Solar Photovoltaic Systems for Social Infrastructure and Village Electrification in Mozambique:

Study of Existing Systems in two Provinces

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List of Acronyms

AC	alternating current
Ah	ampere-hour (capacity of a battery)
AMES-M	Access to Modern Energy Services Mozambique (project implemented by GIZ)
ATP	ability to pay
AV	audio-visual
CB	cost-benefit
CDM	Clean Development Mechanism
CFL	compact fluorescent light
DC	direct current
DED	German Development Service
DIPREME	Provincial Directorate of Mineral Resources and Energy
EDG	Energy & Development Group
EDM	Electricidade de Moçambique
EPC	Escola Primária Completa (Primary School offering grades 1 to 7)
ERAP	Energy Reform and Access Programme (financed by the World Bank)
FUNAE	National Energy Fund of Mozambique (Fundo Nacional de Energia)
GIZ	Deutsche Gesellschaft für Internaitonale Zusammenarbeit (GIZ) GmbH (Formerly: German Technical Cooperation, GTZ)
GoM	Government of Mozambique
HC	health centre
ICT	Information and communications technology
kWh	kilo-watt-hour (of energy)
LED	light emitting diode
LPG	liquid petroleum gas
LV	low voltage
LVD	low voltage disconnect
O&M	operation and maintenance
Norad	Norwegian Agency for Development Cooperation
MINED	Ministry of Education
MISAU	Ministry of Health
PAV	Extended Vaccination Programme (Programa Alargado de Vacinação)
pm	per month
PV	photovoltaic
RSA	Republic of South Africa
SHS	Solar Home System
SLI	Start, Light and Ignition (battery type)
TV	television
UV	ultraviolet
V	volt
VRLA	valve regulated lead acid battery
W	watt (of power)
WB	World Bank
Wh	watt-hour
WHO	World Health Organisation
Wp	watt peak (of a solar plant)
WTP	willingness-to-pay

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EXECUTIVE SUMMARY

Over the past years, in order to provide an alternative to grid electrification in rural areas of Mozambique, an increasing number of solar photovoltaic systems have been installed by different actors under a variety of projects. The two main types of projects carried out have been targeting, on the one hand, social infrastructure buildings (schools and health centres) and, on the other hand, village coverage with solar PV systems.

The present study has looked at PV systems funded and commissioned by various organisations in different institutional settings. Overall, the site visits revealed that where PV systems function as intended, they create important benefits and these benefits are much appreciated by the beneficiaries. At the same time, the visits also found that the maintenance and sustained functioning of PV systems in rural settings is a formidable challenge. Various institutional arrangements have been set up to address this challenge, and FUNAE has overall assumed a very important role in assisting and supporting activities aimed at ensuring the proper functioning of the PV systems.

There remain some issues that reduce the effective functioning and use of the installed PV systems: It appears that the potential benefits of PV electrification are in some cases not fully realised, either due to users' limited awareness of possible uses, or as a result of system or component failures. In some projects, shortcomings in the quality of components, of system installation, and of system engineering more generally have been observed. Quite a number of cases were found where system breakdown or maintenance problems took considerable time to be addressed. This appears partly due to the fact that different institutions' responsibilities and capacities for project implementation, monitoring and maintenance were not discussed and agreed upon in detail before project start. Also, the sustainability of maintenance needs (in terms of funding, human resources, spare parts and logistics) had not been thoroughly assessed before project start, and there had been limited analysis of the affordability of PV systems for private users.

Given the varied nature of challenges encountered in the functioning of existing PV systems in rural areas, it appears recommendable to address them in a systematic way, looking at all the stages of a project, including preparation, inception, realisation and maintenance. Hence it is recommended to address both technical and institutional requirements comprehensively throughout the project process, including post-installation maintenance and recurrent funding. The planning process should incorporate internal loop-backs to consider critical trade-offs and facilitate inputs of sectors, communities, procurement specialists and other stakeholders early and continuously throughout the project process. It is advisable to consistently include consultations with independent specialists to take advantage of existing experience and expertise.

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1 Introduction and Objectives of the Study

Mozambique has significant electric power generation capacity, and grid coverage in and near the population centres is growing steadily and reached a country-wide average of approximately 14% (in 2009). However, Mozambique is a vast country with the majority of the population (around 65% in 2009) living in dispersed rural communities. Grid coverage in rural areas is currently at below 4% of the population, which means that at least 12 million people living in rural areas are not connected to the electricity grid.

Over the past years, in order to provide an alternative to grid electrification in rural areas of Mozambique, an increasing number of solar photovoltaic systems have been installed by different actors under a variety of projects. The two main types of projects carried out have been targeting, on the one hand, social infrastructure buildings (schools and health centres) and, on the other hand, village coverage with solar PV systems.

A considerable number of these projects have been realised by the Mozambican National Energy Fund FUNAE (Fundo Nacional de Energia). FUNAE is a public entity that has the mandate to promote rural electrification and rural access to modern energy services in a sustainable manner, and as a contributor to economic and social development in the country.

In order to better understand the success and challenges encountered with solar PV in rural areas of Mozambique to date, together with FUNAE AMES-M has realised the present study on existing PV systems in rural Mozambique.

The study aims to identify and analyse factors that affect long-term functioning of solar PV systems at social infrastructures (schools, health centres, and administrative offices) and for village electrification. Hence, the general objective of the study has been:

> *To assess the experience gathered by different organizations in the implementation of solar PV projects in social infrastructure and village electrification, with a view to defining a sustainable approach.*
>
> *Specifically, the study has evaluated:*
>
> 1. *The challenges being faced in installation, operation and maintenance of the solar PV systems;*
> 2. *The viability of the organizational structures chosen to support system maintenance;*
> 3. *The potential and actual benefits of PV systems for social infrastructure and village electrification.*

The methodology of the study is described in Annex 1. The following table gives an overview of the types of systems and localities visited, in each case indicating the implementing agency and the funding agency (the latter in parenthesis).

