IEA INTERNATIONAL ENERGY AGENCY

PV Systems for Rural Health Facilities in Developing Areas

A completion of lessons learned

PVPS

PHOTOVOLTAIC
POWER SYSTEMS
PROGRAMME

Report IEA-PVPS T9-15: 2014

INTERNATIONAL ENERGY AGENCY

PHOTOVOLTAIC POWER SYSTEMS PROGRAMME

PV Systems for Rural Health Facilities in Developing Areas

A completion of lessons learned

IEA PVPS Task 9, Subtask 2

Report IEA-PVPS T9-15: 2014

ISBN: 978-3-906042-31-2

November 2014

Author: Adnan Al-Akori (Fraunhofer ISE)

COVER PHOTO:
A PV system for a ward Hospital in Ethiopia
Source: DGS-Berlin

Contents

List of Figures and Tables

Foreword

The International Energy Agency (IEA), founded in November 1974, is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) that carries out a comprehensive programme of energy co-operation among its 23 member countries. The European Commission also participates in the work of the Agency.

The IEA PVPS Programme

The IEA Photovoltaic Power Systems Programme (IEA-PVPS) is one of the collaborative R & D agreements established within the IEA and, since 1993; its participants have been conducting a variety of joint projects in the applications of photovoltaic (PV) conversion of solar energy into electricity.

The 24 participating countries are Australia (AUS), Austria (AUT), Belgium (BEL), Canada (CAN), China (CHN), Denmark (DNK), France (FRA), Germany (DEU), Israel (ISR), Italy (ITA), Japan (JPN), Korea (KOR), Malaysia (MYS), Mexico (MEX), the Netherlands (NLD), Norway (NOR), Portugal (PRT), Spain (ESP), Sweden (SWE), Switzerland (CHE), Thailand (THA), Turkey (TUR), the United Kingdom (GBR) and the United States of America (USA). The Copper Alliance, the European Commission (EC), the European Photovoltaic Industry Association (EPIA), the US Solar Electric Power Association (SEPA) and the US Solar Energy Industries Association (SEIA) are also members. An Executive Committee composed of one representative from each participating country or organization, heads the overall programme. The management of individual Tasks (research projects / activity areas) is the responsibility of Operating Agents. Information about the active and completed tasks can be found on the IEA-PVPS website: www.iea-pvps.org < http://www.iea-pvps.org>

Task 9, Deploying PV services for regional development, addresses the use of PV as a means to enhance regional development – both for rural electrification applications and, more broadly, in the urban environment. The Task achieves this by developing partnerships with appropriate regional and national organizations plus funding agencies, and by carrying out work on specific applications of interest and relevant business models.

In this context, this research publication “PV Systems for Rural Health Facilities in Developing Areas” comes as Subtask-2 under the umbrella of Task9. This document briefly presents technical guidelines and recommendations on PV systems design and standards for rural health facilities. International experiences from past and existing projects are analysed, and lessons learned are highlighted. The targeted audiences of this publication are decision makers, international development organizations, engineers and renewable energy practitioners.

Acknowledgements

This research publication was carried out at the Fraunhofer Institute for Solar Energy Systems (ISE), and financed by the Federal Ministry of Economic Cooperation and Development (BMZ), Germany. The research project was managed, and valuable inputs were added by the project leader Friedemar Schreiber (Fraunhofer ISE). Significant technical inputs were also added by Georg Bopp and Norbert Pfanner (Fraunhofer ISE).

Additionally, the document also received valuable contributions and comments from the IEA Task-9 experts and others. Many thanks to Bozhil Kondev (GIZ), Erik Lysen (Lysen Consulting), Dr. Anjali Shanker, Grégoire Lena, Silvia Puddu, and Taric de Villers (IED), Caroline Bastholm, Sofia Sparr and Mona Norbäck (SERC), Dr. Sharaf Al-Najjar (Consultant), Dr. Kavita Rai (Energy and Development Expert) and Prosper Magali (ensol-Tanzania).

Abstract

This report outlines a technical overview towards deployment of PV systems for rural health facilities in developing areas. The demand and supply of energy in health facilities is analysed, and international standards are presented. Technical and economic aspects of different power generation options are discussed. Experience of international development organizations is widely elaborated, main conducive factors of PV supply are outlined and lessons learned from fields are concluded, with an aim towards enhancing PV systems sustainability for rural health facilities.

Executive Summary

"Sustainability factors have not been considered in many cases in the past, due to improper system design, battery misuse, and daily load under estimation"

In the context of rapidly increasing price and the intermittent supply of fossil fuel, photovoltaic (PV) systems are an alternative energy supply option. Numerous PV system projects have been installed in health facilities in the past, and are mainly used to power vaccine refrigerators and lights. Nevertheless, the sustainability factors have not been considered sufficiently in many cases, due to improper system design, battery misuse, and under-estimation of the daily load.

Main criteria for selecting the appropriate technology are the economic and technical aspects of power generation options in rural areas. In small off-grid health facilities, where the daily load is low, experience shows that autonomous PV systems are considered to be the best energy option. However, for medium and large facilities, where the daily load is high, hybrid systems (e.g. PV with diesel generators) are likely to be the most economic and reliable power option. Lessons learned from field activities recommend installing a separate PV system only for vaccine refrigerator powering. Due to their energy efficiency, compressor refrigerators are recommended more than absorption refrigerators, and the new generation of solar direct-drive vaccine refrigerators can be an appropriate choice.

