch, and J. Kenna, Comparative Assessment of Photovoltaics, Handpumps, and Diesels for Rural Water Supply, Technical Report No. SAND87-7015, Sandia National Laboratories, Albuquerque, NM, 1987.

13 See Ministry of Mines and Energy of Namibia, Final Report: Feasibility Assessment for the Replacement of Diesel Water Pumps with Solar Water Pumps, 2006; Solar Electric Light Fund, A Cost and Reliability Comparison between Solar and Diesel Powered Pumps, 2008; B. Barlow, B. McNellis, and A. Derrick, Solar Pumping: An Introduction and Update on the Technology, Performance, Costs, and Economics, World Bank Technical Paper No. 168, Washington, DC, 1993.

14 A guide to community-based assessment of solar water pumping is available at www.greenempowerment.org

FIGURE 11: COMPETITIVE RANGE FOR SOLAR PUMPS VERSUS HAND PUMPS AND DIESEL GENERATORS



Source: Walt Ratterman, Jonathan Cohen, and Anna Garwood, *Solar Pumping Systems (SPS): Introductory and Feasibility Guide*, 2003, Revised, January 2007 (www.greenempowerment.org).

with significant participation of the community, as well as the facility owner, staff, and beneficiaries.[14] The following list of survey questions suggests the range of issues to be covered:

- Is there an existing well? If so, what is the level of the water depth, recharge rate, and water quality? Is it potable?
- If there is no existing well, what information is available on local water depths, recharge rates, water quality, hygiene, and sanitation issues?
- How is water supply currently managed and financed?
- What would the community's role be in installing, operating, and maintaining a solar water pump?
- How would costs be shared? How would funds be collected and managed? Would there be charges? What would be the rate structure if community members were permitted to access a facility's water supply?
- What licenses or permits would be required for a solar water pump? Is there a government agency responsible for the water supply? What would its role be in operation of the solar water pump?
- Is theft an issue? If so, what measures are currently used or have been suggested to deal with this risk?
- Is the existing pool of trained PV technicians, professionals, and firms or other entities that provide maintenance and repair services adequate for the critical service of water?

Separate plan for water supply

Rural community-water supply is a specialized field with an established body of good practices. Thus, if a project decides to include solar water pumping for community facilities, particularly if the water is shared with the community, a separate, detailed plan should be prepared.

DECIDE ON IMPLEMENTATION MODEL AND INSTITUTIONAL AND TECHNICAL DETAILS

Two major implementation decisions must be made. The first is whether to focus on a single sector, with facilities perhaps dispersed throughout the country, or multiple sectors with the facilities clustered within an area. The second is whether to link with PV market development, including efforts to achieve household access in the same rural communities. Four projects in Sub-Saharan Africa and Southeast Asia illustrate how these options have been variously combined (Table 7).

Sector or area based approach?

Focusing on a single sector, such as rural schools or rural clinics can benefit from clarity on implementation responsibilities and procedures, if the procurements and after-installation services are implemented by a well-established organization. An area based approach, which would typically target facilities in multiple sectors, usually within a more limited geographical area, will have lower costs for both installation and post-installation maintenance and management if facilities are less dispersed.

Both approaches are typically based on procurement, whereby a ministry or other implementing agency contracts for supply and installation and perhaps maintenance of batches of systems. Depending on the local situation, this approach may be appropriate in contexts where there is little PV market development or related activities.

15 A toolkit for designing and implementing rural water supply projects, entitled "Rural Water Supply and Sanitation for Multisector Projects," (2004) is available at www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2005/07/29/000012009_20050729090303/Rendered/PDF/331630rev0PAPER0ENGLISH0rwss1pub.pdf

Whether to link with market development

The second implementation choice, whether to link contracts for the supply and installation and possibly maintenance of the systems with PV market development aiming to increase rural household access to modern electricity services, can be an attractive option in countries that have: (i) a local PV market or activities that support its development; and (ii) a lead institution, such as a rural electrification agency, that supports market development. For example, local PV market development projects already in place (involved in establishing standards, strengthening rural PV supply chains, training technicians, developing local maintenance capabilities and local-language manuals, and developing community financing mechanisms or providing subsidies for system installations) could benefit a project that aims to provide PV systems for community facilities.

The Sustainable Solar Market Packages (SSMP) model, introduced in 2005 by the Philippines Department of Energy with support of the Rural Power Project, combines an area based, multiple sector approach with market development approaches to address the cross-cutting issues of sustainability, scale, and affordability. SSMP contracts bundle the supply, installation, and maintenance of systems in community facilities of target districts with obligations for the commercial sale of systems to households and other private customers in the same districts, along with incentives and support for market development. Successful SSMP contracts usually require that a significant number of households be able to afford the PV systems or lanterns; thus, the SSMP model must address that issue (Box 4).[16]

BOX 4: SUSTAINABLE SOLAR MARKET PACKAGES: INITIAL LESSONS FROM THE PHILIPPINES

The Sustainable Solar Market Packages (SSMP) tackles low sustainability of PV systems in off-grid rural areas, low sales and high prices of household systems, and weak after-sales service in remote areas. Contracts for supplying community systems in clustered villages include obligations to sell systems or lanterns to households; also, subsidies and other supports are provided for developing the household market. The aim is to establish a business volume sufficient to attract strong bidders and secure business sustainability by spreading the costs of operating in the remote communities over a larger number of transactions. By the end of 2009, 18 SSMP contracts had been awarded to three contractors in three rounds. By March 2010, systems had been installed in 337 of the 347 target villages, but only 300 of the targeted 6,800 household sales had been achieved.

Key recommendations from experience with successive contracts are:

- Ensure affordability of household systems and lanterns (e.g., access to microfinance, small size units) and that market development supports are in place and functioning.
- Provide for change orders to adjust to changed conditions (e.g., political, security, or competition) in communities and market.
- Link progress payments for installations in community facilities to progress on household sales as an incentive not to delay household sales.
- Facilitate disbursements to contractors (delays crimp cash flow, which can hamper marketing for household sales).
- Require contractors to have their own quality assurance and, in cases of quality problems, to cover costs of return verification visits.
- Provide strong supervision and independent verification capabilities, including PV engineer, in a timely fashion.
- Fix firm funding arrangements for maintenance before rollout of installations.

Source: Authors' observations, 2010.

16 The SSMP model relies on private dealers and microfinance capabilities for the required household sales, which are a constraint, despite significant subsidies and other support for business development, credit, and development of local-service capabilities. Concerned about the scalability of the SSMP approach in the Philippines given the weakness of private sector capacities in relation to aggressive national targets for off-grid electrification in the targeted remote communities, the Department of Energy is now piloting fee-for-service approaches using the main distribution utilities (electric cooperatives) and new concession holders in waived franchise areas under a new regulatory framework in an effort to mainstream PV use for off-grid electrification.

TABLE 7: IMPLEMENTATION MODEL OPTIONS FOR SELECTED PV PROJECTS

Option	Zambia (Zambia Social Investment Fund) 2000-2005	Mozambique (Energy Reform and Access Project) 2009	Philippines (Rural Power Project), SSMP 2007	Tanzania (Energy Development and Access Expansion Project), SSMP 2009
Implementation type	Sector-based.	Area-based, multiple sectors.	Area-based, multiple sectors, with market development.	Area-based, multiple sectors, with market development.
Location of facilities	Widely dispersed around the country.	Spread out within an area.	Clustered within an area.	Clustered within an area.
Facility types	Schools, clinics, staff housing, police posts, and others.	Health and education facilities.	Health clinics, schools, community halls, and streetlights.	Health clinics, schools, police posts, streetlights, and staff housing.
Provision approach	Contracts to supply and install systems in community facilities.	Contracts to supply and install systems in community facilities.	Contracts to supply, install and maintain community systems with obligations for household sales.	Contracts to supply, install and maintain community systems with obligations for household sales.
Project features	PV procurements are examples of the supply and installation of PV systems in community facilities spread throughout the country, including hard-to-reach communities, with no significant clustering; no firm provision for managing or financing component replacements or longer-term maintenance and unclear ownership arrangements. Anecdotal reports indicate improved quality of systems and installations.	Each contract is about 45 kWp; 1-year installation contract and 1-year defects period, with no maintenance obligations. Maintenance is responsibility of each social-sector ministry at provincial level. Six PV packages designed for various types of facilities in the selected sectors. All systems are 100% grant-funded.	SSMP contracts bundle system supply, installation, and maintenance in community facilities in a contiguous cluster of villages with obligations to meet minimum targets for commercial sales to households in the same communities. Performance-based subsidies and business and credit support provided for household sales. Contracts aggregate enough business volume to support continued commercial sales and after-sales support for public and private PV systems.	Market packages are designed to maximize geographical densification benefits. Each contract is about 35 kWp and covers several villages. Contracts are for supply, installation, and maintenance in community facilities, with obligations to meet annual targets for sales to households and private entities in same communities. Private-sector sales include all sizes of SHS and solar lanterns. Potential for innovation by service provider in user finance, including rentals. Public-sector facilities 100% grant-funded. Small incentive ($/Wp) for household or other private sales.
Key challenges	Sustainability is major issue. Difficult bid evaluations, weak bidder qualifications, weak performance, no standardization, low maintenance, weak institutional context, and “organizational silos.”	Little harnessing of area-based economies of scale in operational phase; little coordination with other PV projects from other donors in same villages.	Limited bidder interest; procurement delays; unexpected and sudden grid extensions; security concerns; weak private-sector capacity; slow household sales; equipment (inverters), installation, and maintenance quality issues.	Limited range of 6 packages may not provide the best fit for the wide range of facility types on the ground.

Source: Authors’ calculations, 2010.

Continuity of maintenance

A critical phase of implementation is continuity of maintenance—the arrangements for owning, operating, maintaining, and funding systems after installation—which must be carefully and completely defined for both the project and post-project periods. At this rapid assessment stage, broad choices should be explored: Is maintenance to be done in-house or contracted out? If contracted out, might it initially be part of a supply and install contract? How these issues will be resolved are not decided in the rapid assessment phase, but the pros and cons of possible options can be identified.

In clarifying implementation model options, the key questions are:

- Who will fund the investment?
- Will implementation focus on a single sector or cover facilities across multiple sectors within an area?
- Will there be obligations for sales to households and linkages with market capabilities or other projects?
- Who will be the lead organization for implementation of supply and installations?
- Who will own the PV systems once installed?
- Who will be responsible for maintenance during the project and post-project periods?
- Will maintenance be done in-house or contracted out during the project and post-project periods?
- Who will fund the recurrent costs of operation during the project and post-project periods?

RESULT: PROJECT CONCEPT AND PREPARATION PLAN

If this rapid assessment determines that PV is a viable option, then it results in a brief concept for a possible project and the plan for its preparation. The project concept would be discussed with stakeholders and independent specialists, including off-grid renewable energy specialists, and adjusted as appropriate. The plan for project preparation would take into account an assessment of the available information and activities to be undertaken during preparation to fill gaps and generate additional and/or improved data.

Part 3. **Preparation of the PV Implementation Plan**

Preparing the detailed PV implementation plan requires a broad range of skills. Whether using in-house or contracted experts, the services of highly qualified specialists, including a PV expert for technical guidance, are vital. Project managers must decide whether to hire a consultant to assist with the entire process—from design and procurement through supervision of installations and commissioning—contract a series of consultants, or use in-house expertise. In many cases, it is good practice to use a single consultant over the entire process, along with independent reviews at key points. The time required for plan preparation, estimated at 1–3 months, depends mainly on the quality of existing data and how much new information must be generated from the field on facility site characteristics and energy requirements. This phase addresses many of the same questions as the rapid assessment, but at a deeper, more detailed level (Box 5).

BOX 5: SUMMARY OF KEY STEPS IN PREPARING THE PV IMPLEMENTATION PLAN

1. **Gather information and conduct field surveys.** Collect data on numbers, locations, physical layouts, and energy requirements for types and levels of facilities. Assess institutional and market capacity (Annex 3). Conduct wide stakeholder consultations and field surveys at representative facilities. Review sector priorities and policies and grid extension plans.
2. **Update rapid assessment data on facilities and prioritize services.** Deepen and update information from the rapid assessment on numbers and types of facilities. Rank energy requirements by the priority of the services they support, with rankings determined by sector policies and likely impacts. (If PV water pumping is included, conduct separate site-by-site assessments guided by water specialists).
3. **Refine energy requirements and size and configure PV systems.** Calculate requirements through several iterations comparing use and configuration options, considering country experience and international best practice. Refine solar-resource estimates with disaggregated data, including regional and seasonal patterns. (National meteorological office may have detailed data.) Size and configure systems with engineering design methods simulating component and installation options with reliability/cost and other trade-offs.
4. **Construct cost estimates and fine-tune least-cost option.** Build up investment and operating estimates with unit cost data for components, shipping, local taxes and handling, installation labor and logistics, maintenance, and component replacements. Run iterations comparing technical and organizational design options. Consider PV procurement cost trends. Customize least-cost assessments and simulations with data on specific technologies and locations.
5. **Decide on implementation model and institutional and technical details.** Identify opportunities to cooperate with other projects and organizations. Conduct multiple consultations with stakeholders on all aspects. Agree on responsibilities for supply and installation, maintenance, financing, ownership, and any links with market development. Determine procurement methods. Build up project budgets, schedules, and draft procurement packages, including technical specifications and terms of reference for capacity building, implementation support, and system performance tracking (Annex 4). Consult with independent specialists, including off-grid renewable energy specialists.

Source: Authors' observations, 2010.

GATHER INFORMATION AND CONDUCT FIELD SURVEYS

A well-organized effort, with active participation of the organizations that own the targeted facilities, aided by mobile phones and Internet technology, can fairly quickly result in a comprehensive compilation of basic information on the facilities. At this stage, field surveys of representative facilities and communities, including those that already have PV systems, should be conducted to confirm data and identify any unusual patterns or issues. Participatory rapid rural appraisal methods, including focus groups and selective interviews that draw on the experiences and expertise of facility staff members and communities, can be effective in collecting data that fairly reflects on-the-ground realities.

