IEA INTERNATIONAL ENERGY AGENCY

Social, Economic and Organizational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T11-05:2011

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Social, Economic and Organizational Framework for Sustainable Operation of PV Hybrid Systems within Mini-Grids

IEA PVPS Task 11, Subtask 40, Activity 41
Report IEA-PVPS T11-05:2011
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with contributions from T11 experts

Cover Picture left: Pomelo, Indonesia, 24kWp, 20 kWh battery, 125 kVA genset, (photo TRANSENERGIE)

Cover Picture right: King's Canyon, Australia, 225kWp, 3 gensets operating continuously, utility operated 11 kV distribution network, (photo NOVOLTA Pty)

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1. Foreword

The International Energy Agency Photovoltaic Power System (IEA PVPS) Executive Committee has launched Task 11: "PV Hybrid Systems within Mini-grids" for the period 2006-2011.

The scope of Task 11 includes PV-based hybrid generators that combine PV with other electricity generators and also energy storage. A particular focus is on mini-grid systems in which a micro power plant consisting of electricity generators, storage, and loads is connected by a "stand-alone" alternating-current distribution grid with relatively small rated power in a limited geographical area. The mini-grid concept has potential applications that range from village electrification in less economically developed areas to "power parks" that offer ultra-reliable, high-quality electrical power to high tech industrial customers. These systems can be complex, combining multiple energy sources, multiple electricity consumers, and operation in both autonomous (stand-alone) and utility grid connected modes.

The main goal of Task 11 is to promote PV technology as a technically relevant and competitive energy source in hybrid power generation systems and mini-grids when its inception is the most favorable solution/alternative. It aims to enhance the knowledge base of PV hybrid mini-grids and reduce barriers to market penetration by these systems.

The current members of the IEA PVPS Task 11 are: Australia, Austria, Canada, China, France, Germany, Italy, Japan, Malaysia, Spain, and United States of America.

Falling within the framework of Subtask 40 and focused on PV hybrid mini-grid sustainability conditions, the objective of Activity 41 is to make recommendations that must be taken into account as factors of system sustainability to ensure appropriate long-term electrical service. Sustainability aspects consider the organizational, social, economic, and environmental conditions in which PV hybrid power plants are installed, operated, and maintained.

This technical report has been prepared under the supervision of PVPS Task 11 by:
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with contributions from other Task 11 experts.

The report expresses, as nearly as possible, the international consensus of opinion of the Task 11 experts on the subject dealt with. Further information on the activities and results of the Task can be found at: http://www.iea-pvps-task11.org and http://www.iea-pvps.org.

2. Executive Summary

In remote parts of the world where hybrid photovoltaic (PV) systems have been installed, it has been shown that, in addition to a suitable design and proper installation, non-technical aspects have to be considered. The social and economic aspects described in this report deal with long-term conditions for operation and management of hybrid PV systems and their overall sustainability.

Considering organizational, social, and economic conditions in which PV hybrid power systems (PVHPS) are installed, operated and maintained, key lessons learned from designing and operating PVHPS systems are highlighted, typically:

- The design of the system should be adequate to the conditions and needs of the community (including importantly an equal role of women).
- Unfamiliarity of the developer with local conditions and a top-down "development" approach (design based on what developer assumes development should be) are negative factors.
- A condescending approach (ignoring know-how, contribution, capacity, voice, self-respect or dignity of local communities) has harmful effects.
- Inhabitants of communities (like everywhere) will always find new ways to consume electricity: systems must be planned to promote efficient and responsible consumption oriented to minimizing the load increase or to allowing easy and sustainable expansion.
- An understanding of the difference between literacy and education, and the capacity of the community to develop for themselves is essential, rather than a focus on the goal of the project. Knowledge in villages should be used and external dependency limited.
- An agreement must be reached in advance so that the users are aware of the energy limitations and of the need for efficient appliances.
- The system should be highly efficient and robust.
- Nothing is maintenance free: the operation and maintenance (O&M) of PV systems have to be paid for.
- The tariff paid by the users within their willingness to pay must be able to sustain at least operation of the system and replacement of its components.
- Follow-up actions after implementation, if supported and managed with users, prevent potential difficulties.
- Repairs in remote locations are difficult and expensive: logistics for spare parts and high-efficiency appliances could be critical.
- Vandalism, theft, and the adoption of preventive measures could be issues to consider.

Most failures are not due to technical problems but to the lack of a clear organizational scheme to operate the system (managing the O&M tasks and the user payments), and also to the lack of an energy management concept which encourages the responsible use of energy where supply is limited.

Achieving sustainable, economic and widespread use of hybrid power systems is possible if local management schemes, effective policies, meaningful finance, and cooperation with/amongst system integrators, technology providers, and final users are put in place.

3. List of Abbreviations

HPS	Hybrid power system
IEA PVPS	International Energy Agency Photovoltaic Power System
MSG	Multi-user solar hybrid grid
O&M	Operation and maintenance
PV	Photovoltaic
PVHPS	Photovoltaic hybrid power system

4. Definitions

Engineering consultant	Organization, company, or person responsible for translating the needs of the potential user into technical requirements in accordance with the relevant technical specifications and for preparing the call for tenders (proposals).
Maintenance contractor	Organization, corporate company, operator, or person contracted by the Operator to perform maintenance operations on the installation.
Owner	Organization, company, or person financially responsible for the whole system and maintaining titles to all the equipment. The owner could also have another role, such as project developer or operator, but may be a completely separate organization.
Project developer	Organization, company, or person who defines and promotes the rural electrification project, assigns the project implementer, determines compliance with the specifications and is also responsible for obtaining resources for financing the project.
Project implementer	Organization, company, or person entrusted by the project developer to perform the work or have this work performed pursuant to the general specification (possibly through some subcontractors).
Service operator	Organization, company, or person in charge of plant operations, management, and maintenance.
Subcontractor	Organization, company, or person in charge of the execution of a selected part of the work relative to the project.
Training provider	Organization, company, or person contracted by the project developer to provide training to the different participants to use, operate, and maintain the system.
User	Person or organization that makes use of the installation service(s) to satisfy their energy demand.

5. Figures and Tables

6. Introduction

The objective of this study is to point out issues that must be taken into account when providing sustainable photovoltaic (PV) hybrid power systems (PVHPS) and to highlight conditions that, when technically appropriate, could ensure appropriate long-term service.

Aspects considered are social, economic, and environmental conditions in which PVHPS are installed, operated, and maintained.

This document is a compilation of the experiences of institutional bodies, such as non-governmental organizations, financial bodies and engineering companies, and a collection of data and examples from case studies provided by the Task 11 participants. This collection of examples of multiple energy sources for power generation including PV (mainly diesel genset + PV) has been compiled to illustrate field situations with observed facts. Follow-up with users on their experiences in operating and receiving energy services is not included.

7. Scope of the study

The PVHPS considered are autonomous, rural, multi-user, solar hybrid grids (MSG) with energy distribution by means of a micro-grid.

Sustainability needs to be ensured by implementing the project in a way that guarantees a self-sustained operation after the project is commissioned.

The objective was to study the following aspects:

- Management of the PV hybrid mini-grid project and realization
- Social organization of the users as well as the role of the project implementer
- Success / failure factors and types of social, institutional, organizational, etc., problems that had to be solved
- Related comments useful to understanding which practices could be recommended for future projects
- The role of the PV technology in the sustainability of the projects, if any.

8. Overview on sustainability of power systems

8.1 About sustainability

When looking at the meaning of sustainability, the following definitions can be considered:

- A sustainable plan, method or system is designed to continue at the same rate or level of activity without any problems [1]

Or

- To sustain: to keep in existence, especially over a long period (to maintain, to keep up, to continue, to prolong...) [2]

Or

- To meet the needs of the present without compromising the ability of the future to meet its own needs [3]

Three main issues and associated criteria are commonly used to assess the sustainability of a system [6]:

- Environmental issues (climate protection, resource protection, noise reduction)
- Socioeconomic issues (overall socioeconomic matters, individual socioeconomic interests)
- Economic issues (costs and tariffs, maintenance, economic independence, future potential)

A sustainable PVHPS should provide to all key agencies in the project value chain (final user, operator, project developer, project implementer, financial bodies, etc.) the expected technical and economical results for the expected time contracted in a commonly approved specification.