Table 1: *Overview of sites visited*

Implementing Agencies (Funding Agency)				
DIPREME Manica (DED)	**MISAU (Norad)**	**FUNAE – Social Infrastr. (World Bank-ERAP)**	**FUNAE – Villages (*World Bank-ERAP; °Spanish Governm.)**	**Other systems**
Manica Province				
EPC Chipandaumue (Gondola District)	HC Macossa-Sede (Macos-sa District)	EPC Nhassacara (Barue District)	*Mungari Solar Village (Guro District)	Macossa-Sede: District-financed solar water pumps
HC Chipandaumue (Gondola District)		EPC Honde (Honde District)	*Mavonde Solar Village (Manica District)	HC Mutocoma (Gondola Distr.); FUNAE financing
EPC Mozambizi (Honde District)				
Nampula Province				
			°Chinga Solar Village (Murrupula Distr.)	
		HC & EPC Imala (Muecate District)	°Imala Solar Village (Muecate District)	
		EPC Iuluti (Mugovolas District)	°Iuluti Solar Village (Mugovolas District)	

Overall, it is important to indicate that the results of the present study do not pretend to be representative. The type of systems, their installation and maintenance, and conditions of use and upkeep may differ from Province to Province, within Provinces and also between villages, depending on who did the installation, what technical specifications were used, who commissioned a project, as well as local conditions and socio-economic dynamics. Meanwhile, the results have validity for the two Provinces and the types of systems visited.

The remainder of the report is structured as follows: Chapters 2 to 5 summarise the information obtained in interviews and during field visits. Chapter 2 looks at the present state of functionality of the visited systems, and at the quality of components and installation. Chapter 3 describes the maintenance concept in place, and the actual maintenance services delivered at the system sites. Chapter 4 analyses the potential and realised benefits of the PV systems. Chapter 5 looks at system costs as well as beneficiaries' willingness and ability to pay for PV system services.

Chapter 6 presents conclusions and Chapter 7 proposes some recommendations for the way forward.

2 TECHNICAL EVALUATION OF THE INSTALLED SYSTEMS

The technical evaluation is based on observations at the visited sites. Also, some short performance tests were done to support observations and conclusions. For the performance tests, field measurement equipment was used, including voltmeters, power meters, scope meters, light meters and solar radiation measurement devices.

2.1 System functionality and operational status

The systems visited were checked for functionality and whether they were operational: A functional system is one that has all components in place and can potentially generate the foreseen system services, but it may be either operational (i.e. its services are being used) or non-operational (its services are not being used, e.g. because the system loads are broken, or because night classes are not held). Functionality is determined by on-site measurements, whereas operational status is assessed from interviews.

The following paragraphs summarise the functional and operational status of the visited systems, first for social infrastructure, and then for village electrification systems.

2.1.1 Social Infrastructure systems

The two schools visited with systems commissioned by *DIPREME Manica* (funded by the German Cooperation Agency DED) in 2006 were non-functional and beyond repair, due to vandalism and subsequent neglect. The one system installed by the same organization in a health centre is possibly repairable but has been in that state from 2007 and has been out of use since then. For these systems, no specific *maintenance scheme* has been put in place. Hence the users/local communities are not aware of any possibility how to get the systems repaired or how to get spare parts.

The *MISAU/Norad* system visited in Manica was installed in 1998 and is partially operational. The PV vaccine fridge system is fully functional, and the health centre lighting system is operational with some direct current (DC) lights working. However the systems in the staff houses are not used as the DC strip lights have failed and have not been replaced. The staff sometimes have access to a local mini-grid and thus seeking out DC strip lights may not be a priority. MISAU PAV *maintenance* staff provide some support for the vaccine fridge, but it appears that no maintenance (and, especially, spare parts) is provided for the lighting systems at the health centre or staff houses.

The functionality of *World Bank* financed social infrastructure systems at schools and health centres (commissioned by FUNAE), both in Manica and Nampula, falls into two distinct categories:

a) PV vaccine refrigeration systems are by and large fully functional and supported by PAV maintenance staff.

b) PV lighting systems fall into the category of partly functional, as the power supplies are working, both at schools and at health centres. But widespread failure of the large majority of DC lights within 2-3 months of installation means that most of the systems are non-operational and therefore of very limited or no use. These component failures have not been addressed on a large scale for many months. Few other problems were found relating to system functionality, but long term issues of quality of installation may affect some sites realised by one contractor.

   The systems have been installed and there is technically a one year defects period. But importantly, many of these failures occurred before completion of handover, which is due to latent defects in the equipment supplied. Hand-over of the systems to the sector authorities can only take place once such shortcomings have been addressed. Responsibility for the rectification of this situation lies with the project management (i.e. the supervision consultant, FUNAE project managers, and funding agency supervision). Contractual and financial mechanisms need to be in place to address such issues, and they need to be applied and enforced in order to achieve the intended results.

2.1.2 Village electrification systems

The solar villages visited in Manica and Nampula are based on 2 different technical specifications and approaches (details in Annex 2):

In *Manica*, 9 different PV system types – so-called kits A to J – have been installed in villages, each kit foreseen for a specific target group and use. FUNAE established the technical specifications and implemented the project.

During visits in the filed, it appeared that the small solar lanterns (Kit A) seem to be improperly used and/or of inadequate quality and failing at a rather high rate. Systems with small inverters (Kits B, C, E) feeding AC sockets are experiencing problems with the inverters/charge controller interconnection, which causes the AC sockets to become non-operational, or causes the charge controller to fail totally. Some of the DC lights are still operational, but also show significant failure rates in all kits (Kits B, C, E, F, and G), without otherwise affecting system performance.

The operation of fridges (Kits C and F) is also problematic but does by itself not cause total system failure. The water pumping systems (Kit D) seem to be fully operational, and street lighting systems (Kit H) are mainly functional.

Overall, in the village electrification in Manica there are many problems but none of them seem to be fatal, and most systems (except lanterns) are at least partially functional and operational. However, the systems with inverters are incorrectly wired up through the charge controller, resulting in charge controller burn-out, and these all need to be physically corrected.

In *Nampula*, 2 types of larger AC-based systems have been installed for village electrification, based on technical specifications developed by the Ministry of Energy. Implementation was realised through FUNAE.

Of the 13 systems visited, 8 were fully operational, 2 were functional at partial output due to reduced array capacity, and 3 were non-functional due to inverter failure which means that the system does not provide any service. Failure of charge controllers was also a problem in some systems, but appeared to coincide with inverter failure. Theft of panels resulted in reduced array capacity in one system.

In the two provinces visited, theft and vandalism are of some concern, but do not appear to affect system operation at a wide scale or at a project inhibiting level. Cases of vandalism and theft were most often observed in schools, especially during school holidays. In one case, it appears that components were stolen or vandalised only after the system had broken down.

2.2 Quality of major components and installation

The table on the following page (Table 2) gives an overview of the component types and brands used in the different systems. For the main components, a short indication regarding quality and adequacy for the given system and use is given. A more detailed technical description of the system components and installation can be found in Annex 3.