Data on facilities and their energy requirements

Information to be collected on the facilities includes:

- **Number of facilities,** categorized by sector type (e.g., rural hospitals, health centers, or health dispensaries).
- **Location of facilities,** categorized by their proximity to existing and planned grid; if GIS spatial information is unavailable, spreadsheet lists are a workable solution for small numbers of sites.
- **Typical building and site layouts** for each type of facility, which can be quickly surveyed by selective visits to representative sites; ministries may have databases including architectural or schematic drawings of buildings and equipment/appliance lists for the facilities.
- **Organizational, sector, and other policies and rules** for equipping facilities (e.g., classifications of schools and health facilities), which may specify the number and types of equipment and lighting to be provided, depending on the facility classification; if not, a participatory, collaborative process should be undertaken to agree on the standard rules to be used.
- **Energy use and expenditure** of staff at facilities with and without electricity (including those that already have PV systems determined via surveys with questions on hours of appliance and equipment use and substitute products (e.g., kerosene lanterns and radios with dry-cell batteries). Although not included in the services to be provided by solar PV, energy for thermal purposes (e.g., cooking, sterilization, water and space heating, ironing, and hair-drying) should also be included in the survey.
- **Local community and facility staff information** on lightning strikes in the area, theft and vandalism risks and possible counter measures, and other factors that may impact the systems to be installed in the facilities; if the community and/or facility staff may be expected to contribute to maintenance costs, they should be carefully consulted during the field surveys.
- **Site-specific water supply information** if water pumping is to be a project-supported application, water specialists will need information for each site on the volume of water required per day and the lift head at each site, as well as data on borehole or well depth, static water level, water rate and dynamic water level, and seasonal patterns. Data may be available from the water department. Information is also required on the water jurisdiction and existing borehole and pump condition, ownership, and responsibility. Assumptions on water demand and minimum days of storage, depending on the nature of the demand and uses at the facility, will need to be clarified. Ultimately, each site will require detailed drawings.

Institutions and markets

Assessments of institutional and market capacities, opportunities, and constraints are fundamental and should precede determining the details of how the supply, installation, and later operation of the systems will be managed. These assessments will contribute to (i) realistic decisions about the viability of PV systems as a supply option and (ii) design of practicable implementation arrangements. They should be undertaken at a level of detail proportionate to the case. Preparing to implement PV systems for significant numbers of facilities warrants thorough assessments (Annex 3).

The suggested assessments are:

- Market capacities and barriers—size and performance of local PV market, including prices, quantities, and quality; local capacities to support PV, including number and track records of local and international companies operating in the local PV market, organizations, and specialists; PV-related capacities in communities near the targeted facilities; and market development activities and projects planned or already under way.
- Grid extension plans and costs and tariffs.
- Diesel prices and supply reliability in communities located near facilities.
- Country PV experience—local experiences (including those of targeted communities); implementation models used; results; sustainability track records of facilities in government, for-profit, and non-profits sectors.
- Institutional implementation capacity (design, procurement, supervision, training, ownership, operation, and maintenance), including those of:
    - lead organization in project preparation and initial implementation;
    - likely facility owner(s) (may differ from lead implementing organization during procurement); and
    - other national and local institutions (e.g., central government ministries, local governments, technical institutions, NGOs, private firms, and individuals) that are potential project participants.
- Cooperation opportunities with other projects:
    - PV market development projects and possible links with activities to sell and provide credit for PV systems for households in the same communities;
    - other PV-related capacity-building projects or

activities planned or under way; and
  - potential arrangements for inter-agency coordination and cooperation and collaboration with other projects.
- Framework issues and barriers:
  - regulations, standards, and enforcement; and
  - duties and taxes and customs practices.
- Maintenance capabilities—a specific assessment of maintenance experiences and capabilities, especially for long-term arrangements.

UPDATE RAPID ASSESSMENT DATA ON FACILITIES AND PRIORITIZE SERVICES

Information from the rapid assessment on the number and types of facilities will need to be deepened and most likely updated, as project area and sites may have changed since the provisional data was gathered. Also, by this stage, more accurate information will have been generated via the data collection and field surveys.

Oftentimes, demand ("load") assessments simply list desired uses or applications and their corresponding energy requirements. But good practice is to rank these by the priority of the services they support, with the rankings determined by sector policies and likely impacts, taking international experience into account (Table 8). It may not be cost-effective to supply certain services with PV systems. For example, it may become evident that general purpose refrigeration and even vaccine refrigeration might be better served by LPG or kerosene. And cooking, sterilization, and water heating are usually best served by traditional fuels. Prioritization decisions can be reviewed later as part of the process of bringing the overall project scope in line with budget realities.

REFINE ENERGY REQUIREMENTS AND SIZE AND CONFIGURE PV SYSTEMS

With the additional information now available from more extensive data collection on the facilities and the field surveys, a PV specialist can refine the initial energy demand estimates.

TABLE 8: EXAMPLE OF PRIORITY RANKING OF HEALTH AND ENERGY SERVICES, BY FACILITY LOCATION

Purpose/location	Service	Priority ranking (example)
Cold chain and Expanded Program on Immunization (EPI) refrigeration	Vaccine refrigeration	High
External lighting	Security lights at all main doors	High
	Security lights around buildings, front gate streetlight, outside toilet block lighting	Low
	Veranda lights	Medium
Outpatient department (OPD) lighting and appliances	Laboratory lights and appliances (list)	High
	OPD lights and medical appliances (TV, list others)	Medium
Maternity and Mother Child Health (MCH) lighting and appliances	Maternity and MCH lights	High
	Medical appliances (suction, ceiling fan, list others)	High
Office lighting, appliances, and communications	Cell phone charger, TV	High
	Office appliances (computer, printer), office lights, and ceiling fan	Medium
Operating theatre (OT) lighting and appliances	OT lights	Not applicable for this typical site
	OT appliances (list them)	Not applicable for this typical site
Ward and patient kitchen lighting and appliances	Ward lights	Medium
	Ward appliances (list them)	Low
	Kitchen lights	Low
Staff housing lighting and appliances	Staff lighting	Medium/high
	Appliances (TV, radio, ceiling fans, and cell phone charger)	Medium/high
General purpose	Water pumping	Medium
	Refrigerators	Medium
	Cooking for institution	Medium
	Sterilization	High

Source: Authors' calculations, 2010.

ENERGY DEMAND REFINEMENTS

Verify priority services. The data gathered during the surveys of typical electrified, non-electrified, and PV-electrified facilities should be reviewed to confirm the ranking of services. Good judgment is necessary to weigh the cost of using PV to provide the service against the importance of the service to a facility's mission. For example, it may have become evident that, although PV vaccine refrigerators are costly, they are critical to the clinic program, while ceiling fans are not and thus can be omitted, except in maternity wards and office buildings.

Apply a service-levels approach. For consistent calculations, guidelines should be established for the number of hours of lighting or service required per day and days per week and the required number of lights for each room type. Broad assumptions should be reviewed; for example, an approach of one light per room can result in unimportant, smaller rooms being too well lit, while more important, larger rooms are underserved. For good lighting distribution and adequate illumination, multiple lights should be considered in larger rooms. Each light (or multiple lights in one room) should be separately switched with the assumption that lights are switched off when rooms are not used and that ambient lighting is reduced when dedicated task lighting is provided. For instance, using reading lamps or medical spot lamps reduces the need for high general lighting levels, and some ceiling lamps can be switched off. This design approach applies to appliances as well.

Consider daily and seasonal demand variations. Facility load requirements, particularly for schools, may vary by day of the week and over the school year. Optimizing the system design will take these factors into account.

Use efficient lighting and appliances. Energy demand can be reduced by more than half by careful selection of efficient lights, good practice lighting design and layout, and use of efficient appliances (e.g., low-power computers and TVs), without affecting user satisfaction and outcomes. For example, replacing high-intensity background lights (usually CFLs) with low-intensity lights supported by a dedicated task light (possibly a more efficient LED light) and using reflectors for lights in rooms without ceilings (or painting the ceiling white), will save energy and improve lighting quality and effectiveness. As lighting technology has developed and become more cost-competitive, long-life LEDs and lights with automatic motion detectors have become increasingly available. An efficient lighting plan for each type of facility should be developed (Annex 2).

Allow for reasonable load growth; assume reasonable management. Load growth may or may not be desirable. For example, having lights on during evening hours allows clinics to remain opening longer and improve services that require more light hours; on the other hand, load growth may mean excessive TV viewing or cell-phone charging, possibly as a source of private income for staff. A vaccine refrigerator system should not experience load growth (though other items have been known to be stocked), while a computer system may increase energy use dramatically. It is prudent to allow for reasonable load growth of 10–20 percent for lighting and appliances in a health center or school, while also assuming reasonable management and strong enforcement of rules.

Clarify and adjust the reliability of supply standards. The cost of a PV system is sensitive to the design requirements for supply reliability, and reducing reliability levels of some services can save costs. Good design practice is to size the PV panels and batteries to meet requirements during the month of lowest solar radiation while differentiating the necessary reliability levels of the services. For example, the reliability of a vaccine refrigerator system is more critical than that of lights in a staff house; the battery for a vaccine refrigerator is typically sized to operate through five days when the sun is not shining, while batteries for lights and other services are often designed for three days of continuous cloudiness.

Impacts of demand refinements

The refinements can contribute to substantial cost reductions and increased sustainability while meeting energy demand requirements at agreed levels of service reliability. For example, during the rapid assessment stage, the demand estimate for an OPD building in a rural health center might initially provide for one light per room for four hours per day, one external light for 10 hours each night, and a computer and cooling fans for a few hours a day, resulting in a first-estimate energy demand of 3,810 Wh per day. In the detailed design stage, demand refinement steps include: (i) more efficient types of lamps; (ii) accurate calculation of light output including reduced lighting levels in non-critical areas; (iii) reduced hours of use for some services; and (iv) painting the ceiling to increase utilization and reflectivity and thereby reduce lamp wattage. The total load estimate can be reduced to 1,460 Wh per day without sacrificing quality of service, but effectively reducing the system investment cost by half (Annex 1).

System investment and operating costs are also sensitive to the reliability factors used in the design. Distinguishing between those services and energy requirements that are mission critical and those more tolerant to supply interruptions (e.g., during extended periods of heavy cloudiness) allows the PV design specialist to apply various design factors. Using reliability design factors appropriate to each case reduces investment and O&M costs. For any system, the periodic costs of battery replacement are particularly sensitive to reliability design factors.

Resource assessments: Solar radiation data

A decision that will have a significant impact on system costs is the level of solar radiation to be used as the design factor in sizing systems. Data on solar resources in the regions where the facilities are located will indicate the PSH for the worst solar month. However, while solar radiation may vary within a country and over the year, in many cases the PV design specialist can minimize seasonal and regional effects by providing for the optimal tilting of the array of solar panels. Where optimal tilting is not sufficiently effective, good practice is to use various PSH factors for each region. Although this will result in systems of various sizes for the same type of facility in different regions, it will save on overall costs and reduce both system undersizing—a main contributor to low sustainability—and oversizing, which unnecessarily increases investment and operational costs (Annex 1).

The many variations of PV sizing methods are often used in simulating options; they generally yield similar results if similar inputs are applied. Using PV simulation programs may assist with further reducing system size by using loss of power probability analysis on long-term statistical solar radiation data (e.g., 20 years of data on an hourly analysis for the specific sites under consideration). However, confidence in the design method and data quality is paramount. The PV technical specialist should state the method and data used.

"Technical" issues and trade-offs

Many design decisions are not strictly technical, as they have differential impacts on investment and recurrent costs and sustainability. The handling of these types of issues should be clearly described, and the options and trade-offs should be discussed transparently (Table 9).

TABLE 9: SYSTEM DESIGN ISSUES AND GUIDANCE

Issue	Guidance
PV panel and battery sizing. An option sometimes considered cost effective is to slightly increase the PV array size, possibly to compensate for reducing battery size, particularly as the prices of PV panels continue to decline. While slightly oversized panels might address a concern about not fully charging batteries, using slightly smaller batteries would lead to allowing a greater depth of discharge.	This can be risky as not fully charging batteries and allowing greater depth of discharge are both associated with reduced durability. Using batteries in a cycling regime outside their optimal regime can sharply reduce battery life and raise operational costs.
PV panel sizing for seasonal solar radiation. In regions with pronounced, extended rainy seasons, it may be possible to adjust load requirevments to avoid increasing size of PV panels.	Consider seasonality of demand; for example, schools may be out of session during the worst months; consider reducing wet-season loads; consider combining loads into centralized hybrid systems with a backup generator for no- or low-sun periods.
Battery choice. The choices are typically locally available, less expensive batteries versus higher-cost but longer-life, imported deep-cycle batteries. Life-cycle cost analysis points toward quality, genuine deep-cycle batteries as the first choice if the long-cycle life can be realized. However, there are compelling practical arguments for other considerations, including risks associated with substantially higher capital investments, costs of initial and replacement batteries, availability of replacement batteries, battery servicing requirements and capabilities, logistical issues for heavy batteries, quality assurance, and battery disposal.	Interesting options include: (i) installing quality, 8-year deep-cycle batteries and then replacing those in systems that are still operational; or (ii) installing lower-quality batteries initially and then upgrading with better ones later in successful PV systems, while ensuring that the charge controller is suitable for multiple battery types (see www.iea-pvps.org/products/download/rep3_06.pdf).
Engineering design margins. A good practice—though not always followed as it increases costs—is to include margins for temperature effects, component degradation over time, and other causes of losses in the performance and lifetime of components and systems.	Omitting engineering margins in the urgent rush to design minimally-sized and lowest-cost PV systems will compromise system reliability and ultimately increase life-cycle costs.
Lightning protection. Comprehensive lightning protection is often recommended for all systems in lightning-prone areas.	Lightning protection is necessary for essential systems and those 300 Wp and larger. Lightning risk should be assessed based on statistical lightning strike data or local information.
Technical standards. Good practice is to require that PV system components meet international standards and to send clear requirements for documentation of compliance. But there may be local commercial interests or policy objectives in favor of using local standards. Also, local capacities for enforcement of equipment standards and testing may not be adequate.	There should be little, if any, compromise on standards for the main components. It would be a mistake to bend to local commercial interests or industry policy objectives. Procedures for accepting certifications of equipment conforming to specifications and any local testing should be practicable and based on independent assessment of local capabilities.