"With PV systems for rural health facilities, the installation itself is often less a challenge, than it is to establish sustainable financing for system maintenance and spare parts replacement"

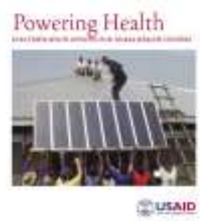
In the deployment of off-grid PV programs in developing countries, a significant role is played by main conducive factors, which include regulatory frameworks, institutional frameworks and business models. These factors can function through setting-up a clear policy and establishing an efficient management system, as well as a transparent financial scheme to enable ambitious programs.

Lessons learned from past projects show that the sustainability of PV systems requires consideration of technology aspects, capacity building, operation and maintenance. With PV systems for rural health facilities, the installation itself is often less a challenge than it is to establish sustainable financing for system maintenance and spare parts replacement.

1. Introduction

In the present, around 1 billion people in developing countries lack access to the basic-modern health care, as they are served by health facilities without electricity. The deployment of PV systems for health services is recently considered by international development organizations and governmental agencies which are active in this field worldwide. The Millennium Development Goals (MDGs) initiated by the United Nations also prioritizes maternal health and include the provision of suitable health services for all.

In the context of spreading knowledge and technical expertise on renewable energy technology for rural health facilities, the National Renewable Energy Laboratory (**NREL**) earlier published a document on deployment of PV systems for rural health clinics "*Renewable Energy for Rural Health Clinics*" in 1998. The guidebook presents renewable energy generation options which are applicable for rural health clinics.



The **USAID** energy team, also, has its online knowledge portal "**Powering Health**", which presents a wide experience and case studies on PV systems and other energy supply options for rural health facilities in developing countries. The portal contains rich information and documents e.g. "*Powering Health: Electrification Options for Rural Health Centers*". The document comprises an updated knowledge and economic figures on different power options. Another published document called *"Powering Health: Energy Management in Your Health Facility" m*ainly focuses on energy management and load balancing in rural health centers.

This document "PV Systems for Rural Health Facilities in Developing Areas" is written in response to provide an updated knowledge on PV systems for rural health facilities in the developing world. Up-to date technical solutions and recommendations on the system design and components selection are introduced. The main objective of this publication is to present international experiences and lessons learned from different countries and to provide technical solutions and recommendations towards enhancing the sustainability of PV systems.

This publication is structured in five chapters: Chapter one (this introduction) presents a general overview on "PV systems for health facilities" and relevant publications. It also explains the main objective of this work. The energy demand in health facilities is presented in chapter two, where main loads and a common classification of health facilities are discussed. Chapter three elaborates on technical and economic aspects of power generation options with main focus on PV systems. International standards of PV systems and financing approaches are described. In chapter four, international experiences from the past and current projects are highlighted. Lessons learned are concluded in chapter five.

This document was written based on literature review, and field investigation. Relevant international organizations and companies were contacted and data was analyzed. For getting comprehensive information on the status of existing projects, a tailor-made questionnaire was designed.

2. Energy demand in health facilities

PV systems convert solar energy into electricity. In rural areas without electricity grid access, stand-alone PV systems are an alternative energy generation option. The generated electricity can be instantaneously consumed or stored (e.g. in batteries) to be consumed at night. When planning a stand-alone system, the most important task is to match energy supply and demand. This can be a challenging task, mainly when considering the fluctuation of solar insolation in the winter rain season. Furthermore, the daily demand of such a facility is not always constant throughout the year.

A crucial task in solar stand-alone systems planning is to analyse the energy demand. In rural areas, health facilities conduct several health and non-health services. This chapter presents main loads and classification of health facilities. It also highlights economic figures regarding investment cost and running costs of PV systems.

2.1. Main loads

The primary results of a load inventory are quantified estimates of the facility's electrical loads and consumption [1]. The electrical power of each device is indicated in watt (W), and its daily operation time in hours (h). The total energy consumption is indicated in watt-hours (Wh), by multiplying the power of each load with its daily operation hours. Annex -B shows a load estimation sheet for a typical health facility (modified [2]).

Professional solar system design requires a detailed inventory of all loads and their consumption. The load assessment includes a listing of the quantity, power and daily hours of the loads. This information can be evaluated to yield the total daily electricity consumption. Strategic thinking should consider the increase in the total daily load which can be expected in the future, by setting the system design specification higher than the currently determined daily load.

In this subsection, the main focus is on the services provided by rural health facilities and on consequently required loads. These include vaccine refrigeration, light, medical equipment, and surgical treatment. Further relevant services provided are e.g. education, communication and water pumping.

Vaccine refrigeration

Vaccines prevent debilitating illnesses and disabilities of millions of children from dangerous diseases including cholera, polio, typhoid and hepatitis. Immunization programs depend upon the reliability of refrigerators to preserve the vaccine in a good environment and prevent its deterioration. In this way, a vaccine refrigerator is an important link within the Cold Chain of immunization programs.