Generally the main components in place are of adequate quality, but there are instances where quality or choice of a particular component is in question, or matching with other components in the system is a problem, or where environmental considerations (e.g. exposure to direct sunlight) affecting component location or operation should be taken into account.

The main component issues which arose from the site inspections were:

- Certifications: valid product certifications (panels, vaccine refrigerators, light bulbs);
- Quality: are the components suitable for professional system or just for Solar Home Systems (SHS) or recreational usage (batteries, solar charge controllers, inverters);
- Component matching: match between charge controller and battery, or match between the inverter load shed point and battery requirement, and compatibility of inverter and charge controller;

- Serviceability: maintenance requirements and access to spares for specific components offered (batteries, pumps, light bulb types chosen);
- Appropriateness for temperature environment and exposure (battery).

The *installation engineering, quality and balance of systems* issues are also very briefly summarised in the table that follows (Table 3); more details can be found in Annex 3. Generally, installation was undertaken by local contractors using the major components offered. In general, there was good consistency between installations within given projects. Issues that raised concerns were:

- Array structure quality and installation on roofs, shading of array;
- Lighting layout within the buildings is non-optimal in general;
- AC or DC plugs sockets incompatible to those available in rural areas and provide no useful access to the user;
- Battery enclosures are insecure or poorly located, compromising battery life or user safety;
- System protection: inverter compatible with charge controller in provision of low voltage protection, and no use of lightning protection in inverter systems;
- Electrical protection and fusing or lack thereof.

Table 2: *Main PV system components used*

	DIPREME (German Coop./DED)	MISAU (Norad)	FUNAE (World Bank ERAP)	FUNAE Villages Manica (World Bank ERAP)	FUNAE Villages Nampula (Span. Gvt)	District installed & financed
Solar panels	unknown	Naps	Angelique: Central Electronics Limited (Indian) Mohan: unknown	Rentech (RSA)	Isofoton	unknown
Quality:	*n/a*	*compliant*	*not clear*	*compliant*	*compliant*	*n/a*
Int'l certification?	*n/a*	*yes*	*not clear*	*not clear*	*yes*	*n/a*
Batteries	Royal mod. SLI	Naps/Tudor flooded tubular	Triumph VRLA Powerstack VRLA	Deltec/Excis mod. SLI	Hawker flooded tubular	Not used
Quality / suitability:	*SHS*	*professional*	*professional*	*SHS*	*professional*	
Charge controllers	Sollatech	Naps	Phocos CX & CA series Morningstar Prostar series	Phocos CX & CA series	Isoter D30 series	unknown
Quality /suitability:	*SHS*	*professional*	*professional*	*professonal / SHS*	*professional*	
Inverter	n/a	n/a	n/a	Onmipower 150VA (RSA)	Isoverter 1,800VA Isoverter 700VA	n/a
Quality:				*SHS*	*professional*	
Water pumps and controller	n/a	n/a	n/a	All-Power(RSA)	n/a	Grundfos SQF
Quality / suitability				*professional but pump requires annual servicing*		*professional*
Fridges (vaccine or general purpose)	n/a	Naps CFS49Isi DC WHO-approved vaccine fridge	Sunfrost RVB143a DC WHO-approved vaccine fridge	Snowmaster general purpose DC fridge (RSA)	n/a	n/a
Quality and certified:		*yes*	*yes*	*SHS/camping*		
Lights	DC FL PLS9W with separate ballast	Naps DC FL strip 9W with separate ballast & other types	DC 18W CFL various	DC 18W CFL various	AC CFLs, Isofoton branded	Unknown
Quality/certification:	*Good*	*Good*	*Poor*	*Poor*	*average/unknown*	
Suitability:	*No local or compatible spares*				*Local compatible spares available*	
Overall assessment of component quality:	Mediocre /poor	Good	Good / variable except lights	Mediocre	Good	Good /mediocre

Table 3: *Quality of engineering, installation and balance-of-system components*

	DIPREME (German Coop./DED)	MISAU (Norad)	FUNAE (World Bank ERAP)	FUNAE Villages Manica (World Bank ERAP)	FUNAE Villages Nampula (Spanish Governm.)	District installed and financed
Array structures	Pole-mount thru-roof (non galvanised)	Aluminium gable mount	Galvanised roof mount or pole mount	Galvanised pole mount	Galvanised ground mount	Galvanised roof mount or ground mount
Quality:	*poor*	*Good*	*Variable*	*Good*	*Good*	*Good*
Orientation:	*good*	*Average*	*Variable*	*Good*	*Good*	*Good*
Installation	*Poor*	*Good*	*variable*	*variable*	*Good*	*Average*
Array junction boxes	Not used	Not used	Not used	Not used	Good	Good on pump systems
Quality of cabling and wiring work	poor	good	Variable /poor	variable	good	
Plugs and socket outlets	DC socket	DC socket	DC socket	AC socket	AC socket	
Appropriate for use?:	*Not used*	*Not used*	*No, uses standard AC socket for DC*	*Yes, but South African socket*	*Yes, but incompatible with Moz standard plugs*	
Lighting layout	Ceiling / wall mount lights	Wall mount lights located for convenience, incorrect spacing, without reflectors in rooms without celings			Non-optimal layout	Poor
Quality:	*poor*	*poor*	*poor*	*poor*	*poor*	
AC systems: battery low voltage protection	DC via charge controller			DC via charge controller. AC inverter connected to charge controller	AC inverter direct to battery	
Adequate for system/battery type?	*yes*	*yes*	*yes*	*no in AC systems*	*No*	
Battery enclosure and battery locations	Inside wooden battery enclosure	Intrernal polyplastic battery enclosure	Internal battery in classrooms with no enclosure	Internal polyplastic battery enclosure for SHS Pole mount polyplastic battery enclosure for streetlights	Steel external battery enclosure	
Quality:	*Acceptable*	*Acceptable*	*Prefer adequate lockable enclosure*	*Acceptable, streelights battery exposed to sunlight*	*Prefer internal battery storage or two skin steel full encloure with vents*	
Safety and protection	No battery fuse		No battery fuse, No lockable battery enclosure	No battery fuse, no lightning protection	No battery fuse no lightning protection	NA
Overall assessment of installation quality:	poor	good	Good but variable between contractors	Variable between contractors	good	good

3 ASSESSMENT OF MAINTENANCE EXPERIENCES WITHIN THE SECTORS AND CURRENT PROJECTS

This chapter gives a short description of the existing maintenance models and experiences based on interviews with the sector planners and maintenance teams at Provincial level, as well as interviews and observations in the field.