TABLE 9: SYSTEM DESIGN ISSUES AND GUIDANCE (CONTINUED)	
Issue	**Guidance**
AC system, DC system, or both. DC systems are 10–15 percent more efficient and cost less than AC ones. But they are limited to small, stand-alone PV systems for small buildings, and availability of DC appliances may be limited.	AC systems allow greater flexibility in choice of appliance and can be easier to install. Combined AC/DC systems may be optimal in some cases. Centralized PV systems for multiple buildings must have a higher voltage (110 or 220-V) AC to avoid losses and keep system sizes relatively small.
Whether to include supply of appliances. Where efficient appliances are not readily available, especially DC ones, they may be included as part of the PV supply contract.	Consider separate supply contracts for any appliances. PV equipment suppliers rarely have capabilities to support appliances after installation.
Whether to include PV systems for staff housing. Some organizations provide PV systems for staff housing, while others do not, although the latter may support subsidies or credit to facilitate staff purchases of systems. In some cases, providing PV systems for staff residences will be considered essential for staff recruitment and retention in remote communities.	If systems are to be installed in staff housing, then prior to installation, settle issues of ownership, contributions to capital and/or operational costs, and responsibilities for repairs and replacement of lights and components. For example, staff can reduce their spending on kerosene and dry-cell batteries. Design decisions will include whether to provide AC or DC systems. Practices vary by country and program; for example, the Uganda ERT project provides health staff 100-Wp AC systems, while a similar project in Ethiopia provides 40-Wp DC systems.

Source: Authors' calculations, 2010.

CONSTRUCT COST ESTIMATES AND FINE-TUNE LEAST-COST OPTION

A simple spreadsheet model can be used to readily and easily understand the investment and operational costs of the various technical and organizational options being considered as the design moves through multiple iterations.

With data from the market assessments and reviews of recent procurements, the full cost-to-serve estimates for the systems can be constructed using up-to-date unit costs for components, shipping, local taxes and handling, installation, and logistics, maintenance, and component replacements (Table 10). The supply estimates should take into account local prices, as well as international trends, particularly the declining supply cost curve for PV panels.

In estimating the costs in anticipation of entering into a contract with a supplier, a provision should be included for a minimum supply of spare parts. The annual costs of system maintenance, including the periodic replacement of batteries, should also be thought through thoroughly.

The least cost curves used in the rapid assessment can now be fine-tuned if necessary and confirmed with the additional information gathered on diesel pricing in rural areas, grid extension costs and electricity tariffs, and the solar resource. These analyses can be easily done by a PV specialist using engineering design software or the web-based software of RETScreen (www.retscreen.net/) and HOMER (www.homerenergy.com). If not used in initial preparation, these programs are useful as a due-diligence cross-check of both technical design and costs.

DECIDE ON IMPLEMENTATION MODEL AND INSTITUTIONAL AND TECHNICAL DETAILS

The information collected during the institutional and market assessments, including past experiences with PV for community facilities, should be carefully reviewed before settling on an implementation model. Regardless of the capacities, weaknesses, or opportunities that the data may suggest, the reality is that the choice of implementation model for providing PV systems for community facilities is largely determined by the policies and procedures of the lead implementing organization (e.g., health ministry, energy ministry, social investment fund, local government, or rural electrification agency) and the funder, although these may be negotiated if multiple organizations are participating. Within social-sector programs, the provision of PV systems is typically an activity or component within a larger project (e.g., lowering maternal mortality, raising primary-school enrollment, or responding to community-driven infrastructure requests). In such cases, the basic pattern of responsibilities and inter-organizational relations is rarely driven by the activity for the supply of PV systems.

That said, the implementation model options introduced during the rapid assessment should now be carefully considered (Table 7), taking into account the market, developing opportunities (e.g., Clean Development Mechanism financing [Box 6]), and institutional information and understanding that have been developed.

TABLE 10: ILLUSTRATIVE EXAMPLE OF COST ESTIMATES, 250 WP SYSTEM

	PV System Investment					Lifetime Costs (present value)	
Component	**Life**	**Unit cost**	**Capacity**	**Cost (US$)**	**Share (%)**	**Total cost (US$)**	**Share (%)**
Panel Wp	25	5	250	1,250	34.9	1,250	17.7
Battery (12V) Ah	7	2.8	309	866	24.2	2,096	29.7
Inverter	8	200	each	200	5.6	404	5.7
Controller	8	175	each	175	4.9	354	5.0
Lightning protector	7	220	each	220	6.1	441	6.3
Subtotal				**2,711**		**4,546**	
Other equipment	25	10%		271	7.6	271	3.8
Equipment cost				2,983		4,817	
Shipping		5%		149		149	
Install, local transport	25	10%	each	298	8.3	298	4.2
Other startup	25	5%	each	149	4.2	149	2.1
PV system cost				3,579		5,413	
O&M (per year)		4%	(as % system cost)			1,642	23.3
Total cost				**3,579**		**7,055**	
Discount rate	6%				Investment $/Wp	14	
Years	20				LCOE, $/kWh	2.14	
Maximum discharge	70%				Investment as % total LCOE	51%	
Days of autonomy	3				Annualized total cost PMT	615	
PSH	5				Annualized O&M plus replacements cost PMT	303	

Source: Authors' calculations, 2010.

BOX 6: CLEAN DEVELOPMENT MECHANISM

Established under the Kyoto Protocol, the Clean Development Mechanism (CDM) allows one certified emission reduction (CER) credit to be earned for each equivalent ton of carbon dioxide (CO_2) reduced. The CERs are marketable. Projects qualify through a rigorous process of verifying emissions reductions that are additional to what would otherwise have occurred without the project. There has been interest in leveraging CDM financing for off-grid solar PV projects, mainly for solar home systems (SHS) and lanterns that avoid CO_2 emissions, mainly from kerosene lanterns; a project in Bangladesh is the most advanced in pioneering the process of securing financing.

The difficulties of attaining CDM financing for off-grid solar PV are many, mostly linked to the small amounts of CO_2 avoided at each location and the sheer complexity of the scheme. Arranging CDM financing, which in any event would not be available until several years after system installation, is a specialized activity. Any organization preparing a program of activities under the recently available programmatic CDM methods might be interested in including a project for PV systems for community facilities. These opportunities are expected to become more frequent as experience is gained, although the small CO_2 size of off-grid PV projects would limit the interest of any CDM credit purchaser.

Source: Authors' observations, 2010.

Choice: sector or area-based implementation?

A key choice is whether to base implementation on sectors or areas. This issue will have been raised during the rapid assessment, but it should be revisited at this stage, taking into account the more detailed institutional and market assessments conducted. For many sector ministries (e.g., health, education, or water), the sector-based approach is an instinctive choice. But other approaches might enhance the possibilities for system sustainability. An area-based approach combining PV systems for multiple facilities across sectors (e.g., schools, clinics, community centers, and public lighting) in defined communities offers, in principle, logistics and cost advantages, particularly during installation and later operation, maintenance, and supervision. This approach is a natural fit for a rural electrification agency, ministry of energy, or other organization with a rural electrification mission and the capacity to successfully handle the coordination complexities of dealing with multiple organizations having varying schedules, budgets, and perspectives.

Choice: link with market development?

A strictly supply and install, and possibly maintenance, contract based approach, whether for facilities in a single sector or area-based, is often preferred by government organizations. Standard bidding documents and procedures are available, and the process is well-established. However, social-sector ministries or similar organizations often will not have adequate PV-specific capacities. Also, most energy-sector organizations, such as energy ministries or rural electrification agencies, do PV procurements only infrequently, so that their procurement and other officials seldom have significant experience with the issues specific to PV procurement. One result is that that, even when using standard bidding documents, the procurement process can be lengthy or otherwise problematic. More importantly for longer-term sustainability, this approach has frequently had the disadvantages associated with organizational silos, with the agency implementing the procurement not benefiting from the advances and capacities of other organizations and projects within the same sphere.

Bundling market development activities and targets in a supply and install contract may at first appear as a more complicated way to provide PV systems for community facilities. But it might also be more viable, depending on the current strengths of the private sector and the state of market development and, on the other hand, the effectiveness of any market-development activities and the strengths of the government agencies and private organizations managing them, whether these activities are already underway or new ones that would be supported by the same or a separate project. Depending on the local context, an approach that linked the supply and installation of PV systems in community facilities to developing the PV market in the same communities may offer opportunities for strengthening after-sales services that would reinforce the longer-term sustainability of the systems in community facilities as well as in households. There may also be opportunities to use market methods to indirectly improve facility services. For example, schools could offer rental lighting programs to provide low-cost, portable lights with high-efficiency LED lights that students could use at home for evening study (as will be done in the Tanzania SSMP). Or a credit-based mechanism could be used to provide PV systems for staff housing, with the staff eventually becoming the system owners, with responsibility for system maintenance and security.

Choice: contract maintenance or do it in-house?

Uninterrupted, long-term maintenance is the vital requirement for system sustainability.

The basic maintenance options are: i) contracted maintenance, as is often done by private entities for remote facilities; or ii) in-house arrangements, possibly with community participation. The optimal approach and the determination of who is best able to do the maintenance will be location specific, depending as much on the policies and practices of the lead organization and future owners of the systems as on the capabilities of the various actors and the requirements of sustained maintenance. The matter should be addressed openly in the context of assessments of organizational track records and broader capacities and constraints related to both in-house and contracted maintenance.

The choice of maintenance approach is likely the single most important decision during project development. The factors to consider in making this decision and the details of the maintenance requirements are discussed in depth in Part 5.

The PV implementation plan is not complete until maintenance plans have been prepared for both the project and post-project periods. These plans should have the solid concurrence of the stakeholders that will be responsible for funding and managing post-project maintenance, including component replacements (Part 5).

RESULT: PV IMPLEMENTATION PLAN

The result of the preparation phase is the PV implementation plan (Box 7).

BOX 7: INDICATIVE TEMPLATE FOR PV IMPLEMENTATION PLAN

Introduction, objectives

- Main aims and goals.
- Sector or cross-sector program linkages.
- Key success indicators.

Project description

- Types, numbers, locations of facilities, and services.
- Energy requirements and solar resources.
- Description of PV systems (detailed sizing, standards, and designs in annexes).
- If part of a market development project, market targets and project mechanisms.

Implementation arrangements for project and post-project periods

- Implementation model description for project and post-project operation.
- Organizational responsibilities: lead and coordination; procurement; rollout of equipment supply, installations, and acceptances; capacity building; post-installation.
- Linkages with other organizations and projects.
- Maintenance plans for project and post-project periods: ownership, financing, maintenance practices and responsibilities, component replacements, tracking of system maintenance and performance.
- Reporting and monitoring and evaluation.

Project activities and procurement plan

- Supply and installation of systems:
    - Preparation of procurement packages.
    - Information and promotion activities.
    - Procurement and tender evaluation.
    - Equipment: certifications, tests, and verifications of conformance.
    - Post-award updating, due diligence on facilities, sites, and requirements.
    - Installations: verifications and inspections.
- Development of post-installation maintenance and management.
- Liaison and workshops (presentation of PV packages, information to staff, communities, and awareness raising and consultations with staff and communities).
- Capacity building plan, technical assistance for capacity building, and terms of reference included as annexes.
- Implementation/supervision support and evaluation; terms of reference included as annexes.

Budgets and financing

- All implementation costs and financing: supply, installation, maintenance and recurrent costs, including component replacements (with confirmed commitments to meet these costs included as annexes) with breakdowns by region, lots, and entity.
- Capacity building and technical assistance.
- Subsidies from other organizations or projects, or from CDM, if applicable.
- Disbursements and provisional cash flow.

Schedule

- Provisional project schedule.

Source: Authors' calculations, 2010.

Part 4. **Procurements and Contract Management**

The procurement and implementation project phase requires a viable strategy for off-grid PV procurement and PV contracts and having certain conditions in place for contract management and rollout and longer-term supervision. This section covers the range of elements needed in each of these several areas that are vital to project effectiveness and overall success.

VIABLE STRATEGY FOR OFF-GRID PV PROCUREMENT

Many off-grid PV projects flounder at the procurement stage. Or delays and blunders during the procurement process set the stage for subsequent low system sustainability. Table 11 highlights the PV procurement problems frequently encountered and actions to avoid them.

TABLE 11: HOW TO AVOID COMMON PV PROCUREMENT PROBLEMS

Problem	Guidance
Too few qualified bidders and high prices, associated with: • Limited, late promotion; information not widely distributed. • Small size of contracts: No certainty on future flow of contracts reduces interest of potential bidders, particularly large foreign suppliers, most of which have limited interest in off-grid market. • Perceived high risk of non-eligibility of PV system equipment, limited capacities to prepare bids and other barriers versus costs of bid preparation deters bidders, particularly local bidders. • Bidders lack knowledge of remote project communities. • Concerns about delays and possible costs for processing approvals may deter bidders or lead to high prices.	Publicize the proposed specifications early and often beyond traditional sites via the UNDB and local newspapers; network and promote widely. Strategically phase and time procurements. Make reasonable lot sizes. Use qualified, independent PV professionals for technical design and supervision. Conduct pre-procurement capacity building to strengthen pool of potential bidders, consulting closely with procurement specialist to ensure that activity is handled appropriately.
Poor-quality equipment and installations, associated with: • Not using international standards; unclear process for determining acceptability of alternative standards proposed by the bidder. • Unclear or inconsistent specifications. • Difficulties confirming that equipment and installations meet technical requirements; lack of accredited local facilities to test components; expensive and time-consuming pre-shipment testing by contracted laboratory; difficulties in determining which laboratories are accredited to perform required certification. • Unclear process for acceptance of certifications and installations.	Specify international standards. Use detailed specifications for equipment and installations. Use modular/standardized system packages. Set stringent requirements for documenting that equipment conforms to specifications. Allow multiple opportunities to establish equipment eligibility. Establish clear process for accepting certifications and installations with standard commissioning checklist and forms.
Poor performance by winning firm, associated with: • Changed on-the-ground conditions. • Unforeseen logistical issues. • Poor, rushed installations, often subcontracted on a unit basis. • Rushed capacity building and training. • Lack of quality assurance by contractor • Late, inadequate supervision of installations and maintenance in remote locations by implementing agency.	Facilitate post-award contract modifications based on changed conditions. Require that contractor-assurance procedures be agreed to by implementing agency. Provide strong supervision with professional technical support for installations and maintenance. Secure funding for maintenance; hand over systems to intended owners.

Source: Authors' calculations, 2010.

Choice of procurement method and process

There are several types of Standard Bidding Documents (SBD) from which to choose. For most off-grid PV systems for community facilities, the **SBD for Procurement of Goods** is appropriate. The **SBD for Procurement of Plant** could also be considered, as the major cost element is equipment handed over and accepted only after commissioning. However, the SBD for Plant is intended for larger, more complex technology projects with significant design tasks. For smaller contracts, the **Procurement of Works** may be suitable. The experience of tender officials and PV suppliers with the SBD for Procurement of Goods may be an advantage (Table 12).