With vaccine refrigerators, different technologies are involved including direct-current compressor or absorption technology for electro-thermal conversion, and electrical (batteries) or thermal (e.g. "ice battery" or phase-change materials) energy storage for autonomy and hold-over time. While compression refrigerators are 3-4 times more energy efficient than absorption refrigerators, some absorption refrigerators can alternatively be operated by gas.

The time when the refrigerator actually consumes power is different from its total operational time (normally 24h/day). The reason is that, to keep the internal temperature constant, the compressor or heater does not run continuously but in a controlled duty cycle mode. Therefore, in order to obtain accurate information about the daily energy demand of a refrigerator, the device's duty cycle must be determined (e.g. by listening), or by measuring the energy consumption for a period of time. A highly energy efficient refrigerator (energy efficiency class A+++) consumes about 100Wh/day per 100l volume.

Solar direct-drive vaccines refrigerators (usually equipped with compressor) are connected directly to a PV array (see Figure 1) and use internal thermal storage instead of a battery with charge controller. With good thermal insulation and phase change materials as storage unit, the autonomy can reach up to 79 hour [2]. This type of technology was recently approved by the WHO.

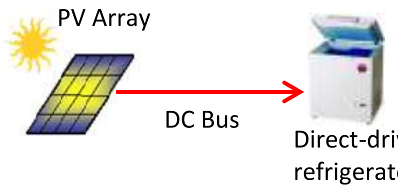


Figure 1 : Schematic diagram of a solar direct-drive vaccine refrigerator

Lighting

Lighting is a very essential service in rural health facilities, mainly at night. Quality and availability of light significantly improves medical emergency interventions, including first aid, birthing and surgery. Also does outdoor lighting, make health facilities more accessible as an attractive social landmark for local communities [3].

Efficient lighting appliances are highly recommended for rural health facilities. As a matter of fact, lighting appliances sometimes consume up to 40% of the energy generated by PV modules. More efficient lamps allow smaller PV system size; for example light emitting diodes (LEDs) are more efficient than compact fluorescent lamps (CFLs). The availability of LED lamps should be investigated in local markets. Different types of lamps are compared in Table 1.

Table 1: Comparison between Incandescent Light Bulbs, CFLs and LED Lights [4]

	Incandescent Light Bulbs	Compact Fluorescent Lamps (CFLs)	Light Emitting Diodes (LEDs)
Average life span	1,000 hours	10,000 hours	25,000 hours
Power required for 800 Lumens of light output	60 watts	12-15 watts	6-10 watts
Contains TOXIC mercury	no	yes	no

Medical equipment

- ***Microscope***: As an essential equipment in rural health facilities, a microscope is used for diagnosis. In developing countries, common diseases which include HIV, syphilis, malaria, and anemia are diagnosed using a microscope. Often, AC power systems are commonly used. Figure 2 shows a mini-laboratory in a small rural health clinic in Yemen.

Figure 2: A small lab shows a microscope (20W) and a centrifuge, Al-Mahwa-Yemen

- ***Centrifuge***: The purpose of a laboratory centrifuge is to spin blood samples in tubes until the substances of the blood mixture settle into layers of varying density. Versions exist which can be connected either to 12V DC or 220/110 V AC power supplies.
- ***Spectrophotometry***: The purpose of the spectrophotometer is the diagnosis of diseases at earlier stages.

There are also other sophisticated medical and non-medical appliances commonly existing in medium and large facilities, including X-rays, jet sonic cleaners, compressors, and water baths.

Sterilization

Autoclaves are used for the sterilization of medical tools, including surgical equipment. Often, sterilization of equipment by air requires a high temperature up to 160°C and takes around two hours, while steam autoclaves, where a temperature of 120°C is sufficient, are even more effective.

Because of the required high temperature, sterilization equipment consumes a considerable amount of energy. Therefore, the most economical way to operate this equipment is through solar thermal collectors or using PV hybrid systems with integrated of diesel generators.

2.2 Load classification of health facilities

Health facilities are classified into many categories based on different aspects. In health sectors, health facilities are classified into health posts, health clinics and health centers. Health posts are the smallest in size and do not have permanent doctors or nurses. They provide basic treatment for emergency cases, and first aid. Health clinics contain some medical equipment and conduct emergency surgical treatments. Health centers are equipped with several medical appliances, and provide health services for around 10,000 people.

In this analysis, health facilities are classified based on the daily load demand of existing medical and non-medical equipment. Three main categories of health facilities are introduced: small, medium and large size.

Small size health facility

Small health facilities, also called ‘health posts’, are typically located in remote areas or islands and have only a few staff. The main function of these facilities is providing basic services such as first aid.

Characteristics of small size health facilities [5]:

- Average daily energy consumption up to 10 kWh/ day;
- Capacity ranges from 0 to 60 beds;
- Limited health services provided in such first aid and limited surgical services;
- Equipped with one or two vaccine refrigerators;
- Temporary working team, such as doctors and nurses.

Power usage in rural health facilities varies from one facility to another, based on load changes and provided services. Analyzing the load profile for example for the Nagasaki facility, a small clinic located in Cambodia, shows that the lights are the most significant load and consume about 35% of the total energy. In cases where a vaccine refrigerator exists, this could be the largest consumer.
The energy consumption of the Nagasaki facility expresses a typical load profile of a health post. Figure 3 shows that the load curve increases gradually during day time until it reaches a consumption

peak at the mid-day and then decreases gradually. The load distributions of health facilities are not necessarily always identical.