3.1 Maintenance for PV systems at health centres and schools

For the PV systems at health centres and schools, there are various maintenance models in place, depending on the project under which the PV systems have been installed. According to information received, presently three main approaches can be distinguished for PV system maintenance at social infrastructures: PV system maintenance is carried out

1. through the general (health or education) sector Ministry maintenance structures: this applies e.g. to the MISAU/Norad PV systems, and other PV systems installed at health centres or schools;
2. by a company sub-contracted by the sector Ministry: this applies to the PV systems financed under the World Bank ERAP Programme;
3. through a local Management Commission: this presently applies to PV systems installed under village electrification schemes commissioned by FUNAE.

The first and second maintenance models are briefly described in the next section. Section 3.1.2 describes maintenance under the village electrification scheme generally, which also applies to systems at schools and health centres.

3.1.1 Maintenance through line ministry structures

Health Sector

Regarding *general health sector maintenance structures*, at the national level, the Ministry of Health has a maintenance department that is in charge of planning and supporting maintenance tasks. They have limited budgetary means though, which have to cover all aspects of maintenance planning and support, including buildings as well as electrical, mechanical, and medical equipment. The Provincial Health Directorates have maintenance teams, which have two subsectors, infrastructure and equipment. The equipment team is also in charge of looking after the PV systems. A district level service exists that supports different sectors (including health and education) in infrastructure maintenance; however, at that level, engineers are geared towards road and building maintenance. Equipment does not play an important role in their activities.

The provincial health sector maintenance plan foresees that every health centre is visited 4 times a year; in reality, this is not always possible. Maintenance teams for medical equipment usually only go out when called, so there is no preventative maintenance in place. The equipment subsector has a limited staff of about four people which must attend not only to health centres but hospital equipment, e.g. including x-ray machines.

The PAV is responsible for vaccine distribution and maintenance of vaccine refrigerators. Over a whole province there are typically 3-4 vehicles which deliver the vaccines and liquid petroleum gas (LPG) for fridges to the remote rural health centres on a regular (monthly) basis. There is one PAV technician to support the vaccine fridges, and he accompanies these vehicles as and when necessary.

Although a general institutional structure for maintenance is in place, the *maintenance experiences and results* are mixed: the teams in charge of equipment maintenance at the Provincial level state that often they do not have updated information on the state of solar system functioning. Also, when there is a breakdown, they lack access to the adequate spare parts (e.g. DC lamps, or specialised solar system batteries). There also appears to be a lack of clarity regarding the warranty applicable to system components, and how to make use of it.

There does not seem to be explicit budgetary planning at Provincial level for the purchase of solar system spare parts, and there is as yet limited awareness of the cost profile of PV system maintenance. The MISAU Maintenance Department in Maputo is aware of the need of battery replacements (especially for the MISAU/Norad systems), but also lacks the funds to make the necessary purchases. Hence, explicit budgeting of spare part purchases has not yet been systematically done.

Education Sector

Regarding *general education maintenance structures*, the education sector does not have in-house maintenance sections or teams. At the national level, the MINED planning and maintenance department focuses on school building programmes, and is trying to develop clear policies on building maintenance. There is no maintenance team at the Provincial Education Directorates. There appears to be little or no mechanical or electrical engineering capacity neither at the national nor at the provincial level, because to date the education sector does not have a significant quantity of equipment that requires such maintenance capacity.

To date, given that the sector does not yet formally foresee maintenance of equipment, the *maintenance experiences and results* are not very encouraging.

At present the reporting lines for faults for the WB and other schools PV projects seems not to be via the provincial education authorities, but rather directly to the FUNAE regional representative. So the MINED tends to be out of the loop once installations have occurred. During the WB PV projects technicians were to be trained as part of the installation process but reportedly this has not been realised. It needs to be noted, however, that reporting by local actors in the field is not always accurate, as actors frequently change location and may not have been present when the reported activity was carried out.

The potential for MINED to be directly involved in PV maintenance must therefore be seen as a long term possibility. There might be scope for mainstreaming energy into the budget cycle, and this could be supported by the decentralisation process.

3.1.2 Maintenance through sub-contracted firms

With financing from the World Bank ERAP programme, FUNAE has commissioned the supply and installation of PV systems at 150 schools and 150 health centres. For these systems, both the Ministry of Health and the Ministry of Education have decided to contract firms (one each) who carry out the maintenance.

MISAU has already completed the tendering and contracting of such a firm, and the arrangement is in the process of becoming operational. MINED has not yet completed the tendering and contracting arrangements.

Also, for the ERAP-financed systems, the training of local persons has been foreseen, so as to have a local presence that can realise basic maintenance tasks. It appears that this intention has not always been successful. This can be due to at least two reasons: either the people who were trained are no longer available to realise their tasks (e.g. they moved away), or the training may not have taken place as intended.

3.2 Maintenance for village schemes

In the village projects visited, the schemes are run by local Management Commissions (MCs). These commissions are composed of a member of the local public administration (president of the commission), a community leader, and a local business representative ("Economic Agent"). Also, in each village, at least two operators are identified who are in charge of realising system maintenance and of collecting the monthly system user fees. 25% of these user fees remain with the MC, 75% are deposited with FUNAE. The user fees remaining with the MC are used for payment of the operators, and to cover the cost of small management and maintenance activities.

The maintenance model foreseen for the village PV scheme is described by procedure manuals established by FUNAE (DENR/09/03/EU and DENR/09/02/MD): During system installation, the operators receive theoretical and practical training for preventive and corrective maintenance through the contractor. Every month, the operators submit a maintenance plan to the MC and carry out routine checks on the installed systems. If any problems occur, the operators inform the MC, which, depending on the seriousness of the problem, seeks support from District Authorities, the DIPREME or from FUNAE.

Once system warranty has finished, it is foreseen that the Economic Agent makes spare parts available through his business networks (in cooperation with FUNAE), and sells them to system beneficiaries at an adequate price (to be defined by FUNAE).

The MC sends monthly reports to FUNAE on all aspects of system management, including system functioning and maintenance.

The actual *experience with the implementation of the maintenance scheme* was difficult to assess, as at the time of the visits, the village systems had not yet been commissioned, and therefore were still under installation warranty. The MC usually informs FUNAE of system problems. FUNAE then informs the installing contractor, whose reaction speed is variable. Among the visited systems, some showed problems that had occurred more than 2 or 3 months earlier and had not yet been addressed. However, in some instances, communication between the village and the Provincial Capital and/or FUNAE is difficult and/or the MC do not regularly establish the monthly reports and therefore FUNAE is not informed about problems unless they visit the locality.