International Competitive Bidding (ICB) is used, given the wide potential interest and supply capabilities of PV contracts in multiple countries and that, in most cases, PV panels and other major components will be imported. Most likely, there is no bidder prequalification. The SBD for Procurement of Goods, unlike those for plant and works, is not intended for bidder prequalification, although pre-qualification was used for the Tanzania SSMP procurement in 2009–10. Without prequalification, some potential credible bidders could be deterred by the high costs of preparing bids (particularly for installations and related services in remote off-grid communities), especially if they are concerned that firms lacking sound capability would underbid to win the contract. This possibility increases the need to generate bidder interest with sufficient advance publicity and information and reduce any perception of risk by establishing clear criteria for post-qualification.

For innovative projects, such as the initial SSMP in a country, it will be important to provide adequate time (at least three months) for the **Clarification Process and Pre-bid Conference.** A bidders conference, conducted in the field in a representative community, can be an effective way to provide vital information about sites, distances and logistics, and organizational and environmental conditions.

Promotion and publicity

Timely publicity increases awareness and provides an opportunity for smaller, usually local PV firms that may not be individually qualified to form joint ventures. Promotion should begin well before and extend beyond publication of mandatory procurement notices in the UNDB online, Development Gateway's dgMarket, and official gazettes. Publicity teasers can be posted on official websites and widely circulated as done under the Bolivia Decentralized Energy, Information, and Communications Technology for Rural Transformation Project and the Philippines Rural Power Project (Annex 5). Targeted promotion of off-grid PV contracts covering local, regional, and international renewable and solar energy networks can also widen the circle of potential bidders. There is no restriction on the advance circulation of draft technical specifications and promotional information on the project concept, areas, and timetable.

Phasing and scheduling

For large projects, phasing procurements, say every 3–6 months, will accommodate the capacities of smaller, often local firms. In many cases, phasing will also permit a good fit with the capacities of the implementing agency to manage the tender and supervise implementation in multiple remote locations. Phasing also gives project managers the opportunity to steadily modify and improve procurement details and align them with cumulative implementation experience and lessons learned. Procurements should be timed with an eye to the weather, local holiday seasons, and business practices. In many countries, it is advisable to avoid scheduling field visits for bidders conferences during intense rainy seasons or tender openings in early December or closings in early January (Table 13).

Bidder criteria

To implement PV contracts for community facilities, bidders must meet specific criteria, which should work as an effective filter for deciding on their qualifications (Table 14).

TABLE 12: CHOICE OF STANDARD BIDDING DOCUMENTS

SBD type	Revision date	Appropriate use
Procurement of Goods	May 2004, May 2005, September 2006, May 2007, and May 2010	Supply and installation of PV components and systems; not immediately suitable for maintenance contracts. Could be modified.
Procurement of Plant: design, supply, and installation	April 2008	Industrial plant with a significant design component; supply and installation of PV systems. Could be modified to include maintenance. In 2008, a version was prepared for Zambia MOF PV procurement.
Procurement of Works: smaller contracts	May 2008	Could be modified for use in extended maintenance contracts using national competitive bidding (e.g., Uganda, 2006).

Source: Index of Standard Bidding and Proposal Documents, World Bank, November 2010.
http://go.worldbank.org/HNBJA3S38

TABLE 13: TIMELINE FOR SYSTEM AND INSTALLATION PROCUREMENT ANTICIPATING SEASONAL CHANGES					
Task	**Period**	**Assumption**	**Completion (months from start)**	**Completion Date**	**Season**
Procurement packages completed				Oct. 1, 2009	
No-objection to procurement packages	3 weeks from submission	best assumption	0.8	Oct. 23, 2009	
Tender advertisements	1 week from no-objection		1.0	Oct. 31, 2009	
Tender issue	1 week from tender advertisement		1.3	Nov. 7, 2009	Wet
Tender period/closing	10 weeks from tender issue	minimum period	3.8	Jan. 21, 2010	Wet
Tender evaluation report	3 weeks from tender closing	reasonable assumption	4.5	Feb. 13, 2010	Wet
No-objection to tender evaluation report	3 weeks from submission of evaluation report	best assumption	5.3	March 7, 2010	Wet
Contract signature	2 weeks from no-objection	best assumption	5.8	March 22, 2010	Wet
Arrival of blueprint equipment	3 months from contract signature	as per contract	8.8	June 20, 2010	Dry
Installation of blueprint equipment	1 month from arrival of blueprint equipment	as per contract	9.8	July 20, 2010	Dry
Arrival of balance of equipment	6 months from contract signature	no equipment problems at blueprint stage	11.8	Sept. 18, 2010	Dry
Installation	4.2 months after arrival of balance of equipment	*	15.9	Jan. 21, 2011	Wet
Commissioning	2 months	running concurrently and ending after installation	16.9	Feb. 20, 2011	Wet

Source: Authors' observations, 2010.

* Installation assumptions: 100 sites, 2 contractors, 3 teams per contractor, and 4 sites per month per team (based on prior history).

Concise and unambiguous criteria and forms should be included in the bid document package to reduce the risk that a bidder submits, wins, and is subsequently found not qualified. Of course, due diligence is done on the data and references provided by the winning bidder prior to contract award.

The bidder and key personnel should be required to list successful project experience in recent supply and installation (and perhaps maintenance) of PV systems in off-grid rural facilities in similar countries (e.g., the firm has supplied and installed a minimum of 200 PV systems in at least 100 community facilities under a minimum of three contracts within the last three years). Vaguely worded experience requirements, or ones referring to more general experience in supplying electrical goods, electrification, or even rural electrification are inadequate. There should be no hesitation in insisting on experience that is relevant, current, and successful.

The bidder should have sufficient financial capacity to handle project cash flow per lot. One aim is to avoid a supplier being unable to complete the contract because of financing constraints. Minimum requirements would demonstrate adequate cash flow (e.g., cash on hand and revolving credits or bank guarantees equivalent to at least four months of operations) and soundness (e.g., having annual turnover not less than the two previous years of no less than two times the annual expected disbursements under the contract). Depending on the case, flexibility may be needed in defining ways to demonstrate the necessary financial capacity, taking into account the potential pool of bidders, contract size, and implementation context.

The implementation plan will include personnel (including CVs and qualifications), schedule of vehicles, tools and equipment used for installations [and whether these must be procured], subcontractors and their qualifications, timetables for inception report, delivery and installation in the communities, capacity building, maintenance and other services). Taken together, these should form a whole that is practicable and capable of meeting the contract requirements on schedule. Bidder qualification is always conducted on a pass/fail basis; however, it is prudent to be demanding when deciding on whether a plan is acceptable. Many contracts for PV for off-grid communities run into problems that could easily be avoided by closely reviewing and adjusting the implementation plan or selecting another bidder. During the examination, evaluation, and post-qualification of bids, it is possible to seek clarification from the bidder on the plan, although no changes in the price or substance are permitted.

<table>
<tr><th colspan="2">TABLE 14: CHECKLIST FOR BID EVALUATION</th></tr>
<tr><th>Item</th><th>Approach/Criteria</th></tr>
<tr><td>Preliminary evaluation
• Tender documents complete, supporting documents and brochures.
• Statement of compliance provided, bid validity periods, bid bonds provided.</td><td>Usually conducted on a strictly pass/fail basis.</td></tr>
<tr><td>Price checks
• Price correction and unconditional discounts (price).
• Currency conversions (price).
• Additions adjustments and price deviations (price).
• Domestic preference (price), if any.
• See also evaluation criteria for other price adjustments allowed.</td><td>Price adjustments made strictly according to SBD guidelines and evaluation criteria.</td></tr>
<tr><td>Post qualification

• Compliance of bidders with financial pre/post qualification requirements and experience.
• Compliance with project time schedules.
• Technical compliance with sizing and completeness of equipment (provide table for major and minor equipment).
• Certifications of equipment offered (provide table for each major and minor component).
• Manufacturer certificates.
• Capacity to implement (analysis of implementation plan provided).</td><td>Pass/fail, however, some aspects require judgment, and certain changes can be requested without price adjustment.
• Pass/fail, with adjustments to suitability to be awarded multiple lots should conditions warrant.
• Pass/fail, however, evaluation criteria may allow alternative schedules, making this negotiable.
• Whether each major equipment item is provided and meets required sizes is conducted on a pass/fail basis; if a general statement of compliance has been made, however, changes to ensure fully compliant equipment may be requested without any cost implication.
• Pass/fail, depending on certifications or request of further information. If a general statement of compliance has been made, then changes to ensure fully compliant equipment may be requested without any cost implication.
• Pass/fail, or submission of these may be requested from preferred bidders prior to “fail.”
• Pass/fail.</td></tr>
<tr><td>Other
• Projected O&M costs based on equipment offered, annual costs, and annual component replacement.</td><td>• For each system and for each sector or area-based lot, depending on who is responsible for maintenance and operational costs.</td></tr>
<tr><td>Recommendations
• Bid award proposal.
• Award of multiple lots.
• Further checks to be undertaken on recommended supplier, based on declaration of technical compliance (e.g., additional equipment certifications, manufacturer certificates, equipment exchanges required, battery suitability and adjustments).</td><td>Note: PV engineer will have re-checked that the components offered when operated as a system meet performance requirements; any further equipment changes required as a result will form part of contract negotiations.</td></tr>
</table>

Source: Authors’ observations, 2010.

During tender adjudication and contract negotiations, a PV engineer should assess and confirm that the components offered meet all performance requirements when analyzed as a system. For example, battery compliance can be a major concern. An assessment of the battery type and its cycle life, given the expected daily depth of discharge, should be based on the batteries offered. While it may not be possible to choose an alternate battery type, battery sizes could be adjusted upward to achieve the designed battery life.

Contract negotiations

Contract negotiations, undertaken with the preferred bidder, clarify outstanding issues (Box 8). At this stage, the purchaser may request equipment changes without any price modification, provided that the bidder is already compliant or has stated compliance. The purchaser may also request changes in the implementation plan (e.g., organization, personnel, scheduling, and logistics) to make it feasible. Any changes in scope that have arisen may be included at this stage.

ELEMENTS OF VIABLE PV CONTRACTS

The PV contract involves: (i) equipment supply and delivery; (ii) equipment installation and commissioning; (iii) maintenance (at least initially); and/or (iv) other related services (Table 15).

The complete bid packages for the Uganda ERT and Tanzania SSMP are provided as examples of recent projects that incorporate many good practices (Annex 6). Also provided is an updated example of a model bid package, based on the 2009 Mozambique ERAP.

BOX 8: ITEMS INCLUDED IN CONTRACT NEGOTIATIONS

Certification of major equipment
- Clarify outstanding issues and items.
- Get overall signed Declaration of Compliance, if not already provided.

Equipment samples for approval
- Get airfreight samples, as necessary, to expedite approvals and ordering; these include CFLs, light fittings and reflectors, medical lamps, reading lamps, inverters, battery enclosures, battery fuses, lightning surge arrestors, and other equipment.

System technical reviews
- Check system sizing offered and drawings; check component matching.
- Make corrections to components, and, if needed, propose changes to standardize equipment.
- Add lightning protection to new specification and as per new drawings (at cost).

Schedule of price variations (if not already included in contract price schedules); obtain for:
- Cabling between buildings (per meter).
- Cabling strain relief ends (supply and install per pair).
- Lamp and switch (supply and install).
- Distribution board (supply and install with main 2-pole CB and 2 x 1-pole CB).
- Lightning protection (supply and install).

Schedule of equipment delivery; obtain for:
- Blueprint equipment and installation.
- Major equipment for main rollout.

Installation program
- Get blueprint schedule and confirm site selection.
- Obtain main rollout plan, including number of teams, supervision, and detailed rollout program per team.

Revised handover and payment proposal
- Confirm practical completion and provisional acceptance stages (with minor snags) with supervision consultant, and confirm payment amount.
- Confirm final acceptance stage requirements, confirm payment amount.

Supervision of responsibilities (may be role of Supervision Consultant)
- Supervise site visits and due diligence.
- Reallocate sites that do not meet PV electrification criteria (e.g., too close to grid).
- Reallocate packages among sites (if numbers of buildings at site do not meet standards).
- Allocate additional lights per package to meet lighting design requirements, with at least one light per room and passage.
- Cable between buildings, with additional DBs.
- Determine array and battery locations in each building.
- Instruct contractor on all of the above items.
- Change order and check pricing based on the variation price schedules provided.

Source: Authors' observations, 2010.

TABLE 15: TECHNICAL REQUIREMENTS OF PV CONTRACT COMPONENTS		
Subject	**Output**	**Comment**
Reasonable lot sizes; cost estimates	Scheduling and phasing, lot sizes, and price schedules.	
PV system packages	System components, standards, specifications, and certifications.	Certificates required; challenge is to vet and confirm certifications of conformance.
Locations of sites and facilities for system installations	Summary table of systems and locations.	Provide as much site information as possible, including map, transport facilities, and major towns.
Delivery, installations, and practical completion	Delivery schedule and key milestones; how and when equipment is to be delivered, usually CIP site of installation within specified time frames.	Samples required; pilot installations recommended to "blueprint" the acceptable quality of workmanship, within 30–120 days of contract award.
Commissioning and acceptance and system handover	Procedure for supplier to request commissioning, when acceptance and handover occurs, and when warranties become effective.	On-site security; specify when risk passes to the purchaser; internal quality assurance of supplier.
Documentation and training	Responsibilities of the contractor outlined in user manual and technical manuals.	Lines of reporting to be specifically included in user manual.
Other related services	May include inception report with due diligence, capacity building, supplier's internal quality control, initial system maintenance, and performance tracking.	
Payments structure, warranties, and guarantees	Component warranties, and one-year defects period on quality of workmanship. Minimum failures per year, time to repair, etc.	Local point-of-presence requirements.
	Payment schedule and financial securities must provide incentives for on-time, complete, and satisfactory implementation.	Liquidated damages and holdback or retention monies are important elements.
Reporting and communication channels (inception report and post-award modifications)	A schedule of variation prices for key components may be required to facilitate change orders.	Changes in sites, facilities, and configurations may be made due to changed on-the-ground conditions.
Maintenance and performance tracking	If a maintenance contract is included, this is specified separately in the schedules.	Fully describe maintenance responsibilities. Must include process for maintaining good records of systems, maintenance schedule/ performance and repair history. Must also include means for reporting problems/failures to contractor and implementing agency.