If a one sentence summary were to be made, we would say that long-term sustainability must be the beacon that guides the project [10].

8.2 Hybrid power systems within a mini-grid

8.2.1 General description

A hybrid mini-grid system is composed of three subsystems: generation, distribution, and demand [9]. Each subsystem varies greatly in its components and architecture according to the availability of resources, desired services to be provided, and user characteristics.

- **Generation subsystem**
  This subsystem includes generation (renewable-based and non-renewable generation), storage (battery or other), converters (convertors, rectifiers, and inverters), and energy management devices of the hybrid power system.

- **Distribution subsystem**
  This subsystem is responsible for distributing the energy produced to the users by means of the mini-grid. The primary issues are whether to use a distribution mini-grid based on direct current or alternating current, and whether to build a single-phase or three-phase grid. These decisions will have an impact on the cost of the project and the appliances that can be used.
- **User, application, or demand subsystem**
  This subsystem includes all equipment on the demand side, such as energy metering, safety, internal wiring, and the appliances that will finally use the electricity generated by the HPS.

8.2.2 Classification

As proposed by the International Energy Agency Photovoltaic Power System (IEA/PVPS) Task 3, the technical classification of PVHPS can be described as [4]:

- PVHPS1: the typical application for this configuration is a small remote site where the variable loads negatively impact diesel genset maintenance costs and fuel transport is expensive. The battery storage plus PV capacity added needs to be sufficient to meet at least daytime demands, ideally leaving the diesel to charge the batteries in a few hours overnight and placing a steady 80% load on the genset.

  The main goal for this micro-grid application is to provide a service and give access to electricity (example: Figure 1).

  Challenges are:
  - Affordability
  - Long-term sustainability
  - Quality of service
  - Maintenance ability

Figure 1: Pomelo, Indonesia, 24kWp, 20-kWh battery, 125-kVA genset
(photo: TRANSENERGIE)

- PVHPS2: As demand increases, the configuration outlined for PVHS1 can become less attractive. Under these circumstances, the PV is configured to feed directly to load and battery charging duties are provided by the diesel generator when it would be otherwise be partially loaded. It serves to reduce the load fluctuations that otherwise cause a problem with diesel maintenance. The diesel set can then be downsized to better match the average load. At night, when demand falls, the diesel can be shut down so that it is not operating under-loaded, and the smaller demand is supplied via the batteries.

  Challenges are the same as PVHPS1 above.

- PVHPS3: in large genset power systems with a demand curve that exhibits a related peak (due for example to running air conditioning or fans), PV capacity can be added to meet the peak. In this configuration, the diesel set(s) carries the base load 24 hours a day. This configuration does not require storage.

Figure 2: King's Canyon, Australia, 225kWp, three gensets operating continuously, Utility-operated 11-kV distribution network
(photo: NOVOLTA Pty)

Additional challenges are:

- Institutional barriers to be overcome
- Grid stability at high levels of PV penetration.

Another point of view could be adopted to classify MSG systems on a non-technical basis, applying user-oriented parameters, as shown in Table 1.

Table 1: Key Parameters for Classifying Hybrid PV Systems

Issue	**Parameter**	**Different observed field situations** *(no necessary link between the different rows)*				
Electric service	**Power**	Only one power phase per user	More than one	During hours genset is operating	Three phase, according to power plant status	
	Energy	No limitation for each user	Monthly limitation	Daily limitation		
	Power source	Stochastic only	Daily operating genset	Seasonal operating genset	Auxiliary genset	With or without batteries
Economic aspects	**User investment in capital costs**	No connection costs	Similar to the conventional grid in that country	Related to capital costs and economic status of user		
	Monthly payment by users	No payment	Flat price for daily energy allowance	Based on the energy consumption at conventional grid-connected prices	Partially adapted to the generation costs	
	Financial schemes/subsidies	Subsidy for the capital costs and also for usage costs	Only for the initial investment	Only for usage costs	None	
Social aspects	**Previous electrification experience**	Diesel gensets	Conventional grid	Individual PV systems	None	Recharge of batteries
	Energy savings culture	Not contemplated	Introduced through efficient lighting	Generally all appliances are efficient	High-efficiency appliances are rented or leased to the user as part of the project	
Organizational aspects	**Entity in charge of system management**	None	Government or other public institution	Private company	Users themselves	Community or municipal organization

Source: [17]

8.3 General guidelines for development of a sustainable off-grid electrification project

To maximize the chances of sustaining the operation of an off-grid electrification project over the long term, fundamental project management principles must be observed, as shown in Figure 3, according to a large survey managed by the World Bank [5].

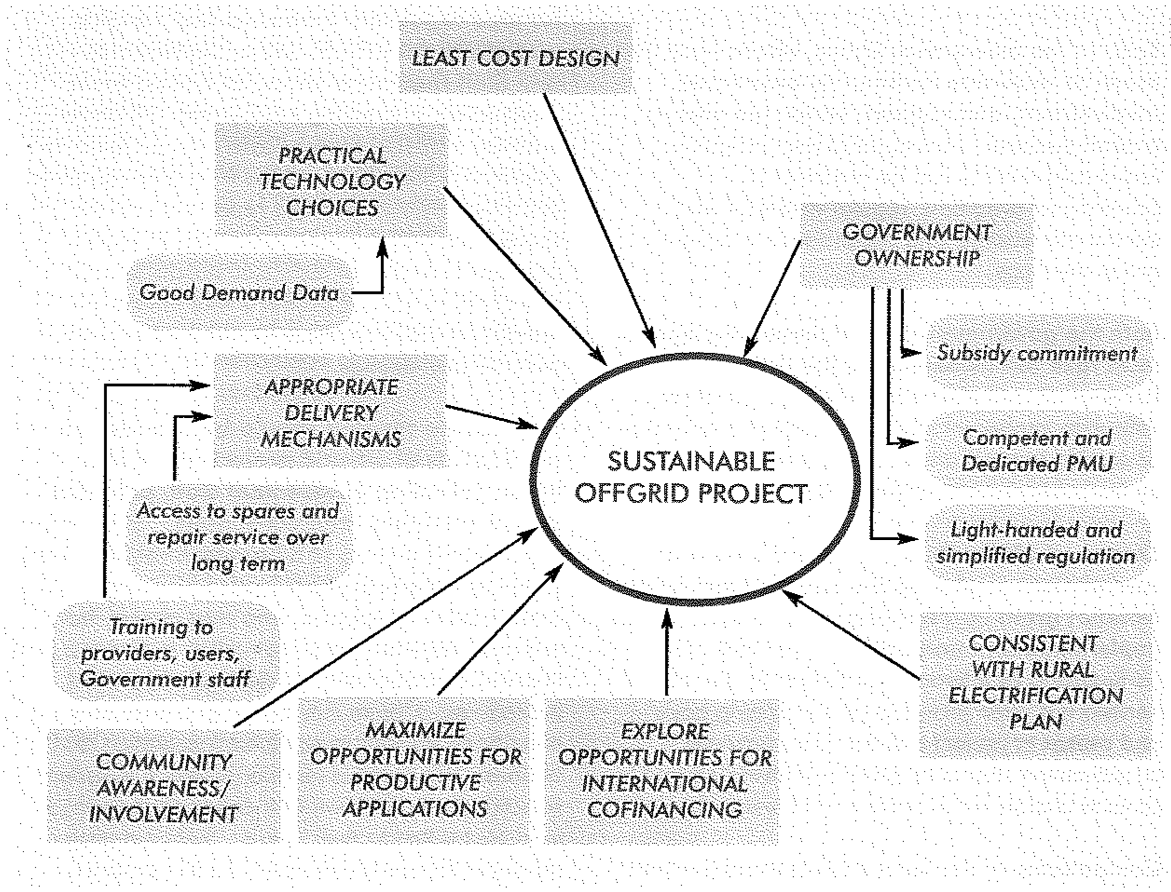


Figure 3: Elements of a sustainable off-grid electrification project

Note 1: Least-cost design: projects should be assessed through the whole life-cycle, including socio-environmental considerations

Note 2: Maximize opportunities for productive applications:
This should be up to the communities

9. Sustainability factors for PVHPS within mini-grids

9.1 An holistic approach

Although one of the elements that guarantees the long-term sustainability of an electrification project with solar energy is technical, its future is also subject to the social, organizational and economical aspects of the community where the installation takes place. Thus, it is necessary to count on high-quality design and engineering, but it is also essential to establish a management model, regulations for the electricity quality and service, and an economic structure. It is crucial as well that the beneficiary community participates in the project definition and decides on certain aspects, for a real "appropriation of project."[20]

> The way to ensure sustainability of services is to combine deep knowledge of and respect for the local context, local participation, and people with technical expertise, management capacity and financial resources.