In two of the three villages visited in Nampula, the information was given that no local operators had been trained during installation; hence at that point in time basic maintenance was not assured. If systems show problems which are not swiftly addressed, beneficiaries are also reluctant or unwilling to pay their monthly user fees. In 4 out of the 5 villages visited, payment problems were reported. The non- or limited functionality of PV systems was often indicated as a reason.

In the time span between the realisation of the field visits and the completion of this final report, FUNAE has adopted various measures in order to address the challenges in system functioning and maintenance, among which:

- FUNAE is purchasing DC lamps of better quality in order to address the frequent occurrence of DC lamp failures.
- in order to enhance the light distribution and effective illumination of classrooms, FUNAE is procuring lamp shades.
- as the presently installed DC power sockets are little used (due to the lack of suitable connectors), FUNAE is working towards the substitution of these sockets with cigarette lighter type sockets, which should e.g. facilitate cell phone charging.
- regarding the safety of batteries installed in classrooms, FUNAE is elaborating a scheme to have battery boxes produced at provincial level in order to prevent any accidents.

4 POTENTIAL BENEFITS AND REALISED BENEFITS OF PV ELECTRIFICATION

4.1 Health sector

There is a long list of potential (direct and indirect) benefits that can be achieved by providing a rural health centre with electricity through a solar PV system. Health sector sites are eligible for PV electrification if they are remote from the existing electricity grid, and it is planned to electrify all health centres as a matter of course. The following table lists the most commonly recognised potential benefits from health centre PV electrification in the first column. The second and third column then summarise to what extent the respective project had (a) intended to realise a given benefit, and (b) actually realised the potential benefit.

Table 4: *Overview of potential and realised benefits of health centre PV electrification*

Expected direct and indirect benefits	**Benefit realised?**	
	ERAP-fin. systems	**FUNAE village systems**
Improved reliability of vaccine cold chain at reduced costs (i.e. no need for regular LPG supply)	Realised, but depends on fridge quality	Not realised; Manica: fridges not operational; Nampula: no fridges supplied
Improved communication between HC and hospital either via HF radio or by enabling staff to charge cell-phones for emergency usage	HF radio foreseen but not supplied by health sector; DC sockets provided not fit for cell phone charging	Cell phone charging possible (AC sockets)
Longer service hours for HCs, and ability to attend to night time emergencies due to improved lighting	Intended but mostly not realised (DC lights not working)	Partly realised (but problems with broken inverters or DC lights)
Improved conditions for deliveries and reduced mortality and complication, due to improved lighting, and access to limited medical appliances	Examination lights foreseen but not supplied by health sector	Not intended; no additional medical appliances foreseen
Greater confidence by community in HC due to improved services, with more expectant mothers coming to HC for delivery. Higher rates of immunisation for newborns.	Realised when lights and/or fridge are operational	Realised in some HC where lights and fridge operational
Improved Mother Child Health teaching using audiovisuals, TV	TV foreseen but not supplied by health sector	not intended
Improved working conditions for staff on site. Improved conditions at staff homes including lights and TV for personal usage, and more incentives for staff to stay at remote sites.	intended and in some cases realised, depending on functioning of DC lamps; DC sockets are not being used; reading lamps foreseen have not been supplied	Manica: partly realised Nampula: mostly realised
Improved on site security and lighting at night for staff	Mostly not realised (DC lamp problems)	Partly realised
Improved access to safe potable water on tap within the HC building using PV pumps	not intended	not intended
Access to computers for improved administration if AC power is provided	not intended; no AC power	not intended; but AC power outlets exists

AC power at staff houses: it must be cautioned that access to "free" electricity has resulted in TVs being on for much more than just a few affordable hours per day, which can lead to system overload and breakdown.

4.2 Education sector

The schools chosen for each of the PV school electrification projects were selected by the Provincial Education Directorates. Specifically, schools were selected that needed to hold classes in the evening due to limited classroom space relative to the number of students. The potential benefits possible from PV electrification of schools are quite substantial, and varied. However, their realisation depends on the ability and resources of the individual schools. Often access to energy is not the only limiting factor to improved education services. The following table gives an overview of potential and realised benefits from PV electrification:

Table 5: *Overview of potential and realised benefits of school PV electrification*

Potential direct and indirect benefits	**Benefit realised?**	
	ERAP-fin. systems	**FUNAE village systems**
Classroom lighting allows realisation of evening classes, either for pupils or adults (alphabetisation)	intended but in most schools not realised (burnt DC lamps)	realised in 2 out of 5 schools visited
Improved teaching quality using audiovisuals, TV	intended, but TVs not provided by education sector	not clear whether intended; no TVs exist
Improved working conditions for teachers by providing lighting in the administrative rooms	intended but in most cases not realised (burnt DC lamps)	realised in 3 out of 5 schools
Improved living conditions for staff on site, by providing electricity for lights and TV for personal use, and more incentives for staff to stay at remote sites.	intended and in some cases realised, depending on functioning of DC lamps; DC sockets are not adequate and not being used; reading lamps foreseen have not been supplied	Manica: not assessed Nampula: realised and much appreciated
Improved communication between school and district, by enabling staff to charge cell-phones	not intended; DC sockets not fit for cell phone charging (nor for radio)	realised; AC plugs are used for cell phone charging
Improved on-site security and lighting at night (for staff and public)	not intended; DC sockets not fit for cell phone charging (nor for radio)	realised in 3 out of 5 cases
Access to computers for improved administration	not intended	not intended, but AC power outlets exists

One school with a large (advanced) PV system from the village electrification scheme in Nampula Province is able to provide the following services, with support from a separate project:

- community radio services for several hours per day;
- up to two administration computers for staff for 4 hours per day. the system is unable to provide energy for additional computers even though these are on site;
- limited photocopying services.

In general, for rural primary schools, the provincial authorities considered access to energy for computers, TVs, and other electric teaching aids as unlikely to be widely realised given the sector’s financial constraints. Generally, in terms of electric equipment, the sector’s focus is on provision of computers for secondary schools before dealing with the rural primary schools. Also, the projects could not be seen to be favouring some primary schools with substantial support while providing other schools with nothing, so a case for equity and sharing the few resources was a critical factor in the project formulation, using a more incremental approach.

Allocation of only 1-2 staff systems per site means that only one or two staff can benefit from the electrification at their homes, which leads to frequent requests for supply of further staff systems. Staff who do have a system at their home are making considerable savings compared to their previous expenditure on traditional fuels and dry cell batteries.