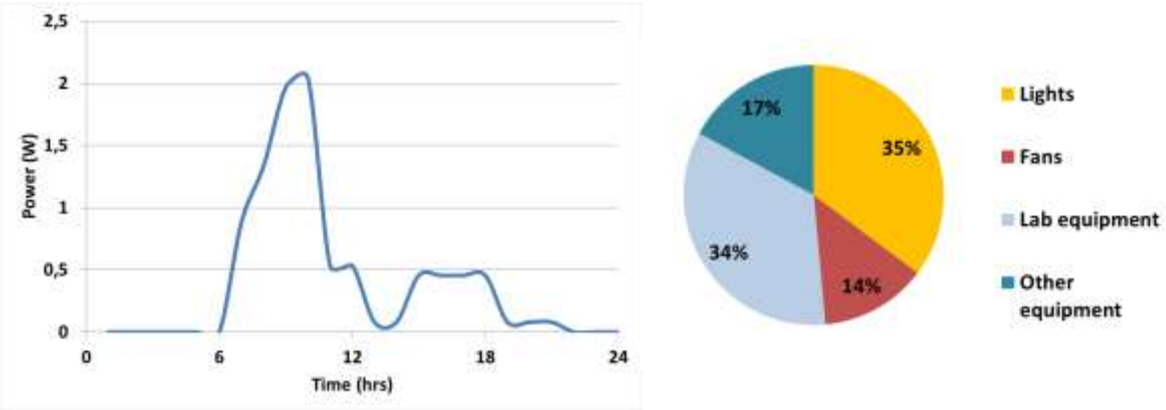


Figure 3: The daily load profile and energy consumption distribution of the Nagasaki health facility, Cambodia

Medium size health facility

The main objective of this type of facilities is the provision of not only basic health services, but also blood testing, dental surgery procedures and delivery services.

Characteristics of medium size health facilities [1]:

- Average daily energy consumption within 10- 20 kWh/ day;
- Capacity ranges from 60 to120 beds;
- Equipped with several medical appliances that do not exist in small size health facilities, such as diagnostic and surgical equipment;
- Maintains a cold chain for vaccines and blood supplies;
  May have an additional refrigerator for food;
- Provision of sophisticated surgical and emergency services such as dental health surgeries; Equipped with advanced equipment, such as small size X-ray machine.

An example load profile of a medium size health facility is given in Figure 4. The load profile shows that the highest energy consumption within day time is by laboratory equipment, while lighting systems and fans consume more within the night time. The electricity distribution, however, highlights that the main consumers are the lighting systems and fans.

Analyzing the energy consumption for such a health facility reveals key figures on its energy behavior, and also significantly helps in designing an efficient operational plan. For example, when a health facility supplied by a hybrid system (e.g. PV with a diesel generator) it would be efficient to size the diesel generator to meet the day-time load plus battery charging. At night, the stored energy in batteries can satisfy the night-time load [1]. Annex-B elaborates a typical load demand for a medium size health facility (adapted from [1]).

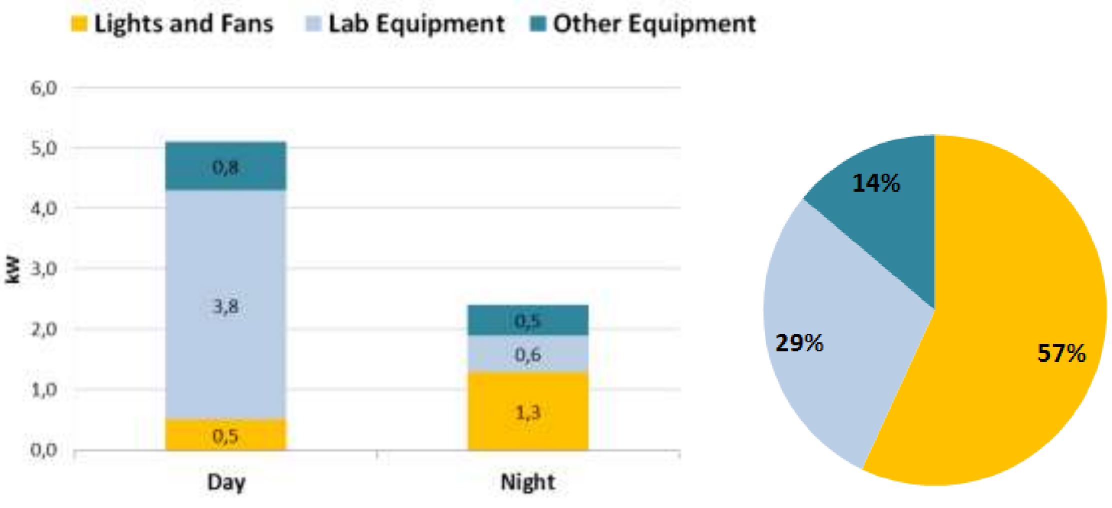


Figure 4: A typical day to night load profile and total consumption by end user [2]

Large size health facility

Large size health facilities or small hospitals are located in urban off-grid areas or cities. Often, these facilities are fully equipped with medical equipment, they have several wards and include nursing school, staff house etc. Large size facilities function as central hospitals which serve thousands of people in rural areas. Therefore, their energy consumption is high.