Figure 4 illustrates different organizational project management schemes that can be observed in the wide variety of rural electrification projects using HPS within mini-grids.[7]

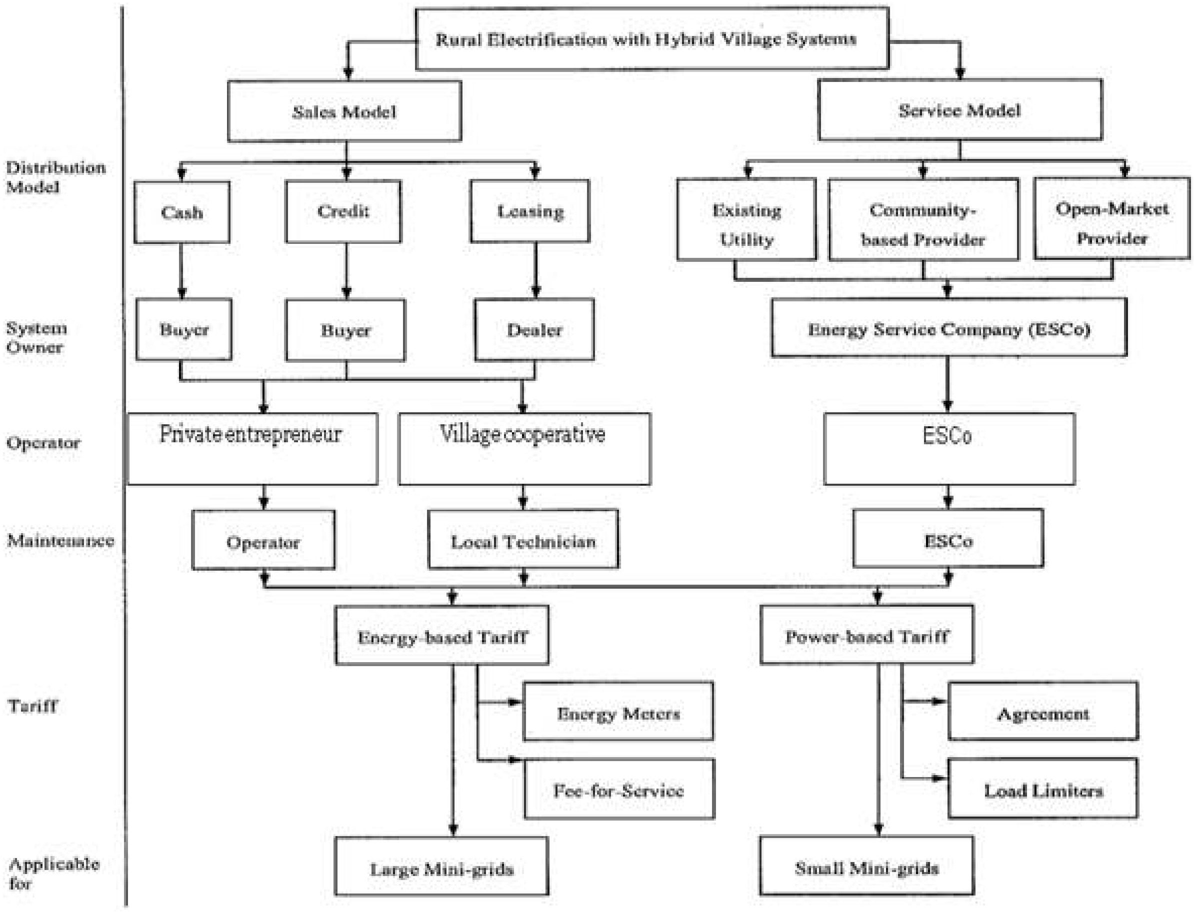


Figure 4: Electricity distribution organizational potential frameworks through mini-grids powered by hybrid systems [7]

9.2 Facts and lessons learned from project developers

Some detailed facts observed in the field, as well as lessons learned from experience and illustrations coming from case studies have been collected using the following template.

Sustainability factor: (specific definition used by the project – see discussion below)
Example: (from project reports)
Lessons learned / recommendation: (from T11 experts feedback)

A synthesis of many factors contributing to sustainability is proposed in Figure 5. These will be referred to generically as “sustainability factors” in this report.

Of course, this inventory is not exhaustive; however, it is important to note that the diversity of the reasons why sustainability can be achieved or not is very wide and complex.

In this report, comments are made when the presence of PV in the hybrid generation system has an influence on the management of the sustainability factor.

9.2.1 "Sustainability factors": general overview

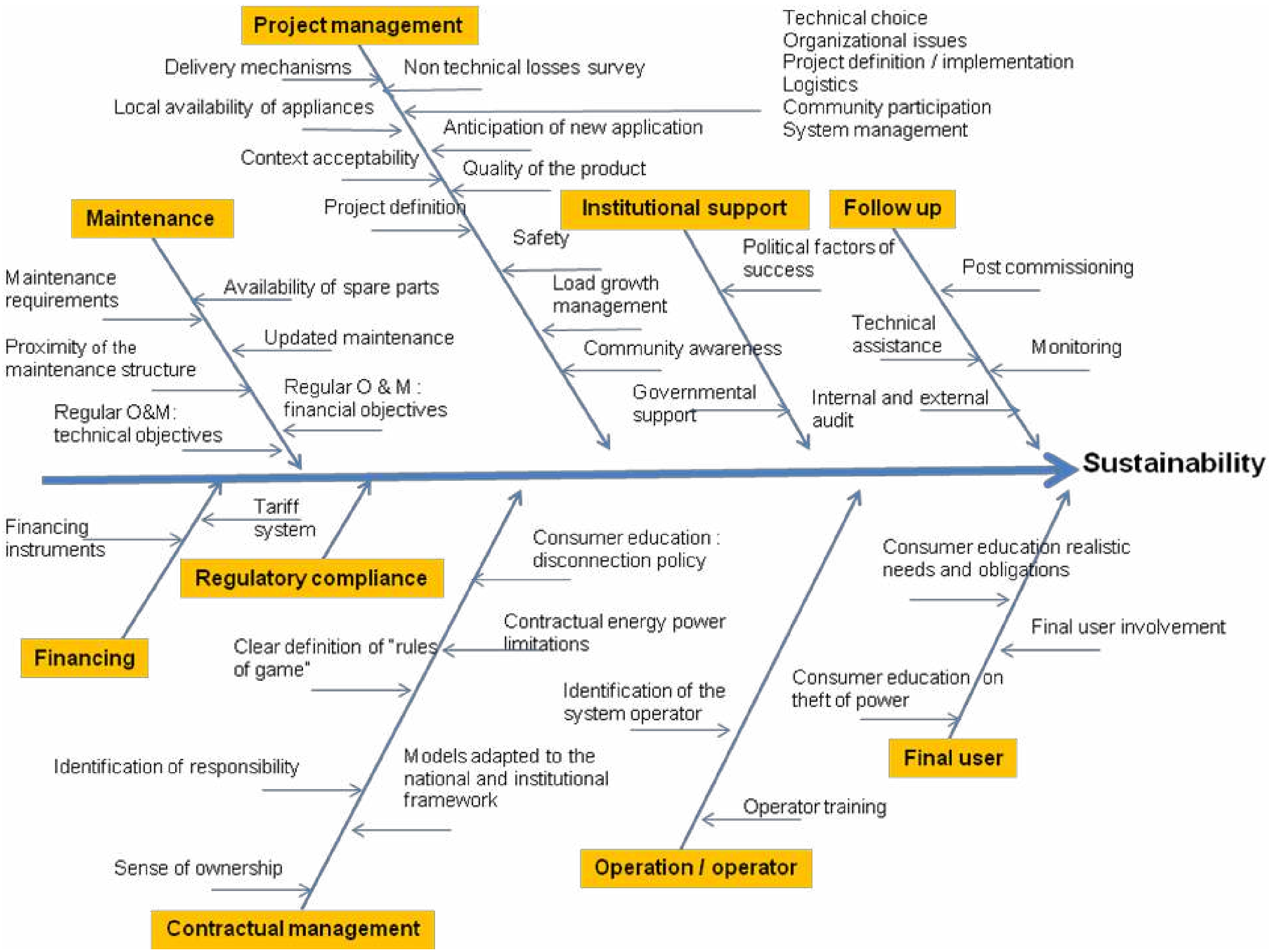


Figure 5: Some factors contributing to sustainability of PV hybrid systems

9.2.2 "Sustainability factors": content and illustrations

FINAL USER

Final user involvement [20]

Example: XeniGwet'in PV/diesel mini-grid, British Columbia, Canada [23]
Four residential buildings were selected for installation of PV systems. The building owners were consulted to ensure their interest and willingness to host PV systems on their roofs. Community members were hired and supervised to install the PV systems on residential rooftops. Different levels of training had been offered to community members in the context of a separate project where PV-diesel hybrid systems are supplying individual off-grid households with electricity. Training included basic information about the workings of a PV system.