Overall the benefits realised vary widely: they are close to zero where systems are not functional due to vandalism or due to lack of functional appliances (especially DC lamps), or they can be very high in cases where evening classes are regularly held. Unfortunately, to date it appears that the education sector has not widely monitored the impacts of the projects. The overall impression is that some benefits come at a very substantial investment cost, and it may be useful to analyse the cost-benefit relationship more closely.

4.3 Administrative Post

Under the presently ongoing process of decentralisation, the Ministry of State Administration sees a big necessity to strengthen the Administrative Posts (Postos Administrativos; PA). Although at the moment, the PA do not have a significant number of tasks that need electricity, potentially, such tasks could be transferred to them in the future (e.g. emission of licenses that are presently emitted by the Districts).

So far, PA have been equipped with PV systems mainly within the framework of the village PV electrification schemes. Here, the PA also plays a central role in the management of the schemes. Some potential and actual benefits of PV systems at PA are illustrated in the table below:

Table 6: *Overview of potential and realised benefits of PA building PV electrification*

Potential direct and indirect benefits	Benefit realised?
	FUNAE village systems
Improved working conditions due to better lighting and access to electric appliances	Realised, but lighting of limited impact during day-time working hours
Improved lighting conditions for community meetings in the evening	Realised; previous use of generator in many cases
Improved communication (for work and private use) by enabling staff and community members to charge cell-phones	Realised; AC plugs are used for cell phone charging
Improved living conditions for the head of the PA, by providing electricity for lights and TV for personal use.	Manica: not assessed Nampula: realised and much appreciated
Improved on-site security and lighting at night (for staff and public)	realised
Access to computers and printers for improved administration	not intended, but AC power outlets exists

4.4 Communal systems

The communal systems provided by the FUNAE Village schemes include

- PV water pump from existing community boreholes in or close to the village;
- communal street lighting in the village.

Water pumping

The potential benefits from the PV water pumps are:

- better or easier access to clean water without the need for hand pumps;
- less time spent queuing for water at hand pumps;
- access to higher volumes of water per household from safe source;
- new access to safe water to those households who could not/did not previously access the hand pumps due to long queues, and who previously used unsafe open water sources such as springs or rivers.

The actual benefits realised from PV pumps installed appear to have been realised wherever the pumps were functioning. The extent of the benefits could not be easily assessed, as there was no baseline on water consumption in the villages. In general the PV water pumps do not provide new water sources but rather exploit the existing village water source(s) more optimally. A problem does arise if the PV pumps fail as these water sources are then inaccessible. At the same time, it is not practical to have both a PV pump and a back-up hand-pump on each borehole.

Street lighting

The potential benefits of the streetlights include:

- easier to move around the village at night if well positioned;
- better security, safety from snakes at night;
- less danger from vehicles travelling through village at night due to better visibility;
- opportunities for informal trade under streetlight on the main road areas.

These benefits were generally realised and very much appreciated by the local population. It was also mentioned that the streetlights are not always well positioned in the village, meaning that they are often concentrated along the main road area, instead of being dispersed more generously along the main village footpaths.

4.5 Commercial and private domestic systems

The benefits of the solar systems are generally more ample for small scale commercial businesses than for private sector households. The commercial systems are often shared between the shop and the shop-owners house. Benefits observed during the field visit include:

- improved quality of light service, and enabling transition from candles and kerosene lamps;
- convenience and improved level of light, ability to turn on/off lights when necessary;
- access to energy for end-user appliances at lower costs (TV, radio, cell phone charging), compared to other options of primary batteries, diesel generators, or commercial charging rates;
- longer hours of usage or operation;

- improved service provision to the community (shops, bioscopes, cell phone charging);
- access to a broader range of electrical appliances in some cases.

The PV systems provided in the FUNAE Village projects in Manica range from small solar lanterns to small household lighting systems, commercial systems for shops and markets, and for bars and kiosks.

In general the benefits listed above are realised when the PV systems are functional. In some cases the systems provide opportunity for sustainable growth of business, but in many cases this seems to be a borderline assumption and for small shops and retailers the PV systems add only limited productive value.

The commercial viability of the privately used systems is determined by a financial analysis taking the above factors into account: If the systems provide energy for production or commercial purposes at a lower cost than from fossil or traditional fuels, then the benefits are generally quite high, and the possibility of sustainability is higher.

The willingness to pay (WTP) and the ability to pay (ATP) for the private PV systems is usually determined by the value added or money saved thanks to the system. While the stated willingness to pay from interviews is often very low, calculations can be done to show the benefits and savings from fuel transitions and this usually gives a good indication of the value of the systems. Based on a household's or a business' avoided expenditure on previously used energy sources, the following table shows estimates of ability to pay for the PV village electrification in Nampula:

Table 7: *Fuel savings and ATP for Village PV packages (Advanced and Basic) in Nampula*

Business	Assumptions	Calculated ATP
Commercial bar and movie theatre	Stated costs MZN 4,000 per month (pm) for generators to run 2 fridges and play movies. Calculated ATP of MZN 12,000 pm	**MZN 12,000 pm**
Small house and movie theatre	Stated costs for previously using traditional fuels in household, and diesel generator for movie theatre, at MZN 2,500pm. Movie income is MZN 6,800 pm (MZN 1per person x 100 people per show x 2 shows per day x 30 days). Also cellphone charging income.	**MZN 2,500 pm**
House of Chefe do Posto	Stated costs of MZN 1,000 pm saved from generator a few hours per day. Now has benefit of energy 24hrs/day.	**MZN 1,000 pm**

5 AFFORDABILITY OF SYSTEMS AND ALLOCATION OF PACKAGES

A critical factor affecting the sustainability of PV systems is their affordability. Affordability can be affected by (partial or full) subsidisation of a product's capital cost. Depending on the level of the subsidy, the owner or user must be able and willing to cover (part of) the capital cost, but at least the operating cost of a system.

For PV systems to be affordable in rural areas the following conditions should be observed:

- The PV system is sized or allocated so that its capacity is used and not wasted or idle. Systems that are too large for the purpose of their use will not be affordable in the long term.
- For the services to be provided, PV should be the least cost energy option based on avoided cost of energy.

- PV systems benefits must actually be delivered (i.e. the system must be functional), in order for willingness and ability to pay to exist.
- For *public systems*: Even if the investment cost of the system is fully subsidised, the full operating costs should be recoverable from user/owner contributions (e.g. from education or health sector).
- For *private (commercial or household) systems*: Full subsidisation of investment cost is not usually encouraged, and therefore beyond operating cost coverage, at least some capital recovery should occur from user tariffs (usually capital recovery from private users is targeted at a minimum of 60%).