Source: Authors' calculations, 2010.

Reasonable lot sizes and cost estimates

Large tenders might attract the attention of large companies with the requisite financial capacity. However, few if any major international PV companies have significant interest in bidding for contracts in off-grid areas; most focus almost exclusively on the large and rapidly growing grid-connected market. At the same time, smaller local companies with off-grid capabilities and bidding interest often lack the financial capabilities to qualify. A common scenario is that a large firm with adequate financial capability but minimal off-grid PV experience wins the contract, handles component sourcing and system integration, and subcontracts installations and maintenance to local firms. In many cases, a third tier of independent contractors is assigned the actual installations. Internal quality assurance by the supplier can be tenuous.

Good practice is usually to construct tenders of significant size composed of multiple area-based lots (slices) so that bidders can qualify for one or more lots. The lots should be spatially optimized for implementation and maintenance.

Cost estimates, including detailed pricing and component analysis, will already have been done during the rapid assessment and implementation-plan preparation phases. At the stage of preparing the bid document, these estimates should be revalidated, taking into account any recent comparative international procurements and changes in local conditions. The estimates are based on the supply and transport of the systems to the location (CIP) and related services (e.g., inception report, installation, commissioning, establishment of local-service capacities and after-sales services, maintenance services, record keeping and reporting, and capacity building).

The standard price-schedule forms in the SBD models are not optimized for rural PV projects. But the forms can be modified and others added as desired; suggested modifications are included in the sample bid packages (Annex 6). Reflecting their importance as major factors in system success or failure and to facilitate contract management, specific schedules with detailed costs of related services should be included.

PV system packages: modular/standardized components

The number of system types and sizes should be limited (e.g., for primary schools, models S-1, S-2, and S-3 would be in line with categorizations by responsible ministries). This will facilitate bid preparation by suppliers and ease bid evaluations. Some ministries have standardized their building designs and the equipment supplied to their facilities, which has made system standardization easier.

Components should be standardized as much as possible. For example, bidders could be required to use a limited number of panel, charge controller, inverter, and battery sizes across all facilities to facilitate interchangeability and lower the costs of installations, training, maintenance services, stocking of spares and component replacements, and supervision.

International standards. International or equivalent standards should be used for the main system components (i.e., panels, batteries, controllers, inverters, and energy-saving lights) (Table 16). This will strengthen the bidding document by reducing uncertainties for both bidders and evaluators and reduce the risk of supplying substandard equipment. The leader in standards development for PV and the balance of system components is the International Electrotechnical Commission (IEC), which is representative of the committees and working groups of standards agencies from most manufacturing countries. (A full list of country standards agencies is available at www.worldwidestandards.com.) Reference is also made to PVGAP certification, which now also falls under IEC (www.iecee.ch). However, as very few products bear the PVGAP mark and seal (only a few models), this requirement is largely ineffective in practice.

TABLE 16: GUIDANCE ON INTERNATIONAL STANDARDS FOR OFF-GRID PV SYSTEM COMPONENTS

System Component	Equipment Standards and Guidance
Panels Use IEC standards	• IEC 61215 Ed. 2.0: Crystalline silicon terrestrial photovoltaic modules - Design qualification and type approval. • IEC 61646 Ed. 1.0: Thin-film terrestrial photovoltaic modules - Design qualification and type approval.
Batteries Use IEC standards and reference performance requirements to these standards	• IEC 61427 Ed. 1.0 b: Secondary cells and batteries for solar photovoltaic energy systems - General requirements and methods of test. • IEC 60896-11: (including amendments 1 and 2): Stationary lead-acid batteries - General requirements and methods of test. Part 1: Vented types. • IEC 60896-22: Stationary lead-acid batteries - General requirements and test methods. Part 2: Valve-regulated types. • PV GAP, PVRS 5A "Lead-acid batteries for solar photovoltaic energy systems— General requirements and methods of test for modified automotive batteries."
Charge Controllers Use IEC standards to define performance	• IEC 62509 Ed.1: Performance and functioning of photovoltaic battery charge controllers. • IEC 62109 : Safety of power converters for use in photovoltaic power systems. Part 1: General requirements, Part 3: Controllers. • IEC 62093 Ed. 1.0: BOS components - Environmental reliability testing - Design qualification and type approval. • IEC CISPR 11:1990, Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment. • IEC 61000-4:1995, Electromagnetic compatibility (EMC). Part 4: Testing and measurement techniques, Sections 2-5. • PV GAP, PVRS6A "Charge controllers for photovoltaic stand-alone systems with a nominal voltage below 50V" accepted for use in the IECEE PV scheme.

TABLE 16: GUIDANCE ON INTERNATIONAL STANDARDS FOR OFF-GRID PV SYSTEM COMPONENTS (CONTINUED)	
System Component	**Equipment Standards and Guidance**
Inverters Use IEC standards as reference to define performance	• IEC 61683 Ed. 2.0: Photovoltaic systems - Power conditioners - Procedure for measuring efficiency. • IEC 62109: Safety of power converters for use in photovoltaic power systems. Part 1: General requirements. Part 2: Particular requirements for inverters. • IEC 62093 Ed. 1.0: BOS components - Environmental reliability testing - Design qualification and type approval. • IEC CISPR 11: 1990, Limits and methods of measurement of electromagnetic disturbance characteristics of industrial, scientific and medical (ISM) radio-frequency equipment. • IEC 61000-4: 1995, Electromagnetic compatibility (EMC). Part 4: Testing and measurement techniques, Sections 2-5. • PV GAP, PVRS 8A "Inverters for photovoltaic stand-alone systems."
PV vaccine refrigerators	Valid certification for vaccine refrigerators are WHO performance standards: WHO/PQS/E03 (refrigerators and freezers for storing vaccines). Note: Since promulgation of these new PQS standards, few suppliers have re-tested refrigerators, and certifications prior to WHO/PIS/E3 apparently no longer apply.
Pumps Use IEC standards to define pump system performance downstream of solar array	• IEC 62253 Ed.1: Photovoltaic pumping systems - Design qualification and performance measurements. • IEC 61702 Ed. 1.0: Rating of direct coupled photovoltaic pumping systems.
Other specialized equipment	Equipment may be tested for compliance against specifications at local testing facility, such as a standards bureau.
Energy-efficient lights Use IEC standards to define performance standards for AC and DC lights	Accept Efficient Lighting Initiative standards (www.efficientlighting.net). PV GAP, PVRS7A "Lighting systems with fluorescent lamps for photovoltaic stand-alone systems with a nominal voltage below 24 V." • IEC 60969 Ed 2: Self ballasted lamps for general lighting purposes - Performance Requirements. • IEC 61347-1: 2007, Lamp control gear. Part 1: General and safety requirements. • IEC 61347-2: Lamp control gear. Part 3: Particular requirements for AC-supplied electronic ballasts for fluorescent lamps, Part 4: Particular requirements for DC-supplied electronic ballasts for general lighting.
Balance of system components and minor equipment (battery and other enclosures, array structures, switches, cabling and wiring, breakers, and fuses and fuseholders)	International standards should apply to electrical components, such as fuses and fuseholders, breakers and cabling. However, local equipment standards will often be used. Certification is preferred. At a minimum, a declaration of compliance with the standards below is needed. Consider those with certificates from independent testing laboratories confirming that performance complies with specifications in the bid document. For example: • IEC 60669-1: Switches for household and similar fixed-electrical installations. Part 1: General requirements. • IEC 60227-1-4: Polyvinyl chloride insulated cables of rated voltage up to and including 450 V/750 V-Parts 1-4: General requirements. For battery enclosure and array structure, require declaration of compliance with the specifications and drawings and provision of detailed drawings. After contract award, samples may be requested and tested at a local testing facility before acceptance. Inspect again for compliance at the blueprint stage. Consider those confirmed as having performed satisfactorily in analogous contexts in World Bank-assisted projects.

Source: Authors' calculations, 2010.

If national standards are also used, equipment certified as conforming to these standards must be identified and the bidders informed. Many national PV standards will be early versions or adaptations (with or without modification) of IEC standards; thus, the international standards are strongly preferred. In certain cases and countries, IEC standards are adopted without amendment. The following standards for crystalline silicon PV modules are substantially the same: IEC 61215: 2005, BS EN 61215: 2005, and DIN EN 61215:2005. As stipulated in the World Bank's procurement guidelines, equipment that meets other standards of "at least substantial equivalence" is acceptable. The challenge, of course, is to determine in a transparent, objective manner whether a proposed alternative is indeed of substantially equal quality to the specified international standard. The process and qualified PV experts involved in making such a determination should be decided on before opening any bids.

A suggestion for establishing domestic preference may arise in the case of locally-produced batteries. This can be part of a broader debate on protecting or stimulating local industry. If deep-cycle batteries are specified, these are usually imported. If "modified" car batteries (i.e., modified SLI batteries) are specified and if certified ones are produced locally, a domestic preference is probably not needed to compete on price. Given that battery performance is of paramount importance to the long-term sustainability of the entire investment, compromise on battery quality is not good practice.

As standards and specifications may be modified late in the preparation process, the approval process for bid documents should allow for the substitution of improved standards and specifications immediately prior to the formal issuance of the documents.

Detailed specifications. Open performance-based specifications provide bidders discretion to propose alternative technical solutions. This is not recommended for contracts for PV systems for community facilities, except for water-pumping systems and vaccine refrigerators, although in the latter case, it is still necessary to specify the PV array size, battery capacity, controller and other components. In performance-type contracts, the output required is specified, and bidders are allowed to size and configure systems based on their own methods. While this is an ideal way to encourage innovation, few countries have adequate facilities for testing the performance of components and systems.

A viable approach is to use proven technical specifications that have been tested and modified in a sequence of successful procurement processes, although these should be reviewed and adapted by a PV expert to fit the immediate project, as appropriate (Annex 6).

Superior options. Notwithstanding the advantages of detailed specifications using established standards, there is always a possibility of superior options being proposed. In some cases, for example, appropriate international standards may not yet have been established for low-wattage, high lumen per watt LED lights or more advanced charge controllers that record usage, although quality LED lights that could be integrated into many systems in ways that possibly improve efficiencies are available. Bidders may submit proposals that comply with the specifications and also propose options they consider a superior alternative that also meet the performance minimums. The bidder would need to present a convincing case with references and certifications, which could be reviewed by PV experts.

Clarification of specifications, standards, and equipment eligibility. Issues often arise regarding uncertainties and possible internal inconsistencies in technical specifications or requirements for documenting conformance of equipment to specifications. Many such problems can be resolved through pre-bid conferences and exchanges of written queries and clarifications.

Prior to the formal start of the tender process, during the promotion and publicity stage, potential bidders can be encouraged to review advance information on draft technical specifications and submit equipment certifications for pre-vetting eligibility. If there is a pre-qualification phase, bidders should be required to include certifications and other documented evidence that equipment conforms to specifications and standards; in cases of non-conformance, they should be given opportunities to submit substitute equipment or documentation in their proposals.

Equipment certification conforming to specifications. The bid documents should define how conformance of equipment with specifications is to be documented. With international standards and detailed specifications, qualification can be based on acceptable certifications by acceptable laboratories. Thus, acceptance of equipment is based on acceptance of certifications, not on tests conducted for the project prior to shipping or after arrival in the country; the facilities to conduct the necessary tests are not available in most countries that require significant off-grid rural PV services.

The main components should be certified by laboratories with ISO 17025 accreditation to undertake the specific tests; this includes certification for a manufacturer's own testing if done under supervision of the inspection secretariat of the IEC Quality Assurance System for Electronic Components (www.iecq.org). Panels and other components that have the Photovoltaic Global Approval Program (PV GAP) Quality Mark or the Golden Sun quality mark issued by the China General Certification Center will have met this requirement.[17,18]

17 The PV GAP Mark (www.pvgap.org/) is administered by the IECEE (www.iecee.org).
18 For details, visit www.cgc.org.cn/eng/

But because these quality seals are not widely used, the evaluation of most procurement bids will need to carefully scrutinize the certifications and issuing laboratories.

Some purchasers may wish to arrange for pre-shipment inspection of equipment by an independent, contracted inspection agency to ensure that the equipment to be shipped is, in fact, the certified equipment offered in the bid. However, contracting and funding inspections can be problematic. They should not be done by the supplier unless the costs of such inspections were included in the bid documents and all bidders were instructed on the inspections in their bid price.

The main components of PV systems—PV modules and batteries—are commoditized, and there is seldom value in visiting factories to inspect production.

The battery boxes and array mounting structure will usually be produced locally, using specified materials and designs. It can be efficient to vet these models prior to any large-scale production and blueprint installations. The contract should provide for submitting samples for approval at the request of the purchaser. Typically, such samples would include air-freighting of any uncertain major equipment and various minor components: CFLs, light fittings and reflectors, medical lamps, reading lamps, battery enclosures, battery fuses, lightning surge arrestors (new item), and other significant minor equipment.

Clear process for vetting equipment certifications. Bid documents should describe the process to be used to determine whether certifications of equipment and installations are acceptable. The more open and transparent the process, the more likely there will be strong interest on the part of qualified bidders.

Locations of installation sites and facilities

The bid package documentation, along with the advance data made available via promotions and on websites, should include project-specific information:

- descriptions and maps of project areas, road access, and major towns;
- descriptions of the lots;
- conditions and facilities available on the sites (e.g., water or generators); and
- environmental conditions, rainfall, temperature, and solar-resource data.

Test Installations

Pilot blueprint installations. A useful first step is for the supplier to complete a series of pilot or "blueprint" installations of the initial models of each type of system, hopefully in a relatively accessible location, which can be closely inspected by all key stakeholders together with technical PV specialists. The purpose is for the contractor and implementing agency to reach agreement that the blueprint installations indeed meet all requirements prior to the start of a large, rapid rollout of multiple installations. The blueprint installations are used as benchmarks for acceptance of future installations, as well as for training both installers and inspectors of installations.

Practical completion, commissioning and acceptance, and system handover

On-site security (after completion, before acceptance). For logistical reasons, there is a delay, in most cases, between the practical completion of system installation and commissioning and acceptance. During this time, the systems are usually being used by facility staff. The responsibility for risk of theft during this period must be clearly assigned. If the contractor retains this responsibility until commissioning, the insurance premium will likely increase substantially. Good practice would be to transfer risk of theft to the implementing agency once the facility staff members have countersigned the Practical Completion Certificate, before commissioning.