XeniGwet'in Enterprise, which owns and operates the mini-grid, has provided information and advice about low consumption appliances. This has been done informally.

Lessons learned / recommendations
Project experience shows that sustainable operation of mini-grids requires much more than reliable technology and a business plan. The role of the user is important. The role of grid-connected electricity consumers is restricted to payment of the tariffs. The situation is totally different for mini-grids. Here, the end users have a vital and comprehensive role to play. They have to be involved right from the inception of a mini-grid project. It is essential that the user community welcomes the new power supply and assumes responsibility at least for the following aspects:

- Realistic articulation of electricity needs
- Ongoing attention to energy efficiency measures
- Awareness of the limitations of the power supply
- Payment of the connection fee and tariffs

Finally, it requires a follow-up with users: have their needs been satisfied?

Consumer education – realistic needs and obligations [7]

Lessons learned / recommendations

End-user expectations of solar systems are often unrealistic –education on the practical application of solar systems must accompany system design and installation.

Detailed user manuals are critical –especially in cases where staff turnover is high

Obligations related to the connection to an electricity supply system: these especially include financial obligations: the understanding of the need to pay for receiving electricity is not to be taken for granted. This has to be explained to consumers in order to make the project a financial success.

A written policy encouraging payment of bills by disconnecting non-paying consumers from the electricity supply needs to be established.

Consumer education – interest in renewables [19]

Example: Eastern Indonesia electrification project [19]
Based on the experience gained to date from developing renewable energy in rural areas, there are several major issues, particularly appropriateness of technology, affordability, and sustainable human resource development.

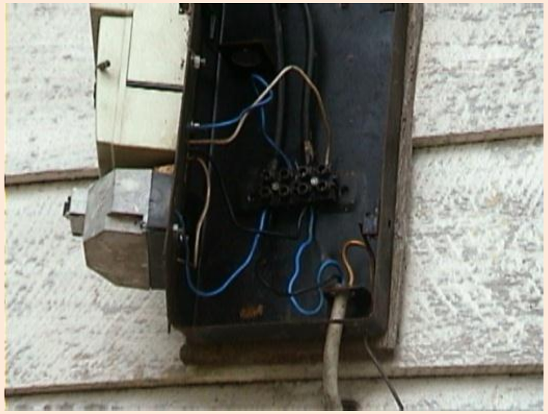
Significant points are as follows:

- The renewable energy hybrid system offers a new approach whereby an affordable service can be provided to all of the villagers.
- The project seeks to specifically build in sustainability and support as a key part of the project itself. Sustainability is to be achieved by the development of local economic activity and a training program to build local capability.
- Renewable energy technology information needs to be improved. Many prospective producers and users do not understand the technology and therefore are not aware of the potential and advantages of utilizing renewable energy systems. This project will assist in overcoming this by the promotion of the project that will be achieved.

Lessons learned / recommendation
The sensitivity of the future consumers to the specific capabilities and the potential of the system they will use has to be developed in the project preparation stage.

Consumer education – theft of power [7]

Example: [11] Example of a bypass:



Lessons learned / recommendations
Consumers must be aware that theft of power, e.g., through bypassing energy meters or current limiters, adds to the non-sustainability of the system.
A course of action should be clearly and explicitly defined if any consumer is found to be attempting to circumvent the normal operating procedure (e.g., bypassing the meters or current limiter or temporarily tapping the main line each evening).

Questions to solve locally:
Few people are willing to risk their life unless they really need to do so: What are the causes of power theft? Low-income, i.e. inability to pay tariffs? Why is this happening? Exploitation of the local community's activities? Distrust in developers? Distrust in government?

One must seek and question the reasons behind power theft to derive a more adequate solution or approach to the problem.

PROJECT MANAGEMENT / SYSTEM MANAGEMENT

Table 2 summarizes the main responsibilities of the different participants involved in a project, as suggested in the IEC 62257 technical specifications series [22].

Table 2: Sustainability Responsibilities of Participants in a Project

Participant	Responsibilities
Project Developer	Obtain resources for financing the project Define/validate the general specifications Define environmental constraints, requirements and decommissioning plan Designate a project implementer Decide if a quality assurance plan is necessary and if so, launch it Prepare a warranty plan Check compliance of the installation with the general specifications
Engineering consultant	Translate user needs into technical requirements Prepare call for tenders (request for proposals)
Project implementer or general contractor	Perform the sizing of the system to comply with the general specification Build the project on behalf of the project developer Achieve the whole installation or appropriate parts of the system pursuant to the general specification Implement the quality assurance process with the subcontractors selected by the project developer Be responsible to the project developer for the conformity of the installation with the following parts of the general specification: − locally available materials and local skills − local laws − time schedule − system-level specifications according to what has been written in the tender/proposal − warranty − quality assurance plan (if specified), including acceptance requirements − commissioning plan, maintenance plan, decommissioning plan (including responsibility) − training initial operators − education of initial users − delivering documentation as described in the quality assurance plan − other information as required Negotiate the best possible warranty for system and components Check the conformity of all or part of the installation-related work performed by other subcontractors involved with the project

Participant	Responsibilities
Subcontractor	Responsible to the project implementer for the satisfactory execution of the selected part of the work as agreed with the project implementer or satisfactory supply of the equipment lot under the project implementer's supervision
Operator	Comply with the quality assurance plan Operate the system in accordance with safety rules for assets and persons Provide the quality of service as contractually agreed with the user Collect fees Plan renewal of parts and components Manage connection of new customers
Maintenance contractor	Manage maintenance and repair pursuant to the contract with the operator including the supply of spare parts
Training provider	Organize and implement the training supports and courses for operating and maintenance agents and for users
User	Use the installation according to the contract with the operator

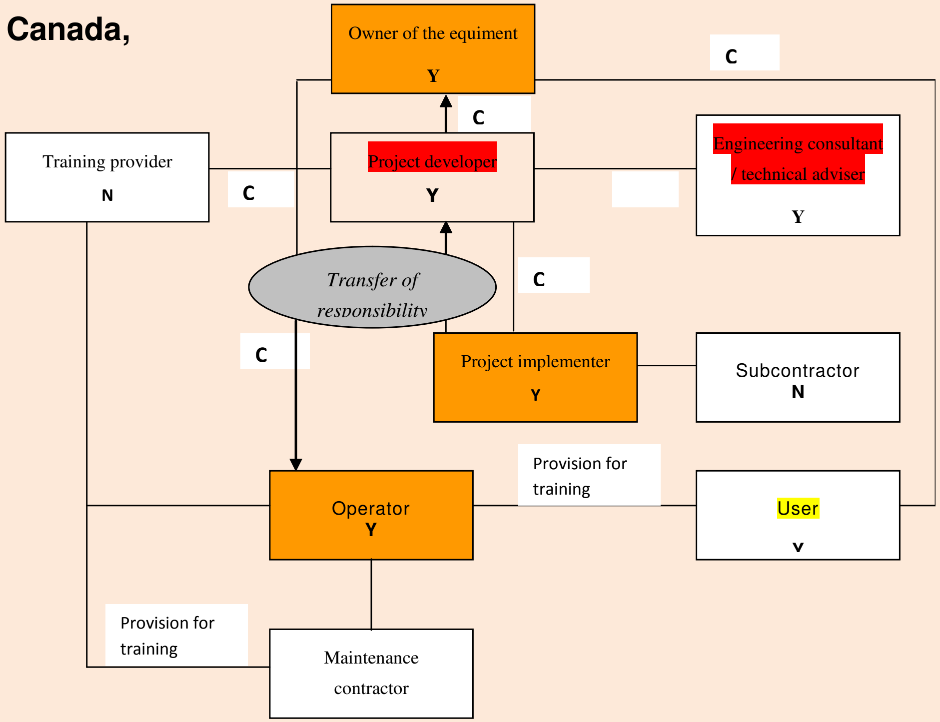
Sense of ownership [5]

Example: general observation

Lessons learned / recommendations
Inclusiveness in project development/design stage:
Establishing an entity that has a stake in the continued successful operation of the system is crucial to cultivating a sense of ownership for ongoing system operation. Innovative financing systems must be properly managed by organizations and individuals who use and pay for the power.