A field study, conducted on Lugala Luthern Hospital in Tanzania, shows that the staff houses of the hospital contribute the largest share to the energy consumption, which is about 30% of the total electricity production. The main reason is that most users switch on all equipment and leave it turned on until it is automatically switched off when the generator is stopped [6]. Nevertheless, this is not a typical case among all rural hospitals.

Characteristics of large size health facilities [1]:

- Energy consumption is high and exceeds 20kWh/day;
- Capacity over 120 beds;
- May contains advanced equipment (e.g. X-ray, CD4 counters, blood typing equipment).

3. Technical and economic aspects

PV systems can be a reliable energy supply option for isolated health facilities. There are main technical aspects that should be considered when designing stand-alone PV systems. A range of stand-alone PV system design configurations are technically possible. However, the main design parameters to be considered are efficiency, reliability and flexibility of the system at an affordable price. In this context, straight forward design aspects are discussed, as well as an overview about commonly used international standards.

3.1 Energy supply in health facilities

Supplying off-grid health facilities with electrical power could be realized through different options. The power supply options are autonomous PV systems, hybrid systems (e.g. diesel with wind, diesel with PV), or diesel generators. Therefore, it is crucial to make financial analyses for different power options, not only by considering capital cost of the system, but also the lifecycle cost (e.g. operation, maintenance and spare parts cost). Availability of fuel and transportation cost should also be considered.

Autonomous PV systems with no diesel back-up are economically viable and recommended when energy requirements are less than about 5kWh/day and there is a good constant sunshine. This frequently covers the energy consumption of small health centers. When the energy requirements exceed 5kWh/day, hybrid systems are likely to be the most economical option [9].

In remote off-grid areas, the most economic power solution is a hybrid diesel-PV system that deploys the available resource effectively at the appropriate time [8]. This option shows significant improvement in saving fuel compared with only diesel generator. This power option is mainly adequate for medium and large health facilities where the daily load consumption is high. Nevertheless, the feasibility of integrated hybrid systems (e.g. PV with diesel generators) has to be investigated case by case. It should be considered that hybrid systems require skilled staff for systems operation and maintenance. An example of a large size health facility is discussed in this document, as a case study on the Lugala Lutheran Hospital in Tanzania (see Annex A, case study two).

Solar irradiation

Solar irradiation is the amount of solar radiation that is actually striking on a specific surface such as a solar PV module, and measured by Watt per square meter (W/m2). The surface that is perpendicular to the direction of the sun receives a maximum solar irradiance, compared to other surfaces facing the sun at other angles. In principle, Photovoltaic cells primarily use visible radiation [10].

Insolation is the amount of solar radiation striking a surface at a specified period of time. For instance, when a surface receives 6 peak-sun hours a day it receives 6 hours at 1000 W/m2. Thus, solar irradiance can be measured in two ways: by daily peak sun hours (PSH) or kilowatt-hours per square meter per day (kWh/m2/day) [9].

Availability of solar irradiation is the main factor for considering a stand-alone PV system scenario. Often, the month with lowest solar insolation is considered as a reference month for the design. There are several resources provide comprehensive data on daily solar irradiation. The National

Aeronautics and Space Administration (NASA) provide an online portal showing a detailed monthly data base on satellite measurements.
https://eosweb.larc.nasa.gov/sse/

Other resources could be useful for extensive data on solar irradiation, such as PVGIS. The PVGIS is a EU portal containing data and links on metrological data from different sites around the world [9].
http://re.jrc.ec.europa.eu/pvgis/

PV system's configurations
The PV system's configuration presents the system components and their interconnection briefly. A main schematic design of stand-alone PV systems can be seen in Figure 5. The components can be coupled on the DC or the AC side. For stand-alone low power PV systems the DC coupling is recommended. For PV hybrid systems the coupling mode depends from range power of the load and the inverter manufacturer. The overall system efficiency is higher with DC coupling if the main average load occurs during night, and with AC coupling if the main average load occurs during day.