5.1 Village schemes

A detailed analysis was undertaken for all the systems to ascertain the applicability of the above-mentioned conditions (Annex 4). The main point is that there seems to be a challenge in matching

1. system package with actual costs,
2. the size of the system allocated to a certain user with his/her actual energy consumption,
3. benefits and affordability (ability to pay) with a user's willingness to pay (WTP).

This process task should be carefully tackled in an integrated manner in the project detail design stage and is not something that can be addressed after implementation.

The following table looks at different aspects of cost/benefit and affordability for the *village electrification scheme in Nampula*, which is made up of two different types of systems (basic and advanced system).

Table 8: *Cost recovery tariffs versus actual tariffs, ATP and utilisation factor for selected PV village electrification systems in Nampula*

User	System type	System utilisation factor	Contribution required to cover O&M only	Actual tariff	WTP (stated)	ATP (calculated)
			MZN per month			
Commercial bar and movie theatre	Advanced	68%	7,600	2,000	750	12,000
Small house & movie theatre	Basic	60%	2,525	750	250	2,500
House of Chefe do Posto	Basic	50%	2,525	750	250	1,000
Small house and private shop	Basic	30%	2,525	750	250	750

Looking at the relatively low system utilisation factor in the example above, the PV systems allocated are generally too large for the actual application. Also, the calculated contributions required to just sustain operation are significantly higher then the actual tariffs users are asked to pay. Regarding ATP, the ATP for larger advanced systems is in fact enough to cover the operating costs, but insufficient for smaller packages.

The packages in this scheme are also rather focussed on the medium-scale energy users and productive use applications. The packages have not been designed to give good coverage to a wide range of users, and there are no affordable packages for the more general small scale retailers and domestic users in the village.

Based on household affordability analysis, kits for the *FUNAE Village scheme in Manica* also do not focus on the majority of domestic users, but rather on the rather high end (170 Wp capacity) and the very low end (10 Wp), leaving a gap in the 25-50 Wp range. However, in the FUNAE village scheme in Manica, the general tariffs match projected operational costs reasonably well, provided no capital cost recovery is intended.

5.2 Institutional systems

For institutional PV systems for the social sector it is naturally more difficult to put financial value onto the benefits of the PV systems and to calculate ability to pay figures. Financial constraints at central and provincial level mean that planning for PV system operation and maintenance (and thereby sustainable functioning) must be part of the detail design stage of the project. Even if initial system costs are 100% grant funded, the responsibility for operational aspects and costs need to be defined and resolved.

There is evidence from the field trips that in general the maintenance and sustainability issues of the social sector PV systems have not been addressed in-depth in the planning stages. However, unclear operational and maintenance responsibilities and vague or fragmented ownership arrangements generally have a negative impact on sustainability. In the visited projects, in some cases ownership of the PV systems post-installation is not clearly specified or there is no clear handover of ownership. Also, from interviews held, it appeared that the sector authorities did not clearly know the value and frequency of maintenance and component replacement costs. Projects that fund the initial system investments are in most cases closed before issues of maintenance, ownership and operational funding begin to impact on sustainability.

6 SUMMARY AND CONCLUSIONS

The present study has looked at PV systems funded and commissioned by various organisations in different institutional settings. The majority of systems visited have been commissioned by FUNAE, either for village PV electrification of for electrification of social infrastructure buildings. Overall, the site visits revealed that where PV systems function as intended, they create important benefits and these benefits are much appreciated by the beneficiaries, some examples being: Where previously only kerosene lamps or candles had been used, the electric light of a CFL lamp is seen as a big improvement in the quality of illumination, be it for a rural family or a health centre. Also, the solar-powered fridges supplied for health facilities by the projects are assessed positively as they can succeed in reducing or even removing the need for regular LPG supply to remote rural health facilities.

At the same time, the visits also found that the maintenance and sustained functioning of PV systems in rural settings is a formidable task. Various institutional arrangements have been set up to address this challenge, including community management committees and mechanisms working through the structures of the health and education sectors. Also, FUNAE has overall assumed a very important role in assisting and supporting activities aimed at ensuring the proper functioning of the PV systems.

However, given the extent of the challenge, there do remain a few issues that reduce the effective functioning and use of the installed PV systems:

1. *It appears that the potential benefits of PV electrification are in many cases not realised, as a result of:*
   - lack of awareness of possible uses and potential benefits among users;
   - system or component failures hindering operation and thereby reducing benefits;
   - lack of access to suitable plugs and/or appliances, which limits usage of the available electricity;
   - system sizes and types are not well matched to conditions in various localities, and to the needs and abilities of the users and different income groups.

2. *The quality of components and of the system installation in some projects does not match with users' expectations, and deficiencies in system engineering have been observed:*
   - component failures in some cases have appeared at a large scale due to the poor quality of equipment supplied (most notable for DC lights);
   - the lighting layouts (placement of the lights) in schools, health centres and private systems could be improved to give much better illumination results;
   - there are potential safety issues for users (e.g. batteries in class rooms);
   - a lack of system protection and battery exposure to climatic influence (e.g. direct sunlight and heat) decrease system performance;
   - in some cases, the limited quality of installation may reduce system life-time and durability.

3. *The definition of different institutions' tasks and responsibilities during the project cycle could be improved:*
   - it appears that in some cases, the contractual obligations of supplying and installing companies have not been enforced (e.g. equipment warranties);
   - the relationship between ownership and maintenance responsibility has in some cases not been defined in a coherent way (usually the system owner should be responsible for maintenance), both in institutional and in village schemes;
   - under most projects, the PV systems have been installed over a large area, leading to a very low density of systems within a given space. This makes area-based after-sales service difficult for public sector authorities (health, education), and very expensive or nearly impossible if maintenance services were to be supplied by a private-sector entity.

4. *Quite a high number of cases were found where system maintenance problems were not addressed within a short time frame:*
   - generally, it appears that the viability of maintenance options (with regard to funding, human resources, logistics and spare parts) has not been analysed thoroughly before project start, which leads to a lack of financial and other resources for maintenance tasks (absence of maintenance plans);
   - users are in some cases not aware of the reporting procedures foreseen for maintenance problems, and in other cases do not follow the established procedures.

5. *The affordability of PV systems for private users (households and businesses) and the sustainability of maintenance obligations have not been fully addressed before project start:*

- in the village schemes, it appears that the size of systems allocated to different users does not match their energy need/demand (over-sizing) nor their ability to pay for system services;
- also in the village schemes, the monthly tariffs charged are in some cases not sufficient to cover the operation and maintenance costs, hence there is also no capital cost recovery for private or commercial systems;
- for institutional systems, it appears that the affordability of maintenance obligations was not analysed in-depth during project planning.