Management scheme: full involvement of the main actors of the project [23]

Example: XeniGwet'in PV/diesel mini-grid, British Columbia, Canada,
In this project, which aimed to design, operate, and analyze the performance of a PV-diesel mini-grid with significant (medium to high) penetration of PV in a Canadian community of 22 households, the following organizational framework has been implemented.



"Y" for "yes" inside the box means that this kind of party was present (otherwise "N").

When two functions are performed by the same party, the same color is used.

The "C" represents a contractual arrangement between two parties.

Lessons learned / recommendations
All the responsibilities described herein have to be present, and contractual arrangements have to be clearly defined.

Note: *Responsibilities may be combined and carried out by one party, or separated out and carried out by several different parties, depending on the structure and participants in the implementation program. In some cases, such as government-implemented programs, many of the different roles may actually be fulfilled by the same institution.*

Technology choice [5]
Lessons learned / recommendations Project design must not be technology-driven. Electricity services should be defined first socially and economically, and then technologically adapted.

Organizational issues [8]
Lessons learned / recommendations Successful programs have to rely on networks of local companies (for product availability, training, O&M, spare parts) and financial intermediaries (access to finance at all project levels). This can be addressed in different ways: support technology transfer and company agreements, link call for tenders with criteria of subcontracting or alliance with local companies, provide technical business training to local SMEs and support business organizations.

Project definition / implementation [8]
Lessons learned / recommendations The projects must be adapted to the local conditions, instead of the local people being asked to adapt to the project. To be successful, projects must respect local conditions and local leadership structures. Capacity building on the technical, business, financing, and institutional aspects of the project and program development is necessary at every point on the project chain and must include all relevant stakeholders. Detailed technical training for end users must cover both electricity uses and limits. The disconnection policy has to be very clear and enforced.

Logistics [5]
Lessons learned / recommendations Local cost and availability of conventional energy (diesel, propane, gasoline) must be managed, as well as local availability of systems, parts, service companies, and technicians. The availability of replacement components (model and brand) from local vendors should be considered when procuring initial system components. Fuel availability and cost are key considerations for PV-diesel technology.

Community participation and training [4] and [8]

Example: Indonesia, Eastern Indonesia electrification project (typical villages of 100–200 houses) [19]
The following actions were planned:

- The project management group will formulate and conduct the training courses for the hybrid systems end users.
- Full system training is to be provided to the regional agents on a cluster basis.
- All villages will receive basic training on system functions and capabilities.
- It is planned that local government agencies will be included in aspects of the training sessions. This will improve the overall exposure of the systems and promote the technologies within each region.

The training sessions will include the following broad areas:

- General description of the hybrid system
- Operation and maintenance of the system
- Organization and management
- Revenue collection and smart card distribution procedures.

Clear and easy-to-understand documentation needs to be provided with the hybrid system. Using this information, the project implementation team will provide training and technical management to the clustered agencies. Training will be implemented from an early stage of the project such that future committed people will be familiar with the systems.

Lessons learned / recommendations
Key factors for sustaining PV hybrid systems are technical training and community participation.

Training, education, and information dissemination to the users is a major factor contributing to successful system operation. Community participation plays an important role in sustaining PV hybrid systems in rural electrification schemes.

For example, this can result in:

- Involvement of local authorities in decision making on the type of power generation to be installed in their community.
- Providing training on maintenance, operation and handling of the specific power generation system for those who are in charge of the system.
- Ownership of the systems by villagers.

Management scheme [6]
Example: [26] Ecuador, La Ye community The hamlet includes 19 households. Communal facilities include a dining house, a community hall, a school, and a health centre. The micro-grid and the isolated micro-PV plants are part of the same ownership and management structure. Ownership of the facility was granted to San Lorenzo Municipality, whereas management of all the installations belongs to an entity created for that specific purpose – the "Junta de electrification rural," which includes the municipality and the community of La Ye. Daily operation of the system is supervised by the "Comision de la luz" (Electricity Committee), a group commissioned by the "Junta de electrification rural" and formed by members of the community who take care of the operation and basic upkeep of the installations, as well as collecting fees and undertaking the management and bookkeeping for operation of the facility.
Lessons learned / recommendations A lightweight, decentralized technical and management structure is recommended, where possible using existing organizations, such as NGOs, cooperatives, and community associations, that can act as local relays.

Reactivity [11]

Example: Indonesia, Transindo Project [11]
In one village, where officials sold off the power station to private operators without having trained replacements, the operators have had to bypass the meter and charge a monthly fee, depending on the user's devices. Of course, this does not necessarily reflect the power used, but represents the value of the product (a sign of wealth or the cost of doing business).

Power consumption and "pirate" consumption, which is no longer controlled, have increased very quickly.

For example, lamps remain illuminated while the building is unoccupied. We even saw a300-W electric rice cooker. Protection related to maximum power and limiting daily energy is imperative to safeguard the system and ensure its sustainability. We met with the village committee to raise awareness of these problems, advising them to increase monthly payments and ban certain loads in order to raise enough money for O&M.

Lessons learned / recommendations
When a problem (social, technical, financial) occurs, the system management must react as soon as possible; if not, a new organization takes over and the "rules of game" may change without analysis of their impact.

DESIGN MANAGEMENT

Context acceptability [6]
Example: Australia, Bushlight Project [18] Remote communities face challenges in using solar technologies to provide sustainable energy services. Isolation from maintenance services and other expertise relating to increasingly complicated technologies can mean experiencing many disruptions to supply. Sometimes inappropriate technologies have been used. Keeping them functioning well could cost more money than available: replacement of parts may not be easy, and the technologies may not suit the level of use they get or the environment they operate in. Community residents might not have the level of understanding or capability required to look after energy technology and use it safely. A premise of the Centre for Appropriate Technology (CAT) is involving local people in the management and maintenance of their assets and identifying the level of responsibility that consumers, service providers, and other agencies need to assume in relation to these activities. The Bushlight project emphasizes informing, training and empowering communities.
Lessons learned / recommendations All operational actions in the field (technical as well as commercial) have to be designed and implemented with respect to the local socio-economic context.

Community awareness [5]
Lessons learned / recommendations Maximizing the awareness and involvement of the beneficiary community early in the assessment phase is vital. Key activities include promotional programs, regular meetings with community leaders, and focus-group meetings.

Project definition [8]
Lessons learned / recommendations O&M organization and costs are the keys to a sustainable project. The project has to be planned with O&M included in the business plan from the beginning in order for the project to generate a cash flow sufficient to cover these costs.

Anticipation of applications [8]

Example: Laos [8]
After the project was implemented, several unexpected technical problems occurred in the mini-grid, and the batteries were running down abnormally quickly. After checking the system, which was functioning well, the O&M team realized that the villagers, encouraged by the success of the project, had purchased warming blankets, an unanticipated gadget in rural areas in Laos, and were using them regularly.

Example: Indonesia – Transindo Project [11]
Loads: Non-planned appliances!
The previous socio-economic study had demonstrated that evolution of loads could be very uneven depending on economic indicators of the villagers. In the village we visited, a significant increase in the number and variety of loads, such as DVD players, karaoke, fridge, etc., was observed.

It is necessary therefore to be very vigilant about load growth and to provide advice and services for the supply of appliances. For example, we found that the CF lamps were gradually replaced by incandescent bulbs, aggravating consumption. Maintenance and preventive audits (one visit per year) are now proposed to the Indonesian agency, LSDE, a laboratory specializing in renewable energy in general and hybrid systems in particular.