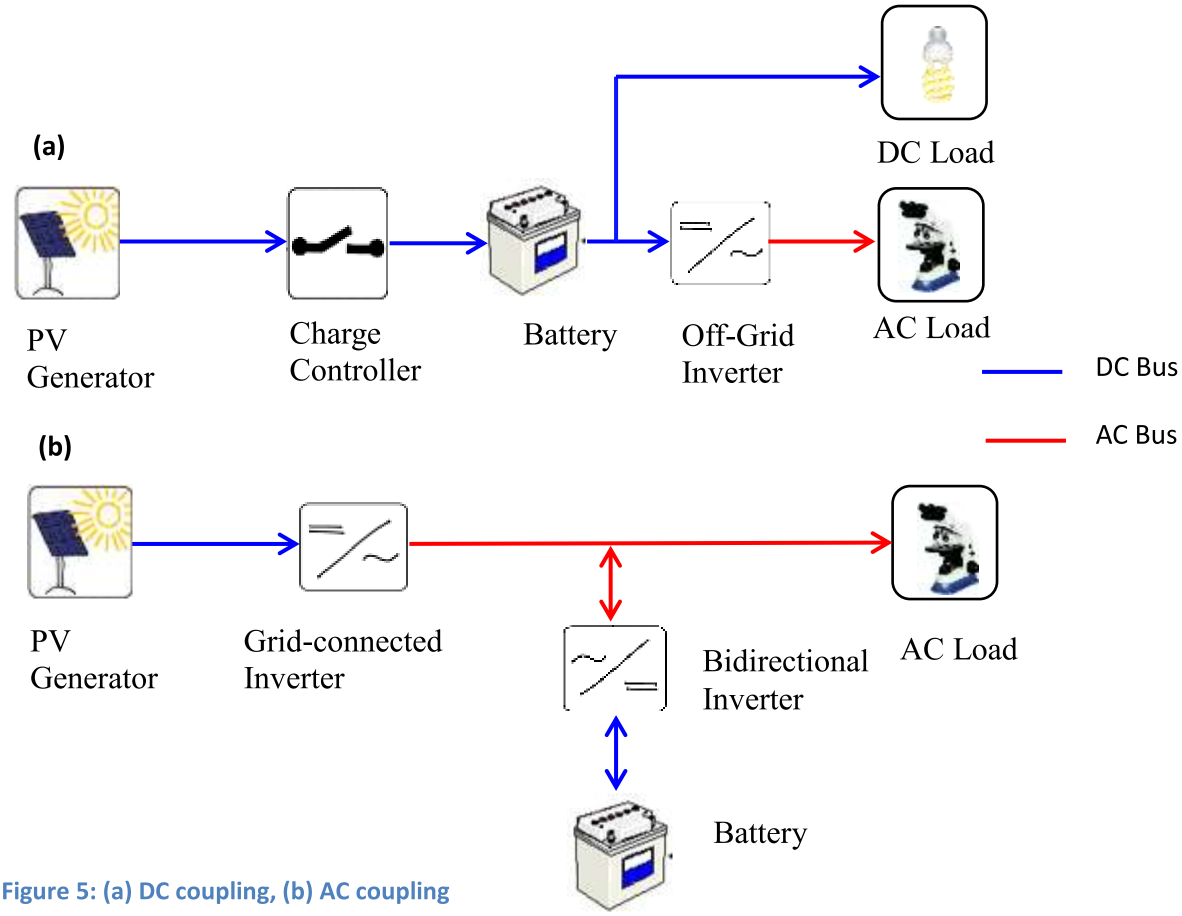


Figure 5: (a) DC coupling, (b) AC coupling

System voltage
A system voltage is the nominal voltage at which the batteries, charge controllers, inverters and solar arrays operate. In the small to medium size stand-alone systems, usually, the system voltage is set to be 12V, 24V, or 48V. If required, an inverter converts the generated power from DC to 110V or 230V AC [9].

PV module (s)

Solar PV modules are classified into three groups: crystalline silicon cells, thin film cells and nano-structured cells [11]. Crystalline silicon dominates the global PV market with 89%, while other groups are under development which aims at producing PV cells at lower production cost by using cheap raw materials and minimizing production process effort. In stand-alone systems with 12V nominal voltage, a PV module suitable for direct connection (i.e., without MPPT) have 36 cells connected in series [12].

Figure 6: Crystalline Silicon PV array Source: phoma GbR

The PV cell or module's current-voltage (I-V) curve is measured to evaluate the performance at different levels of insolation, temperature and voltage [9]. Standard Test Conditions (STC)[1] are applied to measure the modules rated power. The PV array energy output should match the total daily energy consumption. The main information about PV modules is given in manufacturer data sheets. For example, the I-V curve of a PV module provides data about the open-circuit voltage (Voc), the short-circuit current (Isc) and the maximum power point (V_{MPP}, I_{MPP}, P_{MPP}) of the module.

The orientation of PV modules must be considered. In the Northern hemisphere, PV modules should be faced south, while in Southern hemisphere they face north. The declination angle of PV panels is the angle between the plane of a PV module and the horizontal, and should also be adjusted. Often, PV modules are situated to be in an angle equal to the latitude angle of the site. In this case, PV arrays receive the maximum possible amount of solar insolation along the whole day. If solar irradiation is reduced during winter, and if supply continuation is essential in winter times, it is recommended to increase the declination angle by about 20o degree.

Batteries

Batteries are a very crucial component in stand-alone PV systems. The purpose of batteries is to store the electrical energy generated by PV modules during sunny days to be consumed during night or rainy days. The most common types of batteries currently used are lithium-ion and nickel-metal-hybrid and, nickel cadmium batteries for cold climates. Figure 7 shows examples of a stationary lead acid battery with tubular and grid plates.