Practical completion. Once the contractor, who must have an internal quality-assurance program, is satisfied that the systems are installed to the required standards and that on-site staff have been trained in system operation and safety, s/he issues a Practical Completion Certificate, which may be countersigned by a designated representative of the beneficiary facility, and informs the implementing agency.

Commissioning and acceptance. This should follow the practical completion as soon as possible (Box 9). Acceptance tests are an important part of quality control and assurance procedures designed to ensure that systems are performing to specification. The implementing agency tests and declares that the installations meet the necessary standards, the system is performing to specification, and the required user training has been satisfactorily completed. The agency then issues an Acceptance Certificate; the result may be a list of items for completion or correction and other issues, although this may be delayed until an identified list of items for additional work or correction has been completed.

The contractor provides the necessary equipment for the acceptance tests. A full procedure for the acceptance tests should be established during the process of inspecting and accepting the blueprint installations.

System handover. The systems are officially handed over from the contractor to the implementing agency or beneficiary entity via a formal document. The handover could occur at the time of issuing the Acceptance Certificate, in which case the implementing agency may later transfer asset ownership to another entity. In any event, the project documentation should clearly describe the hand-over process and establishment of ownership (Box 9).

Internal quality assurance of suppliers. Suppliers should have an internal quality assurance process, and not rely on the implementing agency's verification and inspection arrangements to discover problems that will later be rectified by the contractor. Such internal quality control should be included in the schedule of related services in the supply requirements. An incentive for internal quality assurance is to impose the added costs of follow-up inspections on the supplier.

Payment structure, warranties, and guarantees

At any stage of a contract, the supplier must balance costs to fulfill the contract with outstanding payments due and their performance bonds. Unscrupulous suppliers may walk away should the balance of costs far outweigh outstanding payments. Ultimately the total contract arrangement of payment structure, performance, and warranty securities, and liquidated damages has a transaction cost, which, if too high, will dissuade potential bidders from participating and drive up project costs.

The structure of payments should provide the supplier adequate cash flow and, at the same time, the incentive to perform on time, completely, and in compliance with technical requirements. PV systems are capital intensive and their costs heavily front-loaded, with most supplier costs incurred in the purchase of panels and batteries. Nonetheless, the payment conditions must provide sufficient incentive to complete the contract.

To ensure transparency and prevent undue frontloading of payments (i.e., shifting of maintenance and warranties into supply and install components, it is recommended that procurement be structured into separate contracts or price schedules, as follows:

1. Supply and install contract schedule.
2. Initial maintenance schedule (say, year 1).
3. Maintenance schedule (years 2–5, with optional renewal).
4. Warranties.

Warranties. Warranty and maintenance periods usually begin after issue of the Acceptance Certificate. Long warranties seem desirable but unrealistically long component warranties simply add cost to the contract. Long warranties are easier

BOX 9: EXAMPLE OF INSPECTIONS AND HANDOVER PROCEDURE

The following procedures shall apply for Acceptance Testing and Commissioning of the installation:

- The Contractor shall satisfy himself that the installation is completed in accordance with the Specification and any variations that have been issued before requesting an inspection by the Project Manager.
- The Contractor will train the staff in basic operational procedure and first-line maintenance before commissioning. The system may be used by the staff.
- The Contractor will complete the Practical Completion Log-sheet as instructed, and submit to the Project Manager.
- Sometime after Practical Completion of the installation the systems will be subject to Acceptance/Commissioning Inspection by the Project Manager.
- Prior to inspection, the Contractor shall hand over to the Project Manager all wiring diagrams and necessary documentation.
- The Acceptance/Commissioning Inspection by the Project Manager will occur within 14 days of notification and handing over of necessary documentation.
- The Contractor and Project Manager will be present at the Acceptance Tests.
- At the Acceptance Inspection, the Contractor will be issued a certificate stating all defects of the installation or part at that time.
- If the defects are minor, then the installation will be taken over by the Project Manager using the Acceptance Certificate. If defects are of a major nature, then the Contractor will correct these defects and request a further inspection.
- The Project Manager will determine whether staff members have been adequately trained in basic operational procedure and first-line maintenance.
- An Acceptance Certificate will only be issued once the above-mentioned, major defects have been rectified and inspected, and the staff members satisfactorily trained.
- The Guarantee and Maintenance Periods will commence from the date of satisfactory completion of the last installation in the contract, as dated in the Acceptance Certificate.

Source: Authors' observations, 2010.

to enforce if combined with a maintenance contract, and supported by performance payments and guarantees.

The typical range of component performance warranties are as follows:

- PV panels: 20–25 years to 80 percent of original specified output;
- Inverter and charge controller: 1–7 years (typically 3–5 years);
- Batteries: 1–7 years (typically 5 or more years can be attained for the best deep-cycle ones but with stringent management and data-recording conditions attached, and a minimum 1 year for modified SLI car batteries); and
- Lights: 1–3 years.

In all instances, the warranty conditions must be realizable; otherwise, the warranties will be valueless. For batteries specifically, manufacturers' conditions for long warranties may be too onerous, and better suited to batteries carefully maintained in standby applications in air-conditioned urban environments in large cities, than the challenging conditions of remote, rural institutions.

A Certificate of Authority is to be provided for each piece of equipment under guarantee. In addition, a copy of the manufacturer's guarantee is to be supplied with the tender. While secure warranties are necessary, it is preferable to rely on the systems and contractor working as specified and agreed. In practice, it can be difficult and time-consuming to execute these provisions. Also, it can become difficult to source replacement panels, batteries, controllers, and other equipment if they must be imported, particularly if the original manufacturers are no longer in business or have merged with other firms.

Warranties should be transferable. For short-term supply and install contracts, warranty certificates are passed on to the purchaser after installation is complete. For longer-term supply, install, and maintain contracts, the certificates remain with the supplier until expiration of the maintenance portion of the contract. Should the supplier go out of business or default, then the warranties are transferable to either the purchaser or another supplier.

Liquidated damages, performance bonds, and retention money. The contract provisions for liquidated damages, performance bonds, and final or retention payments should be carefully structured, with the assistance of procurement and legal specialists, to deal with potential delays in contract implementation and failure to meet warranty and other obligations. In general, liquidated damages are applied to delays or performance failures; the supplier is usually required to post a bank guarantee as a performance bond to cover the contract performance and warranty obligations, and a final payment is retained to encourage completion. Delays and performance failures are most often handled by means of liquidated damages (e.g., 0.1 percent per day or a portion thereof for delays beyond the deadline to a maximum of 8 percent of the value of the supply and installation contract) and subsequent forfeiture of the performance bond. The formulas for calculating the liquidated damages are detailed in the Special Conditions of the Contract.

The basic requirements for equipment performance would cover the following:

- There would be a specified 1–2 year, defect liability period on quality of equipment and installation following acceptance, during which any omissions or faults would be attended to without cost to the purchaser.
- Should a stipulated portion (e.g., 10 percent) of any class of equipment fail within the specified period, that whole class of equipment would be replaced by suitable compliant equipment without cost to the purchaser.
- Any failure of system components during their respective warranty periods, through no act of negligence on the part of the user, would mean prompt on-site repair or replacement, free of charge, by the contractor.

Longer-term equipment warranties are more challenging to enforce. These warranties can be dealt with via performance bonds held until the end of the warranty period, while a less expensive option is to combine them with maintenance performance contracts. Lack of timely response to warranty claims could result in the application of liquidated damages.

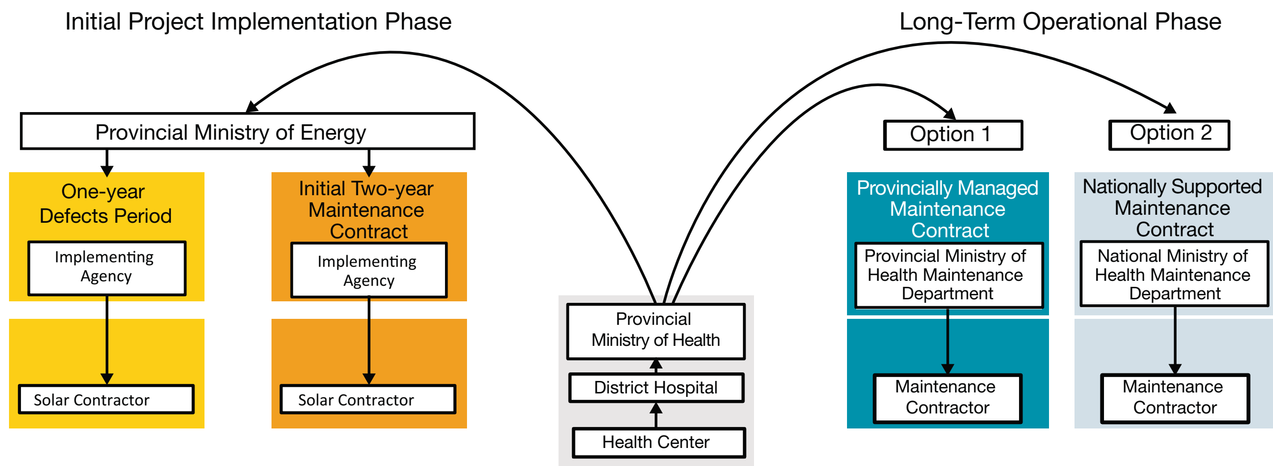
A maintenance performance contract must clearly specify the required system performance (maximum number of failures per year) and contractor responses (time to repair), how these will be measured, and how payments will be affected and liquidated damages applied for non-responsiveness.

Final payments (retention payments) and contract closeout can be scheduled after completion of the initial maintenance and the defect liability periods.

Reporting and communication channels

Contract documentation should spell out the communication and reporting channels and responsibilities during: (i) installation; (ii) the defect liability period; and (iii) long-term operation and maintenance of systems. These would cover communication lines from the contractor to project manager, from user to maintenance manager, including who to call in case of breakdowns. The lines of reporting for the user should be consistent from the implementation to the operational phases (Figure 12, grey area). Additional lines of communication are required for reporting poor maintenance services, as well as how these would be dealt with in cases of non-responsiveness (Figure 12). These communication channels should, in many cases, reinforce and build on existing effective channels. In addition to these institutional channels, arrangements should be made for direct communication between users and the

FIGURE 12: COMMUNICATION CHANNELS



Source: Authors' schematics, 2010.

implementing agency, particularly in cases of system failures not dealt with satisfactorily and other complaints.

Inception report and post-award modifications. For PV projects in remote communities, the field situation surveyed during project preparation will often have changed materially by the time implementation arrives. The information included in the tender documents may not be completely accurate. For example, communities may have been electrified, abandoned, or become inaccessible due to weather or conflicts; new facilities may have been constructed; or staffing patterns may have changed.

To make a rapid and flexible adjustment to changed conditions, it has been useful to require that the supplier conduct due diligence at the sites to confirm numbers and conditions of facilities, grid extensions, and other factors that materially affect the scope of implementation. The results of the post-award due diligence can be reported on in an inception report, which should be included in the schedule of related services in the supply requirements. But due diligence done by the supplier may be viewed as raising conflicts of interest; alternatively it could be conducted by a professional transaction advisor or supervision consultant. In that case, however, the supplier may be resistant to accepting contract changes without independent verification of the on-the-ground situation. The most practicable approach is likely to provide for both elements; that is, due diligence by both the supplier and the transaction/supervision consultant, resulting in an agreed set of necessary contractual modifications.

Price adjustments. If the length of the contract is not more than 18 months, then bid prices can be firm and no provision for price adjustments is necessary, except for changed conditions. If medium- or longer-term maintenance and supply of replacement components is included, the bid documents may need to include the formulas or indexes to be used in adjusting prices to accommodate major cost changes.

Maintenance and performance tracking

It is often desirable to include maintenance in the overall procurement package. The contract will then stipulate exactly how and when maintenance will occur, how it will be managed and supervised, and how it will overlap with supplier warranties. Maintenance plans for the project and post-project periods will have been prepared prior to procurement as part of the implementation plan, and the details and requirements should be included in the bid documents (Part 5).

CONTRACT MANAGEMENT: ROLLOUT AND LONG-TERM SUPERVISION

Contract management and long-term supervision, at a minimum, aim to ensure that the implementing agency receives the contracted goods and services in the agreed-to quantities, quality, and time periods while complying with all procedural, documentation, and legal requirements. However, effective contract management and supervision can well exceed that minimum and be definitive in turning even weak or mediocre designs into sustainable operations. Contract management includes field verification that what is delivered conforms to contract requirements in terms of quantity, quality, scheduling, and later monitoring and tracking maintenance services and system performance. For off-grid PV projects, this takes considerable time and effort in remote, often difficult-to-reach locations. This section highlights the conditions for effective PV contract management and supervisory support during rollout and over the longer term.

Conditions for effective contract management

Clear, well-assigned responsibilities. The agency responsible for contract management should be clearly defined and the delegation of authority within the implementing agency should be agreed on and fixed in advance. If the implementing agency has a pattern of ineffective decision making, delayed disbursements, insufficient integrity, insufficient operating funds (e.g., for staff travel to the field for verifications), or other capacity or practices features that will affect the rollout or longer-term operation, these shortcomings should be recognized and tackled well before procurement begins.

Partnership approach. Many projects that provide PV for community facilities involve multiple agencies and levels of government, private firms, NGOs, and community groups. Supply, install, and maintain contracts are effectively partnerships, with the public sector not only funding the contracts but also, depending on the case, undertaking capacity building, promotion, subsidies, and technical support. Elements of a sound partnership in rural PV projects include:

- **Quality assurance by the contractor.** As a first step, the contractor should supervise its own performance and not rely on the implementing agency for verification (e.g., ensuring that equipment and installation conform to requirements). This requires the contractor to have internal controls (e.g., independent post-installation visits to check quality, documentation and user training), and not simply pass on installer reports to the implementing agency, even when the reports have been countersigned by officials of the community facility.
- **Flexible, no-fault adjustments to changed circumstances.** As a rule, off-grid projects occur in sparsely populated, distant communities that take time to reach. The data on grid extensions, road access, the local economy, household numbers, and other information used during project preparation may be several years out of date and possibly no longer valid by the time field implementation gets under way. All parties must be ready to make appropriate adjustments to changed circumstances.
- **Timely disbursements and decision making by the implementing agency.** Supplier performance is partly conditioned by that of the implementing agency. On-time disbursements, responsive decision making, and no requests for unnecessary or redundant documentation will facilitate the supplier's performance.
- **Frequent stakeholder communications.** Regular stakeholder consultations at multiple levels should be frequent. These consultations should be broad-based, including agencies, contractors, local leaders, and others. An objective is to share information and jointly resolve problems as early as possible.
- **Contract clarity: foundation of a good partnership.** All parties should fully understand the terms and requirements under the contract. An objective during negotiations and later during the inception stage should be to fine-tune a detailed, common understanding of the targets, milestones, metrics, triggers, procedures, forms, and other implementation details.