Lessons learned / recommendations

It is important when designing a system,

- to size it up slightly to leave room for new and unanticipated applications.
- to size tariffs correctly to limit consumption and overuse of the system
- to describe very clearly to the villagers, and especially to the village committee and to the people responsible for O&M, the possibilities and limitations of their system: consumer education and demand management policies are central to the sustainable operation of an off-grid system.

Quality of the products

Example [18]: Australia, Bushlight Project

The survey, "Renewable Energy in Remote Australian Communities/ a market survey" (2000) identified a number of critical shortcomings in the performance of systems installed in remote indigenous communities.

Recommendations made in relation to the identified challenges were:

- There is a need for product innovation focusing on reducing component count, developing "standard" systems, increased use of third-party accredited testing laboratories, and improved quality control during manufacture.
- There is a need for improved education and accreditation of installers for remote areas.
- There is a need for consumer education on demand management, development and manufacture of high-efficiency end-use devices, electronic control solutions for managing demand, and looking at demand management and household energy use as a whole.

One focus of the "Bushlight Project" is to improve the technical quality and reliability of the systems, including finding appropriate technical solutions to demand-side management issues.

Lessons learned / recommendations

Attention must be paid to ensuring that the products provided to consumers are reliable and deliver promised service levels. Where quality was compromised to reduce investments costs, there were serious negative consequences in terms of consumer satisfaction. The resulting non-payments and reputational risks discredited the technologies and projects.

Survey of non-technical losses [14]
Lessons learned / recommendations Non-technical losses arise primarily from such actions as illegal tapping of lines, meter tampering, and collusion of the meter reader with the customers.

Safety [7 & 10]
Lessons learned / recommendations The issue of safety should be addressed because for many areas electricity is a new commodity, and electrical lines and appliances should be handled with caution. Safety of people must be given special attention since target groups are not necessarily used to these kinds of installations.

Delivery mechanisms [5]
Lessons learned / recommendations The simplest delivery mechanism or business model in line with local realities should be applied. Whatever business model is chosen, care must be taken to ensure that users have access to quality products and services at affordable prices and access to qualified repair services and spare parts over the long term.

Local availability of energy-efficient appliances [8]

Lessons learned / recommendations
Energy efficiency is a crucial component for demand-side management, dimensioning of the mini-grid and, as a consequence, the investment costs. Hence, there is a need for ongoing awareness raising and the local availability of energy-efficient appliances.

Protection against theft

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Example: [11]:**Example of special "protection"**

A seen in the picture, a little white bag has been installed by the village sorcerer to discourage anyone from touching the installation, under penalty of being pursued by "evil spirits."

Note: *Is the presence of PV in the hybrid power system an influence on theft?*
Yes, PV modules are the easiest part of the system to be stolen.

Lessons learned / recommendations
Preventive actions against theft must be implemented.

CONTRACTUAL ARRANGEMENTS

A guarantee of sustainable relationships between the different parties involved in the implementation of a system must be clearly defined.

Institutional issues such as service standards, energy service companies and their operating frameworks, responsibilities for the systems after the implementation period, ownership, and user tariffs have to be discussed and agreed to by all parties involved before a system is installed.

Models adapted to the national legal and institutional framework [20]
Example: general observation: for sustainable operation of mini-grids, there is no "one size fits all" solution, so models must be adapted to the national (legal and institutional framework) and local conditions.
Lessons learned / recommendations The following general recommendations can be made: • A stable relationship must be established between the power producer and the end-user. • Balanced regulatory supervision/mediation (dispute settlement, rights and balances of the parties involved) strategies must be put in place • Ongoing involvement by the national utility company (i.e., distribution and payment collection) and/or government agency (subsidy for the investment costs or on the output) must be maintained.

Identification of responsibility [7]

Example: Emnazel community (Palestine) [20]

Service provided:

A 24-hour quality electricity service to 35 families,3 communal services, and streetlights.

Operator:

The operator is a committee of six members elected by the community. One user is appointed to do the routine upkeep and basic checks.

Maintenance:

A corrective (vs. preventive) maintenance technician is a contracted professional in charge of repairing potential failures of the equipment at the request of the keeper. He is trained on the functioning of the micro-grid with adequate workshops and has some spare parts and manuals available.

Contracts:

Each family/user has signed a binding contract with the operator establishing their tariff (based on capacity of each family to pay) and the energy daily allowance. One of the obligations is to regularly pay the monthly fee and to comply with the regulations established for the service.

The payment of fees is aimed at covering the expenses of O&M, that is, the cost of components, fuel, manpower, transportation, spare parts, etc.

The corrective maintenance has been contracted for a 1-year service term, to be renewed if the parties agree to it.

Ownership:

Transfer of the property assets and equipment has been done from the developers to the operator. This transference is made effective through an official document stating, amongst others conditions, the limitations on the future use of the assets (for example, selling the equipment is prohibited), current and future ownership and guarantees, and the inventory of the equipment.

User training:

Users are trained on efficient and rational use of energy in the household.

Conclusion:

The initial responsibilities were clearly and transparently defined. The role of key players has been defined and will facilitate the O&M of the system. Under this model, tracking of activities is simplified and misunderstandings are avoided. The local community has a strong participation and has defined its own way of managing the system.

Lessons learned / recommendations

The operational structure, i.e., questions of ownership and responsibility, is very important:

- Responsibility for the power plant is important with regard to theft and vandalism. Common experiences show that if the question of responsibility is not solved, then theft and vandalism can become severe problems and compromise the whole success of the electrification project.
- Clear roles for O&M are essential (who is in charge of what, when, in which condition, under which management entity?)
- Clear responsibility for the financial management of a plant is necessary in order to ensure payment of bills by consumers.

Contractual energy limitations

Example: Spain: electricity dispenser/meter [16]
The user association SEBA started developing PV electrification projects for rural villages in 1997 that culminated in the execution of a specific program under a European project MSG (2000-2003).

Key elements of the implemented micro-grids are the electricity dispenser and the meter.

The electricity dispenser (patented by TTA) is an electronic electricity meter that is installed in each user's home. It contains an algorithm that limits consumption and guarantees each user an allowance of energy according to the tariff contracted. The electricity dispenser:

- Promotes an interface between users and generation in the power plant (closer link to the value of power).
- Reduces the investment required and encourages maximum use of available energy.
- Enables the establishment of new, sustainable tariff schemes that are better adapted to generation using renewable energy, like the EDA concept (EDA= Energy Daily Allowance) – a response is designed according to the user's needs.
- Avoids risk of individual over-consumption.
- Encourages consumption at times when there is surplus production.
- Provides incentives for the rational use of energy (promotes conscious consumption).
- Offers flexibility in energy sharing between users.
- Facilitates electricity usage (the technology simplifies use, rather than becoming a burden/preoccupation).

We should even use this in the urban settings where rational use of energy is equally critical!

Conclusion:
The users have an understanding of generation limitations while their interaction is simplified. Users become aware of electricity consumption and will seek a rational use.

Lessons learned / recommendations

Operation of mini-grids is frequently disturbed by power plant overloads causing blackouts in the community. In the same way, the economical base of mini-grids can be disturbed if the collective of users don't meet the determined contractual agreements, if the energy demand was wrongly estimated, or if the customers don't pay their energy bills.

These problems could be prevented by:

- Limiting available power for the users. This individual power limit should be defined in a "Supply Contract" with the system operator. An energy meter would be used to control the limit.
- Limiting energy use. The expected energy consumption should also be defined in the "Supply Contract."

Tariff system

Example: [28] Ecuador, La Ye community
The hamlet includes 19 households and communal facilities including a dining house, a community hall, a school, and a health center. To be able to sustain the operation, the fees were established based on willingness to pay and are higher than the national tariffs for grid-connected clients. The scheme is based on a flat fee for “daily energy allowance,” and the same tariff structure is used for the micro-grid and the isolated sites. Each consumer pays a flat monthly rate, which entitles them to consume a certain amount of average daily energy. This energy management is achieved by the means of an alternating current meter at every consumer connection, which can dispense and limit the energy with a certain amount of flexibility. This device reads the energy credit available to the user from a portable digital memory card, therefore making it possible for the users to use their energy allowance from any supply point of the village, not only their household.