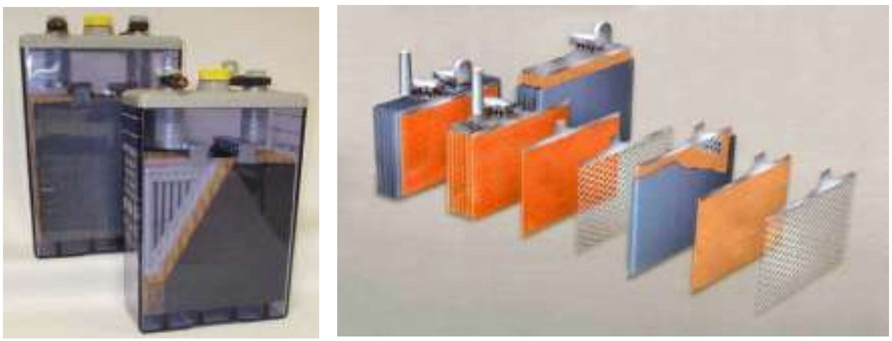


Figure 7: A Typical construction of tubular OPzS (left) and grid plates OGI (right) lead acid-battery Source: Fraunhofer ISE

[1] STC is applied under the following conditions: solar irradiance is 1000 W/m^2 at 25 Ċ and the Air Mass (AM) is 1.5

Main requirements of lead acid batteries for PV systems:

- long service life (6 – 10 years)
- low self-discharge
- high duty cycle
- highly robust to sustain integrity at extended periods of low SOC
- low maintenance requirements

Capacity: Generally, the capacity of batteries is given in Ampere-hours (Ah) for a certain discharge C-rate. For instance, C10 for a 100Ah battery indicates that this battery can supply current of 10 Ampere for duration of 10 hours. To calculate the amount of stored energy (Wh) the capacity (Ah) must be multiplied with the nominal voltage (V).

Depth of discharge (DOD): The Depth of Discharge (DOD) of a battery is defined as the percentage of capacity that has been withdrawn from battery, compared to the totally fully charge capacity. For deep discharge batteries, the DOD can reach up to 80%. However, less DOD results in an increases number of cycles or battery lifetime. In general, the allowable DOD is related to autonomy days that batteries are designed for. Figure 8 shows life cycles of different types of lead acid batteries.

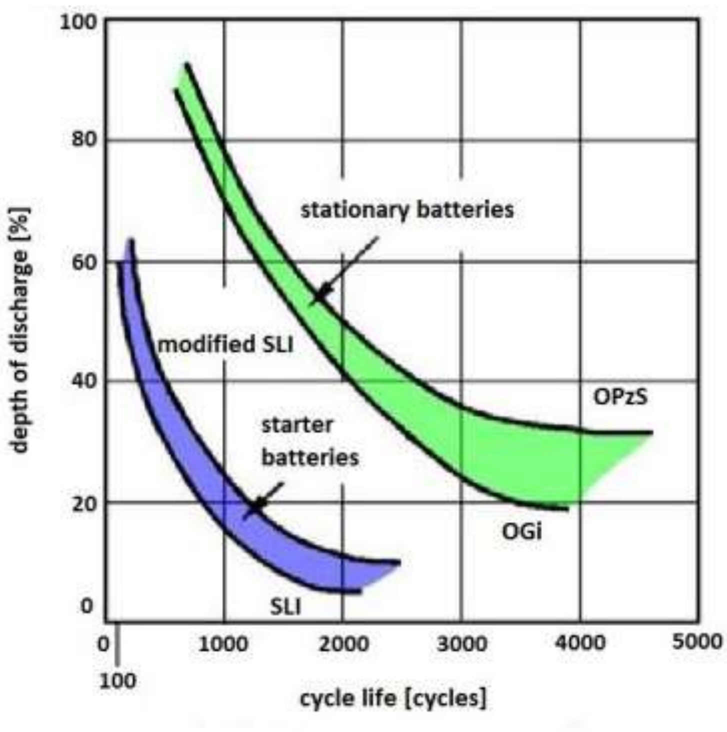


Figure 8 : Life cycles vs DOD of different types of lead-acid batteries
Source: Varta (adapted)

For PV systems it is recommended to use stationary batteries which reach a higher number of cycles in comparison to starting lighting ignition (SLI) batteries. Stationary batteries are produced with two different types of positive plates. The so called tubular plate (OPzS) achieves a longer lifetime in comparison to the grid plate (OGI), and especially it is more robust against deep discharge. In many cases the so-called solar batteries are modified SLI batteries with thicker plates and achieve a little bit more cycles in comparison to SLI batteries, but stationary batteries achieve more cycles.

The voltage of a battery is affected by three main factors: the electrical current, the battery temperature and the state of charge. The battery voltage increases when it is charged and decreases when it is discharged. Hence, the voltage of the battery has to be monitored periodically in order to maintain its performance for the long run. For a properly operation of a 12V lead acid battery at relatively low currents, it's advisable not to reach a discharge voltage less than 11.5 V [13].

The battery capacity should be sized precisely. Three main factors must be considered: system charge and discharge current, allowable DOD and autonomy period. The autonomy is the number of days that the battery can supply power to the load, without any charging power from PV panels, before it reaches the allowable DOD. In typical sizing, it is recommended to design a system based on an allowable DOD of 80% of the nominal battery capacity, since the battery capacity declines along the lifetime [14].

For a long lifetime of batteries it is recommended to keep the DOD very low. Often, a charge controller controls the DOD of the battery bank. This means that, at a certain DOD, it disconnects the load or starts the backup generator. If a DOD > 70% is reached it is important to fully charge the battery within few days, otherwise the battery lifetime will be reduced.