A sound database. The systems database should be developed at the outset. This should include information on the location with GIS coordinates, components, maintenance, visits, complaints, system usage, repair and replacement history, failures and failure modes, and warranties.

Sound Plan B. The best laid plans are not fail-proof; thus, a sound contingency plan is necessary. Contingency arrangements—standard contract forms that lead to warranty securities, performance securities, liquidated damages, and other provisions—protect the implementing agency but on their own do not constitute an adequate Plan B. Aspects to be thought through in advance include access to funds for the transition to and implementation of the contingency arrangements. For example, if performance securities are called for, to whom are the funds paid, and how do they become available to the implementing agency that may wish to contract replacement firms to conduct remedial work and maintenance?

Clear post-project provisions. Who supervises fulfillment of any continuing warranty and maintenance obligations as the project closes? What are the provisions for holding and managing any warranty and performance securities? Most project designs do not adequately address questions of maintenance practices and capacities post-project. The arrangements and resources for contract management and supervision aspects should also be covered during project preparation.

Adequate resources for supervision. Contract management tasks, including in-the-field tasks, should be broken down, the resource requirements assessed, and the budgetary provisions made. Cost estimates should be built up (e.g., how many field trips or days and unit costs per trip) and not simply estimated in a rough manner. The resource requirements will be more significant if the tasks include compliance with regulatory requirements for equipment standards, service quality, and tariffs; alternatively, if the implementing agency serves as a de facto regulator, the resource requirements will be used to supervise the same issues. The resources and capacities to meet these responsibilities should be determined and put in place before procurement of systems.

Two unfortunate resourcing practices too frequently encountered are as follows:

- In efforts to achieve acceptable ratios, project administrative costs may be estimated to be unrealistically low in relation to, say, the investment costs of the systems. This approach can be short-sighted and imprudent.
- Resources formally assigned for in-the-field supervision may be captured by higher-level officials (e.g., four-wheel drive vehicles procured for fieldwork may not actually be available). This obviously weakens contract management and undermines sustainability.

Transaction and supervision support

The supplementary resources and capacities required for conducting procurements and supervising implementation should be carefully defined. These may be necessary for assisting with transactions through the verification of equipment, installation, and services. The required skills may include those of lawyers, PV engineers, procurement specialists, field technicians, economists, and rural PV market specialists.

Technical judgments are made at multiple stages, from initial design through acceptance of final installations. PV engineers who are aware of current best practices and not linked to potential suppliers are required for:

- preparing technical designs and equipment specifications;
- vetting certifications and other documentation confirming that the equipment proposed in the bid conforms with specifications;
- vetting bids to confirm systems with the offered components will meet performance requirements; and
- assisting supervision of implementation progress, including: (i) acceptance of the inception report; (ii) acceptance of the blueprint installations and training; (iii) approval of the commissioning of the initial systems; (iv) approval of user and O&M documentation; (v) approval of the capacity-building program; (vi) approval of the maintenance protocols and training of technicians; (vii) reviews of maintenance performance; (viii) reviews of warranty administration and assistance in addressing any issues; (ix) vetting of final payments and contract close-out; and (x) support and supervision of the verification staff and consultants.

Success will entail systematic, timely, and sustained supervision by PV technicians who can troubleshoot problems, have high integrity, and be at ease travelling efficiently for extended periods in remote areas.

Frequently, local supervision and verification consultants are used for site inspections, commissioning, and verification of performance of maintenance obligations and system performance tracking. Multiple, independent verification consultants are typically necessary for repeated visits (Annex 4).

Rollout supervision

During the rollout, the immediate focus is ensuring that the equipment supplied is of good quality; is correctly installed; and provisions for user training, spare parts, and initial maintenance are done fully and as contracted. This phase requires intensive field supervision, including frequent consultations with the contractor, customers, and community and other officials and leaders.

During this period, contract adjustments are most likely needed. Close field supervision will yield the information and insights needed to support judgments on the appropriateness of any proposed modifications.

Longer-term supervision

Longer-term supervision and oversight, during both project and post-project periods, should be based on sound maintenance practices, clear and appropriate ownership, and good record keeping.

Monitoring fulfillment of the maintenance plan and taking corrective actions as needed form the core of longer-term supervision work (Part 5). The maintenance requirements include the funding and scheduling of component replacements and upkeep of a comprehensive database on the systems and their maintenance.

If well-assigned and the needed capacities have been prepared, ownership will help drive sustainability. The owning agency (whether or not the initial implementing agency) will presumably take the lead supervisory role, and should be supported to develop the capacity to handle it.

Evaluation

At a minimum, evaluation should cover the sustainability of the PV systems. It addresses whether they are working, how well are they performing, and identifies performance and other issues. In some cases, evaluation also focuses on the impacts and benefits levels (e.g., whether expected health or educational benefits have arisen as a result of the PV system, whether any unexpected benefits have occurred, system usage, and demand for more power).

Part 5. **Long-term Operation**

Deciding how to handle post-project maintenance and an array of related issues—system ownership, recurrent funding for spare parts and repairs, and tracking of system maintenance and performance and management—should be decided during preparation of the PV implementation plan and certainly before moving forward to project implementation. Building capacity for the continuity of maintenance, which is critical to achieving long-term operational sustainability of PV systems, should be done during the project.

Project management and supervision tend to center on the capital costs and pace of installations. Contracts to install PV systems include an initial maintenance period by the supplier, and some additional contracting of maintenance may be possible while project funding is available. Eventually, however, the post-project period arrives. From that point forward, system sustainability depends, in large part, on the continuity of maintenance services and financing of maintenance and component replacements.

CONTRACTED OR IN-HOUSE MAINTENANCE?

Choosing a maintenance approach is done initially during preparation of the PV implementation plan. As more funding and capacities are usually available during, rather than after, the project, maintenance will likely be handled differently during project and post-project periods. For both periods, the basic maintenance options are: (i) contracted maintenance, as is often done by private entities for remote facilities; or (ii) in-house arrangements, possibly with community participation.

Many factors must be considered to determine the most effective maintenance arrangements for both the project and post-project periods. The major questions are:

- What are the local experiences, in-house and otherwise, including those with private firms, with maintenance of PV systems in remote facilities? What are the track records; which approaches are promising?
- Will private firms be more cost-effective and deliver better performance results than in-house or community-based arrangements? In many countries, companies with PV servicing capabilities are based in the main cities, and their costs to send technicians to remote areas are high; these may be acceptable during initial maintenance under the supply-and-install contract, but may be unaffordable for many poor communities and budget-constrained government organizations over the longer term.
- Will area-based clustering of maintenance services and contracts be more cost-effective?
- Should extended maintenance form part of the supply-and-install contract or would separate, longer-term maintenance contracts be more cost-effective? Issuing a single contract to cover supply and installation and maintenance (e.g., 5 years with an option to extend) may have value in ensuring that full responsibility is borne by one contractor. However, this single contractor may have good capabilities for supply and installation, but have limited capability for maintenance where on-the-ground capacity is needed.
- How will quality assurance and maintenance management be handled (e.g., can performance and reliability standards for available services be established so that, if a contractor fails to meet them, penalties can be applied)?
- Which maintenance and reporting options best match the component manufacturers' requirements for upholding system and component warranties?
- How will the users—facility staff, who may change over time—be trained and retrained (accounting for staff turnover) and informed of the steps to take to get help in cases of system failures or performance problems?
- How will maintenance and component replacements be funded post project? This is a big question, and the answer must be clear and firm, based on the solid concurrence of stakeholders responsible for the funding.
- Who will own the systems and how will ownership be assigned? The answer will fix the context for post-project maintenance.
- How will maintenance performance be tracked and supervised during the project and post-project periods?

In many countries, health, education, and water sectors have in-house maintenance departments; thus, one possible consideration is to use in-house maintenance capacities to cover the new PV investments. In these cases, the strengths and weaknesses of in-house capacities should be assessed. General observations are as follows:

- Most sectors have limited experience in taking over PV maintenance tasks after installation.
- In most sectors, planning departments can identity financial challenges and constraints in meeting regular maintenance costs and irregular capital costs, such as battery replacements.
- Health ministries usually have the necessary mechanical and electrical skills for servicing medical equipment, diesel engines, and cold-chain maintenance (usually following WHO guidelines). Constraints may include lack of capacity to undertake more work, frozen posts, lack of vehicles, and limited maintenance budgets or finances reprioritized for other purposes (i.e., hospitals first). If WHO/EPI PV vaccine is being successfully implemented, it provides useful country-specific guidelines.
- In education ministries, maintenance departments usually focus almost entirely on physical infrastructure and buildings, and current capacity is often oriented toward civil and architectural skills, with limited electrical and mechanical skills. Other constraints are similar to those of the health sector.
- For rural water ministries, maintenance departments are usually highly experienced in operating and maintaining remote diesel pumps and servicing mechanical equipment. They are usually strong in-house civil and mechanical skills and logistics and are well-equipped with vehicles. But they usually focus on capital projects, and increasingly tend to contract out maintenance in order to expand water services.

OWNERSHIP

Before determining the details of the maintenance plan, it is necessary to determine who will own the system. While it is widely known that ill-defined operational responsibilities and vague or fragmented ownership will lower sustainability, these issues are often inadequately addressed during project preparation. In some cases, post-installation and post-project ownership of the PV systems is not clearly specified, and the “how” and “who” of ownership handover are unclear. In some cases, central agencies retain ownership, even when not involved in maintenance or recurrent funding, which can contribute to weak maintenance discipline and uncertain funding of recurrent costs. Ownership, in the sense of being empowered to manage and take responsibility for the systems, perhaps even more so than the formal condition of ownership, is an important factor in the readiness and capacity of facility users and beneficiaries to use the systems appropriately and contribute to the long-term costs of maintenance and component replacements.

Good practice is to clearly establish what will be the long-term ownership and align responsibilities for recurrent funding and maintenance with ownership.

POST-PROJECT OPERATIONAL FINANCING

Management and financing of PV system use and maintenance, including component replacements, are key to system sustainability over the long term. Oftentimes the most difficult question to resolve is how to pay for component replacements, from light bulbs to batteries. The responsibilities for meeting the recurrent costs of maintenance and component replacements are frequently stated as general understandings, and any commitments that might be made are often not sufficiently firm. Projects that fund initial system investments are usually closed out before issues of maintenance, ownership, and operational funding begin to affect sustainability. Clearly, these matters should be settled before system installation and indeed before final project approval.

When considering post-project operation, the first question to raise is how maintenance will be funded. The principle is “you get what you pay for.” The PV implementation plan should fully articulate how the financing of maintenance, repairs, and component replacements are to be handled. The extent to which financing relies on central government ministries, local governments, beneficiary communities, direct beneficiaries, or other sources will depend on the local context and opportunities, which should be thoroughly assessed before settling on a particular approach as the one mostly likely to succeed. Prior to determining the feasibility of the mechanism, thorough consultations should be held with the entities expected to provide funding.

Annual budgets and financing sources should be developed in collaboration with the parties responsible for providing the recurrent financing. If there are serious concerns about the timely availability of adequate funds to cover operating costs, including battery replacements, the option of collecting and setting aside annual allocations in an escrow account managed by an independent trustee should be considered.

BENEFICIARY CONTRIBUTIONS

It may be useful to consider staff, community, and other direct and indirect beneficiary contributions to maintenance costs as both a financing device and a way to instill a sense of ownership that contributes to more disciplined maintenance and use. But such contributions should only be incorporated into the financing plan after having had open and satisfactory consultations. If not well handled, donor financing could stand to weaken the sense of local empowerment, making it difficult to secure beneficiary participation in maintenance funding.

The effectiveness of beneficiary participation in the operation and maintenance of community water supply has long been cited as a key factor in the sustainability of such schemes,[19] and is a main element in the approach of many NGOs. For PV systems in staff housing, approaches vary from providing systems on a lease-to-own basis, with the staff assisted in purchasing systems via a combination of grants and loans, to staff being charged a flat monthly fee for system use. The possibilities for beneficiary contributions are many, ranging from income generation (e.g., mobile-phone charging or fees to watch community TV) to various fundraising mechanisms (Box 10). What is possible and appropriate will depend on the local context.

If beneficiaries are to contribute to operation and maintenance, more effort than simply acquiring signed letters of intent will be required. Arrangements will entail social-preparation activities with facility staff and other beneficiaries. If facility staff members are to take responsibility for securing at least part of the funds for maintenance and component replacements, this should be carefully discussed with them. If local governments are to contribute, then discussions and agreements should be reached with local government officials, including budget officials.

SECURING MAINTENANCE FUNDING COMMITMENTS

Prior to initiating procurement, the strongest possible recommendation is to secure commitments and obligations to fund the recurrent costs of maintenance and component replacements. Once procurement is under way and installations have been done, the focus of beneficiaries often dissipates, and any previous leverage is quickly lost.

Artificial donor-driven deadlines and targets (e.g., achieving project approval during a specific donor fiscal year or hitting disbursement targets) can push implementation ahead of itself. For example, when inadequate provisions are made during project preparation, it is sometimes suggested to finance a maintenance contract with project funds as an

BOX 10: SUDAN'S COMMUNITY DEVELOPMENT FUND: LESSONS IN BENEFICIARY FUNDING

In remote areas of rural Sudan, the Community Development Fund (CDF) provides PV systems for community clinics, schools, water pumping, clubs and street lights. From the outset, the lack of locally available maintenance services and spare parts and secured funding for maintenance and component replacements were known challenges. Except for vaccine refrigerators, whose maintenance was separately funded via the Expanded Program on Immunization (EPI), rural service facilities and communities were charged with meeting maintenance costs, with each choosing its own methods to generate needed revenues. A pre-condition for receiving the PV systems was a contribution equal to 10 percent of the system cost as seed money for the CDF.