Lessons learned / recommendations
Flat rates based on a daily energy allowance have proven to make operation easier and more cost-efficient without the need to carry out meter-reading and invoicing the users. Flat rates have reduced the risk of users failing to make their payments, allowing a sound cash flow which ensures sustainability.

Consumer education: disconnection policy [14]

Lessons learned / recommendations
Regulations regarding reasons for disconnection and the terms under which this will be carried out must be made clear and should be included in an agreement that the village utility enters into with every consumer.

These must be enforced without exception. Any delay or exception is bound to create further problems in the future with other consumers, to the detriment of the entire system.

INSTITUTIONAL SUPPORT

To increase the likelihood of sustainability, government support, including its financial commitment, is essential, as is the use of light-handed and simplified regulation.

Governmental support and political factors of success [7]

Example: Uganda [20]
The Ministry of Energy and Minerals of Uganda, together with the Private Sector Foundation of Uganda (PSFU), offers annual training on PV system operation and maintenance to rural technicians and inhabitants. The installation of the system in Kabanga would benefit from this initiative to ensure that qualified residents would be available to provide technical expertise in case of failures or for routine maintenance.

Example: Malaysia [25]
Almost all remote electrifications are fully supported by the government for capital expenditures and taken over by the utility company for operational expenditures.

Example: Indonesia, Eastern Indonesia electrification project [19]
The (electrification) project seeks to specifically build in sustainability and support as a key part of the project itself. Sustainability is to be achieved by the development of local economic activity and a training program to build local capability.

Lessons learned / recommendations
Social and financial incentives from institutional bodies are necessary:

- To demonstrate commitment to decentralized electrification.
- To establish electricity laws, legalize rural energy markets and to allow private operators to supply electricity.

Elimination of tax and duty barriers:

- To make the options of renewable energy and hybrid systems competitive.

REGULATORY REQUIREMENTS

Regulatory compliance
Example: Malaysia [25] The Malaysia Standards Department recently (2010) released standards related to stand-alone PV systems. However, standards for grid-connected systems have been in place since 2005.
Lessons learned / recommendations National standards for the placement, design, procurement, installation, and end-use servicing of PV systems can help improve sustainability.

Hybridization of the Mini-Grid
In purely diesel off-grid mini-grids, running costs for O&M and especially for fuel consumption become very costly in the long term. Therefore, many diesel mini-grids are limited to only a few hours of operation during the day.

When integrating solar and wind sources into mini-grids, fuel consumption decreases and consequently so do the operational costs. However, a main issue in hybrid PV systems, besides the fuel consumption, is the maintenance and replacement of the battery bank, if used. Additionally, integration of solar and wind technologies increases the up-front cost; however, in the longer term, the levelized energy cost (the cost of generating a unit of energy) can be decreased.

Example [26]: GLENAN, France
Saint-Nicolas Island, located in the northwest of France, belongs to the Glénan archipelago. Two restaurants are located on the island, whose main activity is tourism in summer. During the rest of the year, fewer than ten people live on the island. Development of the tourist activity and the growing number of daily visitors, especially in summer (reaching 2,000 people a day in July and August), generates large seasonal variations in the consumption of energy, making it difficult to size the power plant.

By operating the mini-grid based only on a diesel genset, the cost of the electricity produced was about 1.1 €/kWh. With the integration of a PV and wind generator as well as a battery bank, it was possible to reduce the cost of the electricity to about 0.6 €/kWh.

Lessons learned / recommendations
Life-cycle cost analyses help to establish the lowest cost system design and solution for a given site over the long term. For PV systems, a 20 year life cycle is usually used.

Financing instruments

Classic assistance for rural electrification in some cases provides subsidies for fuel cost, donations of equipment, or price discounts. Other funds or aid focus mainly on capital investment, available mostly through aid development channels, such as regional policy, agricultural policy or corporate social responsibility (CSR). Other schemes comprise subventions not only for capital, but also for the O&M of PV systems and can be based on installed power (kW), produced energy (kWh), or avoidance of CO_2emissions.

Policies that incorporate attractive incentives have been found to play a catalytic role in the “market pull” effect for renewable energy systems and are practical steps for increasing the share of renewable technologies.

Fixed-price instruments (e.g. feed-in tariffs) are presently operating in several countries. Fixed prices or premium tariffs are mechanisms in which the government sets different fixed premium tariffs or an environmental bonus above the normal or spot electricity price that has to be paid to renewable energy producers.

Example [27]: Feed-in Tariff in Ecuador
In Ecuador, the subsidy granted for the capital investment in a PV system is about 2,000 USD per household or other consumers (CONELEC-Regulación No. 002/05). Through the Feed-in Tariff Law (2007), the subsidy was about 0.52 USD per kWh (CONELEC-Regulación No. 009/06)

Technology	USD-cent/kWh Mainland	USD-cent/kWh Island
Wind turbines	9.39	12.21
Photovoltaic	52.04	57.24
Hydropower less than 5 MW	5.80	6.38
Hydropower 5-10MW	5.00	5.50

In order to use a tariff based on kilowatt-hours, measurement and monitoring systems must be implemented, with the accounting requiring a certain amount of effort. Meters with automated data loggers and other functions are now being developed. This could be helpful in promoting the market for off-grid systems in the future by establishing new financing models, especially ones based on kWh used, rather than kW installed.

At present, the subsidies in Ecuador are officially available only to the electricity supply companies, the majority of which are owned by the government. New financing instruments can be effectively implemented, but the bureaucracy must be reduced and more user-friendly models have to be developed.

Lessons learned / recommendations
Institutional, economic, technical, and administrative frameworks have to be implemented in a transparent and efficient way to make financial support a key issue for the installation and long-term operation of hybrid PV systems.

OPERATION ORGANIZATION

Identification of a local system operator [7]
Lessons learned / recommendations ESMAP, 2000: In rural communities, the potentially high degree of respect and acceptance of elder people within the community could play a role when deciding on a local system operator. Also, the engagement of young people as system operators, having been recently educated at school or having just graduated and looking for work, has been shown to be problematic. Young people tend to be more likely to seek change and to move away to urban areas once trained.

Operator training [14]
Lessons learned / recommendations The individuals who might to be responsible for the operation of the plant should preferably be selected at the outset of the project and be involved in all aspects of the project construction. This serves as important on-the-job training and will also give the community or entrepreneur a chance to gauge the suitability of those individuals—in terms of attitude, aptitudes, integrity and rapport with the community—to assume the role of operator.

Operator financial responsibility [14]

Example: Malaysia [25]
The utility company's meter readers read kWh at each household every month.

Lessons learned / recommendations
Another task of the operator might be to collect the bills from each consumer on some regular basis. This is at times a difficult task because it can pit the operator against some consumers who want special favors (like a reduced bill). To facilitate this task, all consumers must be aware of the fact that they are responsible to other system users, to ensure that all bills are collected and that they are each personally responsible for any shortfall.

MAINTENANCE ORGANIZATION

Experience shows that a lack of maintenance ultimately has a negative impact on reliability and leads to substantial costs in the future. That's why regular and timely maintenance of all equipment is essential for the equipment to function over its planned lifetime. Routine maintenance as well as major overhauls and capital replacement needs to be planned and budgeted for in advance. Maintenance problems often are easily preventable, yet frequently overlooked.

Note: It is relevant to distinguish the activities of upkeep and technical maintenance. An upkeep action plan defines who is locally responsible for operation, basic inspection, cleaning equipment, first diagnosis in case of trouble and calling the maintenance technician.

Some field facts and recommendations are noted below.

Maintenance requirements
Example: PV hybrid systems near Kahang, Malaysia [25] Initially the project was owned by the government. After approximately two years of operation, the project was handed over to the utility company. The utility company is one of the Government Link Companies (GLCs). All the O&M activities on the system are being carried out by the utility company on a clear basis. Funding for maintenance is provided by the utility company.
Lessons learned / recommendations Acceptance, operation, maintenance and replacement policies as well as field actions have to refer to contractual requirements clearly defined between the project developer and the service operator.

Affordable maintenance
Example: Senegal [10] As said by a maintenance company technician: “We don’t have the capacity or funds to change all the old equipment and keep all the parts in working order. If we can’t keep up the maintenance, the systems will become less and less effective and fewer users will pay the fees we rely on to maintain the systems in the first place; currently only 30 percent of the homeowners supplied by the system are paying.”
Lessons learned / recommendations Lack of maintenance: a vicious circle. A tariff paid by the users within their ‘willingness to pay’ must be able to sustain at least operation and replacement of components.