These issues are quite manifold and concern nearly all stages of project implementation. The following chapter makes some recommendations on how to address them.

7 RECOMMENDATIONS

Given the varied nature of challenges encountered in the functioning of existing PV systems, it appears recommendable to address them in a systematic way, looking at all the stages of a project, including preparation, inception, realisation, maintenance, and monitoring. Based on the field work and research carried out in Mozambique combined with experiences from projects in other countries, this chapter makes recommendations on how to systematically address the main challenges of solar PV projects in rural areas.

The preparation of projects for PV systems for multiple community facilities in many cases follows a linear process which may typically have included: the identification of a need (e.g. electrify 100 primary schools); a quick decision to use solar PV for electrification; the establishment of a budget based on general assumptions; system sizing and specification by an expert working without independent professional technical review; the adoption of a contracting method that best fits the practices and interests of the lead organization and/or donor; and protracted procurement, delivery and installation of the systems.

Iterations in the institutional and technical design process tend to be realised only due to budget limitations, political imperatives or procurement procedure concerns. Iterations are usually considered cumbersome and rarely realised to reconsider conceptual approaches and institutional aspects. Once the PV systems are installed and disbursements made, from the funding agency's perspective, implementation is largely complete.

In contrast, a more sustainable approach would:

a) address both technical and institutional requirements comprehensively throughout the project process, including post-installation maintenance and recurrent funding.
b) incorporate internal loop-backs during the planning process to consider critical trade-offs and facilitate inputs of sectors, communities, procurement specialists and other stakeholders early and continuously throughout the process.
c) include consultations with independent specialists to take advantage of a wider body of experience and expertise.

To try to address the issues systematically, it is recommended to incorporate these elements in a three phase process:

1) **rapid assessment** of the scope of the project, whether PV is the most cost effective solution and the implementation models available; this could be done largely by the a non-expert team leader in about a week, and would result in a

tentative project concept and preparation plan for consideration by main stakeholders;

2) **development of a PV implementation plan**: This 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. It would take about one month.
3) **procurement and implementation**: This includes securing firm financing commitments, including for recurrent costs, developing the tender packages, tendering and contracting, installations, maintenance, PV system performance tracking, monitoring and supervision. Contracting and start of installations could be completed within one year.

These points are described in more detail in the table below. As can be seen, the process of project implementation is not linear; rather there are multiple opportunities for addressing the main issues that we have noted in our short research. However it is also important to point out that the design work and tackling of these issues is done in the development of the PV implementation plan, and not at the time of procurement. Jumping from a concept design in the rapid appraisal directly to procurement is very likely to result in shortcomings and gaps in the project design.

Table 9: *Proposed project development process for PV electrification in rural areas*

Stage of project development		**Key Issues identified and opportunities to address**				
Stage	**Tasks/issues**	**Benefits not widely realised**	**Technical quality of equipment, enginee-ring and installation**	**Implementation arrangements**	**Maintenance issues**	**Affordability**
Initial rapid assessment (project concept and preparation plan)	Why consider PV Which facilities, where, how many and which services Energy requirement estimates and PV system sizes Cost estimates and least cost assessments Implementation model options Maintenance options	Meetings with stakeholders, awareness raising of potential benefits of PV to sector. Assessment of site information and data gaps.	System sizing estimates based on international norms for strata of facilities, and basic conversion ratios initially.	Identify initial implementation options for supply, installation, operation. Agree project preparation strategy, requirements, timing	Maintenance responsibilities explained, Maintenance options outlined. What will maintenance cost?	Is PV the cheapest economic option? Will customers be prepared to pay? Will customer contributions be sufficient?
PV implementation plan	Information collection and assessments: facilities, institutions and markets Which facilities, where, how many and which services Detailed PV system technical designs Implementation arrangements, organisational responsibilities Maintenance plan Capacity building plan, implementation support, supervision, system performance tracking plan Budgets and financing for implementation (supply, installation, maintenance and recurrent costs), capacity building and technical assistance Confirmed commitments to meet these costs. Stakeholder liaison and workshop presentation	Develop priority ranking of services for facilities based on <u>achievable benefits</u> • Assess sector priorities and policies and constraints • Data collection and survey on numbers, locations, and energy requirements for different strata of facilities. • Site selection criteria agreed for institutions • Selection criteria for staff systems, commercial and private systems.	System packages sized to provide desired benefits and affordable to maintain • Load assessment refined: priority rankings, service level approach, load growth allowance, reliability of supply. • Detailed technical design including technical and non-technical design trade-offs, between benefits, costs, O&M costs. • Peer review	Implementation arrangements: • choice between area based or sector based models, or links with market development models. • Links with other projects • Ownership and operational financing agreed • Peer Review	Maintenance plan developed, • based on study of options, including in-house or outsourced, optimised for long term sustainability. • Maintenance requirements understood • Peer review	Run iterations comparing technical, organizational, maintenance design options. • Detailed costing (components, shipping, local taxes, handling, installation labour, logistics, maintenance replacements) • Is sector able to pay maintenance and some capital recovery? Subsidy requirements • Staff / private systems mechanism for payment? • Willingness to pay analysis • Confirmed commitments to cover costs.

Procurement stage	RfP, contract documentation, technical specifications		Best practice design International standards and component certification Warrantees and manufacturers certificates of authorization	Binding contracts with enforceable conditions. Performance bonds and incentives covering both implementation and maintenance	Maintenance performance contract After sales service agreements Clear reporting lines defined	
	Tender evaluation, contract negotiation		Technical evaluation criteria, including declaration of compliance Component certifications Request additional information, request changes	Capacity assessment against evaluation criteria	Maintenance proposal assessment against evaluation criteria	
	Implementation		Blueprint sites Acceptance and handover procedure Supervision and change orders	Ownership and handover of responsibilities Scheme in place for income collection and management	Capacity building and training for users and sector staff on use, load management practices, reporting lines	
Operation	System usage, operation, maintenance, payments	Effectiveness survey of benefits planned versus benefits realized Note unforeseen benefits	Track PV system maintenance and performance to anticipate and address problems before failures. Contractual tools to enforce performance: One year defects liability period, Warrantees, Performance bonds		Maintenance supervision and monitoring or maintenance performance contracts Contractual tools to enforce performance Fix and enforce rules for use and maintenance of the systems.	Monitoring of payments, costs Monitor income opportunities