Fundraising mechanisms included fees for mobile-phone charging, school fees, entrance and membership fees for community clubs, and contributions. In some cases, the community levied its members proportionate to families' financial capabilities; in other cases, individuals or families voluntarily contributed. For street lights, the group of families in the vicinity of each light covered the costs of "their" light; if not, the light would be moved to another location.

Still in its early years, the CDF efforts have been built on sound practices; key among them are:

- Solid social preparation, using a bottom-up approach that has included multiple discussions with the community and assistance in identifying their priorities and expectations for the PV systems;
- Firm community commitments, as demonstrated by having raised community contributions well in advance of system installations;
- Effective community leadership;
- Community empowerment and responsibility for the PV systems;
- Community-level capacity building in maintenance services and troubleshooting;
- Development of linkages with spare-parts suppliers; and
- Development of reliable backup technical and support services.

Source: Mohamed Ali Hamid, information provided during Dar es Salaam workshop on PV Guidance and Toolkit, May 2010.

19 Deepa Narayan, Contribution of People's Participation: Evidence from 121 Rural Water Supply Projects, World Bank (1995).

interim mechanism, ensuring maintenance services while transitioning over a period of up to as much as 3–5 years to the more permanent, albeit yet-to-be-defined, post-project arrangement. This is, of course, fraught with the risk that long-term financing questions will not be resolved in a timely way after the systems have been installed.

MAINTENANCE PLANS

PV system maintenance is relatively simple. Structured preventative maintenance will yield significant benefits. However, a lack of preventative maintenance will result in eventual system failure and more costly repair bills. The post-project costs of sustaining systems mainly involve:

- preventative maintenance inspections and system checking on an annual or biannual basis, which may include battery servicing and record keeping;
- replacement and exchange of faulty components that may have failed due to lightning damage or misuse, such as lights, inverters, and charge controllers;
- coordinated battery replacement and disposal every 3–6 years, depending on the predicted and actual battery life; and
- maintenance management, including analysis of routine maintenance, service, and performance data.

Maintenance plans for the project and post-project periods, to be included in the implementation plan, should define tasks, schedules, and responsibilities. They should include a formal agreement on commitments, signed by the responsible organization prior to system installation. Of course, the plans will only be as good as the commitments of the organizations responsible for handling the tasks, including the recurrent financing.

Whether incorporated into a supply-and-install contract, a separate contract, or otherwise handled, maintenance plans for the project and post-project periods should be established with key stakeholders before procurement begins. If needed, details of the plans should be revised after blueprint installations and in discussions with the supplier. Plans should carefully define the procedures and performance indicators and provide resources for:

- **Routine maintenance**, which is done by users.
- **Preventative maintenance inspections** (annual or biannual). This may include battery servicing (if included with the system) and replacement of lights and appliances (depending on how ownership and responsibilities have been fixed), as well as record keeping.
- **Callout and replacement.** This is the exchange of faulty components, such as inverters and charge controllers, which may have failed due to lightning damage or misuse.
- **System reliability and minimum response times to fix service interruptions.**
- **Troubleshooting and expert support.** Capabilities should be in place to respond to user queries and analyze system shutdowns and other issues.
- **Spare parts.** This includes details for supplying and stocking spares for all major and minor components and equipment pieces. A standard may be established for the percentage of repairs to be made with spares (say, 80 percent) rather than by special order.
- **Scheduled component replacements.** These are the details for planned replacement of batteries, controllers, and inverters at the end of their designed lifetime.
- **Lights.** These are detailed rules for replacing bulbs and light fixtures, including the responsible parties for bearing the cost and stocking replacements.
- **Battery disposal.** Commercial disposal or recycling options may be available.
- **Capacity building**. This includes training and refresher training of facility staff, who may change over time, in how to get help for system performance problems or failures.

MAINTENANCE TIERS AND TRACKING

An important principle is that maintenanace arrangements should be tiered, with clearly delineated task responsibilities and capacities at each level. We recommend a three-tier system, with capacity-building provisions in the maintenance plan to address each (Table 17). Facility staff will usually be responsible for day-to-day system control and use and routine maintenance. Their capacity to meet these responsibilities must be built and, as staff change, rebuilt and refreshed with training and supportive supervision.

System performance and maintenance should be carefully recorded. Tracking should cover each maintenance service, system shutdowns, and other events. Records can facilitate accurate and speedy troubleshooting in cases of system failure and can be valuable in anticipating problems, particularly with batteries, before they cause a shutdown. A diligently kept logbook is also essential in dealing with many warranty issues.

At the facility level, upkeep of this tracking system, in the form of a logbook, can be incorporated into the organizational rules for system use, control, and maintenance. Opportunities for recording and tracking system maintenance and performance using Internet technologies offer the promise of rapid responses to problems and sound monitoring, contributing to reductions in operating costs, improved reliability, and longer-term sustainability.

TABLE 17: MAINTENANCE OVERVIEW			
Maintenance Level	**Frequency**	**Maintenance Responsibility**	**PV Maintenance and Reporting Task**
1st tier: Basic user routine maintenance	Daily/Weekly	User/System Operator	System operator tasks • Read and record dial indicators on charge controller and refrigerator thermometers. • Check battery levels without opening batteries and report problems. • Replace non-operational bulbs. • Wipe solar panels and wipe and clean batteries. • Manage load as and when necessary. • Report problems and faults accurately and without delay.
2nd tier: Routine and preventative maintenance; servicing; trouble-shooting	Quarterly/twice a year/annually	Maintenance Technicians	Preventative maintenance inspections • Check system diagnostics and analysis of conflicting information. • Top up batteries and measure battery performance. Replacements • Install minor components needing replacement. Call-out maintenance • Respond to user reports, diagnose and repair. • Report complex problems to specialists. Reporting • Complete maintenance report logs and record measurements.
3rd tier: Skilled diagnostic or major component replacement and rebuilding work	Once or twice over the system life	Skilled Technicians	System performance monitoring • Respond to problems reported by 2nd level. • Perform complex system diagnostics. • Reset/re-program component set-points. • Repair and rebuild equipment. • Deal with warrantee issues. • Plan and manage battery replacements and disposal. • Re-commission systems after component replacement.
Maintenance Manager	Monthly	Maintenance Manager	Supervise maintenance regime • Assure quality. • Monitor callouts and responses. • Plan major component replacements and disposal. • Supervise payment. • Keep all maintenance-visits records for warranty purposes.

Source: Authors' calculations, 2010.

The communications arrrangements for both the project and post-project periods should provide users at the facility level a ready means to contact, first, the maintenance technicians to report faults and problems and, secondly, the mainteance manager (third tier of the maintenance hierarchy) in cases of non-responsive maintenance technicians (Figure 12).

Contributions from each of those responsible for the funding commitments should be tracked. Non-payment or delayed payment by any of those responsible can disrupt maintenance services and rapidly lead to system shutdowns.

MAINTENANCE PERFORMANCE CONTRACTS

A maintenance performance contract aims to ensure a specified level of maintenance and meet minimum performance indicators. An indicative structuring of the key elements of a maintenance performance contract is presented in Table 18.

Even if maintenance is not included as part of the supply-and-install contract, it is useful to describe and include the above information to indicate the responsibilities of the parties to the contract and beneficiaries.

TABLE 18: KEY ELEMENTS OF MAINTENANCE PERFORMANCE CONTRACT	
Contract Item	**Comment/Description**
Routine maintenance	Specification of maintenance tasks, including completion of attached technical maintenance sheet.
Routine maintenance intervals	Usually a visit to each site at least every 6 months. Preventive maintenance intervals depend primarily on battery maintenance requirements and could be as long as one year. For supply, installation, and maintenance contracts, intervals may be front-weighted to address early installation quality issues.
Local point of presence	Local point of presence or call center required for reasonable response times to callouts. Contractor is to have a defined fault reporting chain.
Callout response and repair times	Performance contract should specify maximum callout response time and maximum time to rectify the problem. Callouts are usually restricted to complete system or major equipment failures. Requirements may differ between critical systems, such as vaccine refrigerators, and others, such as staff lighting.
Warranty issues	The performance contract must specify how warranty issues are to be resolved, whether a warranty covers only exchange of defective equipment or also includes re-installation of replacement equipment.
Spare parts management	Contract must specify whether existing spare parts may be used, and how additional ones should be procured and managed. Spare-parts tracking documentation may be required.
Battery replacement	Maintenance contracts may optionally include one or more compulsory battery replacement/ disposal cycles; it may cover only labor, transport, and disposal, with batteries procured in a separate contract.
Documentation requirements	These include: (i) preventive maintenance reports; (ii) callout logging and reporting; (iii) logging and tracking of equipment replacements; (iv) spare-parts tracking; (v) warranty claims tracking; (vi) overall database of site-visit dates, whether preventive or callout; and (vii) system (including battery) performance tracking.
Contract duration	Desired duration of an initial maintenance performance contract is a minimum of 5 years, with performance review every year. This covers electronic system warranties and any premature battery failures and replacements under warranty.
Performance standards	Maintenance performance contract standards may depend on the number of failures per system years. Higher failure rates may require faster response and repair times. If too many system failures occur, additional clauses may come into effect, requiring corrective action by the contractor.
Financial terms	The financial terms and payment schedule should cover: (i) routine maintenance work schedule; (ii) callout response performance and penalty accrual; (iii) battery replacement scheduling; (iv) warranty terms and retentions; and (v) retentions and penalties for non-performance.

Source: Authors' calculations, 2010.

OTHER SUSTAINABILITY ISSUES: LOAD CREEP, THEFT, AND VANDALISM

Increasing demands on the systems can stress the batteries and lead to system shutdowns, dissatisfaction with performance, and ultimately misuse and system failures. Two main contributors to load creep are increasing user demands (e.g., more DVD watching or larger TVs) and agencies and donors that provide equipment for additional or expanded services without taking into account the capacities of the PV-based electricity supply.

Unfortunately, theft and vandalism occur and are often associated with system failures. Hardware (e.g., fences and special bolts) and other measures, such as recording serial numbers of panels and other components and, for large procurements, embedding a project or organizational logo under the glass of the solar panel, may help as deterrents. In some situations, however, basic security is a risk due to conflicts or other reasons. The most promising strategy may be to strengthen community and staff awareness and roles in ways that align their interests with system sustainability and their perception as beneficiaries of the systems. Community participation (e.g., via field surveys and consultations on implementing responsibilities, such as maintenance-costs contributions and system ownership) may be particularly effective in helping to protect the systems.

Part 6. **Conclusion**

Projects to electrify multiple off-grid community service facilities with PV systems have often been too lightly prepared, have focused inadequately on the institutional issues of maintenance, and have not been sufficiently supervised. The information available on experiences across countries indicates that overall sustainability is low.

To enhance sustainability, we have recommended measures for many aspects of design and implementation. In conclusion, we highlight best practices in three key areas:

Preparation

- During preparation, address both technical and institutional requirements comprehensively, including post-project maintenance and recurrent funding.
- Early on and throughout the planning process, incorporate internal loopbacks to consider trade-offs and facilitate the inputs of communities, PV experts, procurement specialists, and other stakeholders.
- Include consultations with independent specialists to take advantage of a wider body of experience and expertise.

Contract Management and Supervision of Installation and Maintenance

- Put in place robust, timely, intensive, independent, and professional capacities for supervision. These are absolutely essential at every operational stage. They include technical support for vetting equipment and installations and regular, repeated, in-the-field monitoring and reviews of performance, whether done under contracts or through various types of in-house maintenance arrangements.

Maintenance and Operation

- Establish robust maintenance arrangements for the project and, critically, post-project periods: Maintenance continuity is the sine qua non of the sustainability of long-term operation. This includes securing funding for battery replacements and other recurrent costs; clearly identifying ownership responsibilities; building necessary capacities at each tier of maintenance; and installing a reporting and tracking system to provide the data to monitor the maintenance services, track performance of the systems, and anticipate problems.

Finally, we have proposed that project development be phased in four equally important stages: (i) rapid assessment; (ii) development of the PV implementation plan; (iii) procurements and contract management; and (iv) long-term operation. In closing, there are multiple opportunities to address the issues covered in this guide and toolkit to establish the basis for sustainability.

Abbreviations and Acronyms

AC	alternating current
AFREA	Africa Renewable Energy Access Program
AFTEG	The World Bank Africa Energy Unit
AGM	absorbed glass mat
CDM	clean development mechanism
CEIF	Clean Energy Investment Framework
CFL	compact fluorescent light
CG	Consultative Group
CIP	carriage and insurance paid
DC	direct current
DVD	digital video disc
EPI	expanded program on immunization
ESMAP	Energy Sector Management Assistance Program
GIS	geographic information system
ICB	international competitive bidding
IEC	International Electrotechnical Commission
JRC	Joint Research Council
LCOE	life-cycle costs of energy
LED	light emitting diode
LPG	liquefied petroleum gas
MDTF	Multi Donor Trust Fund
NASA	National Aeronautics and Space Administration
O&M	operations and maintenance
OPD	outpatient department
PSH	peak sun hours
PV	photovoltaic
PV GAP	Photovoltaic Global Approval Program
PVGIS	photovoltaic geographical information system
SBD	standard bidding documents
SHS	solar home system
SLI	starting, lighting, and ignition
SSA	Sub Saharan Africa
SSMP	sustainable solar market packages
TOR	terms of reference
TV	television
UNDB	United Nations Development Business
UNICEF	United Nations Children's Fund
UPS	uninterruptible power supply
WHO	World Health Organization
ZAMSIF	Zambia Social Investment Fund

Units of Measure

Ah	ampere-hour
CO_2	carbon dioxide
kVA	kilovolt-ampere
kWh	kilowatt hour
kWp	kilowatt peak
lm/W	lumens per watt
m/s	meters per second
MWp	megawatt peak
V	volt
Wh	watt hour
Wp	watt peak

Africa Renewable Energy Access Program (AFREA)

1818 H Street, N.W.
Washington DC 20433, USA
Internet: www.worldbank.org/afr/energy/afrea
Email: africaenergyunit@worldbank.org

ESMAP
Energy Sector Management Assistance Program

1818 H Street, N.W.
Washington DC 20433, USA
Internet: www.esmap.org
Email: esmap@worldbank.org

THE WORLD BANK

1818 H Street, N.W.
Washington DC 20433, USA
Internet: www.worldbank.org/afr/energy
Email: africaenergyunit@worldbank.org