Maintenance organization and availability of spare parts

Example: Inner Mongolia [7]
Different PV diesel hybrid systems were installed for village electrification, repeater stations, and household systems in inner Mongolia (PV generator up to 10 kW, diesel genset 8-24 kW). The executing company is Hua De New Technology Company (HDNTC). There was no agreed-upon management system for the plants with the villages. In most cases, the villages decided to choose the operator of their previously used diesel genset to operate the hybrid system. The chosen operators were then trained by HDNTC with a mobile training bus and additional on-the-job-training during and after installation.

The operator of the village system is responsible for maintenance of the systems and all expenditures for it. However, HDNTC can be contacted via telephone and gives advice in case of technical problems. Most appropriate after-sales service is difficult, since many villages are situated far from the company. In the case of a major breakdown and the need for spare parts from Germany, downtimes of one or two months may occur.

Example: Malaysia [25]
The maintenance office is located at a regional office approximately 50 km away. Although there is no formal agreement between the operator and the local people, usually local people contact the operator's maintenance office in case of a power failure. For minor breakdowns that do not require replacement of components, downtime is usually 2 days. However, for critical components such as inverters, which are not locally manufactured, the downtime can be 2 to 3 months.

Example: Malaysia [25]
Prices for balance of systems (BOS) components change very fast. Many PV service providers do not store expensive components for use as spare parts. Problems arise when BOS components that are not locally manufactured have to be sent back to the country of origin. There were no tool kits available at the sites.

Example: Indonesia, Eastern Indonesia electrification project [19]
In each region where systems can be operated on a cluster basis, a central service company is appointed to attend to local service and to support the systems by having spares and any necessary components available.

Lessons learned / recommendations
It is preferable to have maintenance support available at all times.
Proximity of such support to the user will guarantee longevity of the service [6].
Dependency on a resource not locally available, e.g., a high-tech product, leaves no means to plan actions to minimize potential downtimes

Questions to solve during the project definition:
Is it possible to use local equipment?
How critical is the distance to the spare part supply?
How much does a lack of spare parts affect downtime?

Regular maintenance [14]

Example: Malaysia [25]
All maintenance actions are carried out by the utility company with adequate competency and skill.

Lessons learned / recommendations
A skilled person should be committed to perform planned actions, for example:

- Starting and shutting down the plant on an established schedule.
- Making regular inspections of the mini-grid, ensuring adequate right-of-way clearance in the vicinity of the line, trimming any branches that could threaten the integrity of the lines, looking for signs of irregularities along the lines (such as unofficial taps to the line), and foreseeing potentially hazardous conditions along the line (e.g., caused by a broken guy or a deviation in the alignment of a service drop to circumvent a new home being erected).

POST-COMMISSIONNING / FOLLOW UP / MONITORING / TECHNICAL ASSISTANCE

Post-commissioning [11]

Example: Indonesia – Transindo Project [11]
The project comprises electrification of four villages with hybrid systems (40kVA, 24kWc each).
The first months of operation showed that the usage pattern originally designed for was not being followed, and it was imperative to maintain support for the project over the initial months.

Monitoring and adjusting operational schemes have since been undertaken to achieve optimized operation (autonomous and perennial).

Some issues from the engineering company report:

Preventive maintenance
The preventive maintenance procedures carried out by local operators appear to have been validated and operational through training prerequisites.

However, during our last unannounced visit to a village, in June 2002, we observed that maintenance of the station and its surroundings was poor. We have therefore taken the operators hand, raising awareness of the problems engendered by such negligence (e.g. shadows on the modules, structural damage) then discussing these issues with them.

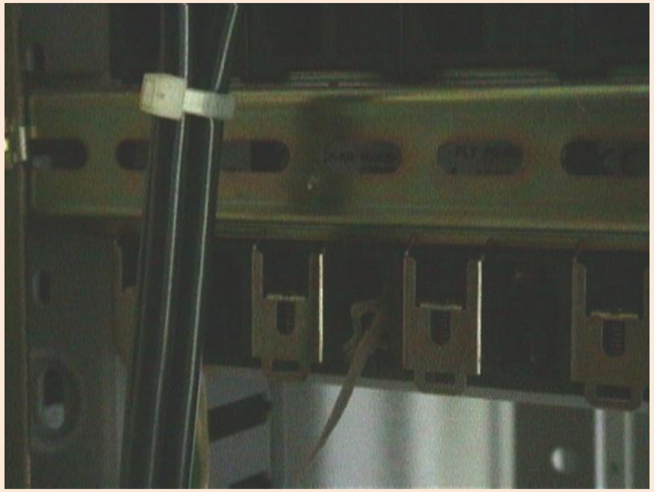
Moreover, as various waste littered the area around the station (packaging, empty oil bottles) we asked them to make an incinerator with an old oil drum.

The message is to explain that maintenance starts with cleaning the surroundings and the basic maintenance of buildings and this sets an example for villagers without significant expenditure.

Initial state

Final state after visit

Curative maintenance



The technical quality of components and equipment has produced some power outages (inverter, charger) and control issues (data acquisition system, satellite phone).

The main reasons for outages:

First, small lizards entered the cabinets through small gaps in the sealing. The sealing has been strengthened with canisters of foam polyurethane. But, given the ambient temperature, ventilation grids are necessary for natural convection and these small, flexible lizards are able to get through the mesh covering the grid.

Secondly, short circuits on the network:

The overhead network:
The internal network to the villages, having been made outside of the overall contract, has escaped the overall maintenance process. It was then apparent that the vegetation was becoming pervasive, and some poles were collapsing.

Fortunately such cases are rare and additional information has been given to overcome these shortcomings.

It should be noted however that the most serious failures reported have been caused by short circuits on the network (either at the user level or in the aerial network after high winds, for example). This suggests that the protection systems in the energy meter are not always operational.

Lessons learned / recommendations
Evaluation is usually considered as a final step in development projects. However, it should be a continuous process to allow readjusting the initial project plan and contribute to the sustainability of the project.

Technical assistance
Lessons learned / recommendations Technical assistance includes training, both through workshops and a program of on-site professional visits, resource assessment, preliminary analysis of alternatives, program/project development, and performance monitoring and evaluation.

Monitoring [20]
Example: Malaysia [25] In general, there are two stages of monitoring: Stage 1: Manual monitoring activity where all the data are uploaded manually every month. This is the current practice. Stage 2: The data will be uploaded automatically using satellite communication. This is in the planning stage.
Lessons learned / recommendations To evaluate required modifications, we must be able to trace and analyze the history of the system. Monitoring facilitates can estimate the increase in electrical demand, indicating if systems for household consumption should be scaled up or if new users may be allowed to connect to the existing network.

Internal or external audits [11]
Lessons learned / recommendations Follow-up with the users' system operation is crucial in order to establish whether it complies with requirements. Checkups should be regularly performed using a check list of technical, social, organizational, and financial criteria.

10. Summary

Key lessons learned from the field experiences documented in this report can be summarized as follows [15]:

- The project design must not be technology driven. Electricity services shall be first socially and economically defined, and then technically adapted.
- Participation of the users from an early stage in the project definition, in project execution and in operation helps realize a design that matches the actual demands and makes the final users take more responsibility to maintain the installations.
- Robustness is often better than high efficiency.
- Agreement must be reached in advance so that the users are aware of the energy limitations and of the need for efficient appliances.

Most failures aren't due to technical problems but rather to a lack of an organizational scheme to operate the system (managing the O&M tasks and collecting payments from users), and also due to a lack of an energy management concept which encourages the responsible use of energy.

The main observed causes of weakness in a system are:

- Not covering the electrical needs of users
- Increase in demand (unplanned consumption by users)
- Logistics (for spare parts and high-efficiency appliances)
- Lack of provision for maintenance.

Careful design of the hybrid system to meet the requirements of the community and a responsible choice of system components, together with training to operate and maintain the system, are basic requirements for the sustainability of the system.

However, achieving sustainable economic and widespread use of hybrid systems will only be possible if local management schemes, effective policies, meaningful finance, and cooperation with system integrators and technology providers are put into place. [24]

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