Most batteries need to be maintained regularly, such as keeping the electrolyte at the level assigned by the manufacturer, by adding distilled water. When using maintenance free batteries with a fixed electrolyte, it is strongly recommended to use Gel types. When AGM (absorbent glass mat) types are used, it is recommended to install them in such a way that the internal lead plates are orientated horizontally.

Charge controllers

The main function of a charge controller is to protect the battery by regulating the energy generation and consumption. This is done by limiting the voltage of the battery at charge and discharge. A typical stand-alone charge controller can be seen in Figure 9.

Figure 9: A typical stand-alone charge controllers (from Steca)

Main features of charge controllers:

- low voltage or SOC disconnection of load
- automatic start of backup generator
- over-charge protection
- calculate state-of-charge (SOC)
- display charging and discharging current, battery voltage and SOC
- protect output against overloading
- Overvoltage protection (min. class III) at the input and output side

Because the end-of-discharge voltage depends from the current, it is better to calculate the SOC for protection of the battery against deep discharge. Charge controllers must be sized to the system voltage, the maximum output current of the PV array and the maximum load current. For example, when the system voltage is 48V, the rated voltage of a controller must be also 48V.

Inverters

The basic task of the inverter is to convert the direct current (DC) into an alternating current (AC), to be adjusted to the frequency and voltage of the designed electrical system. There are four types of inverters: off-grid inverters, bidirectional inverter, multi ports inverters and grid-connected inverters. The bidirectional inverter functions as an inverter and charge controller. The most common types of stand-alone inverters are sine-wave, modified sine-wave and square-wave inverters. Sine-wave inverters are suitable for all appliances. Some appliances do not work correctly or can be destroyed by modified sine-wave inverters, and especially by square-wave inverters.

Some inverters are built with a charge controller to self-manage the state of charge and discharge of the battery simultaneously. A typical type of this inverter is shown in Figure 10. The nominal power of the inverter should cover the summation of the nominal powers of AC loads which must be supplied simultaneously. It needs consideration that a compressor refrigerator has an inrush current for maximal 1 second of about 5-10 times of the nominal current. The inrush current of other inductive loads like motors is about 3 times of the nominal current.

Figure 10: A typical sine wave inverter/charge controller (AJ 700-48 (-S) from STUDER)

The main requirements of stand-alone inverters:

- alternating current (AC) adjusted to be as sinusoidal as possible
- very good conversion efficiency (about 95 % at half load)
- very low no-load losses (max. 1 % of nominal power)
- high overload capability (3 times nominal loads for 1 second)
- tolerance against battery voltage fluctuations
- economic standby-state with automatic load detection
- disable or switch off the input
- protection against damage through short-circuit at on the output side
- Overvoltage protection (min. class III) at the input and output side

Many cheap available inverters at the market are not designed for PV systems and sensitive loads. Hence, inverters should be selected carefully, so that its wave-shape matches the loads (e.g. X ray, spectrophotometer) requirements.

System losses

Energy always is lost due to inefficiencies in cables, modules, batteries and inverters. The overall losses include the above named, temperature loss, dust irradiance loss, and the losses caused by unused solar energy due to full battery. This overall losses in stand-alone systems is about 35% and can reach upto 60%. This loss factor should be considered at the design stage of the system.

Designing software

There are several designing tools which could help sizing stand-alone PV systems. Some of them are commercial, others are free.

Table 2: PV system designing software shows examples of designing tools for PV systems.

Table 2: PV system designing software

Tools	Features
Homer	- Presents different design options including hybrid systems - Optimizes a design based on net present value - Conducts financial analysis
PVsol	- Designs and simulates sand-alone, and hybrid systems - Conducts financial analysis
PVsyst	- Supports design of DC systems only - Conducts financial analysis
HOGA	- Multi objective optimization - Lifecycle emission, and buy–sell energy supply analysis
RETScreen	- Technical, financial and economic analysis (dynamic excel sheet)

Box 1: Optimization of PV system design

A system design can be optimized through demand side management. Through load shifting, the energy demand can be modified to match the energy supply instantaneously. A simulation analysis*, which was conducted on a planned health center based in Yemen, shows a significant decrease in PV system costs through load shifting. In the study, medical and non-medical appliances (e.g. Autoclave, jet sonic cleaner) was put into operation during times of peak solar irradiation and instantaneously utilized the electricity generated by PV modules. In this way, the required battery capacity decreased due to the reduced amount of energy which must be stored. Thereby the net present value (NPV) of the system through its lifetime decreased to 20%.

Nevertheless, PV system optimization through load shifting is not always applicable. Different working cultures and social aspects play a role in the daily working schedule and operation hours of rural health facilities. Furthermore, several appliances can be operated in different periods of time whenever needed. At the planning phase of PV systems, therefore, it is recommended to conduct a technical and social-health survey to the targeted areas, in order to precisely estimate the daily operation status of facilities.

**A scientific study was conducted by the Author* [36]

3.2 Economic aspects

PV systems can be an attractive energy option for isolated health facilities, compared to conventional energy sources such as diesel generators. For example, the lack of diesel fuel, and the transportation and operation costs are the main barriers to considering diesel generators. In contrast, the price of PV modules dramatically decreased in the last few years, see Figure 11.

Figure 11: International pricing of PV panels from 1990 to 2011 ($\$/W_p$) [35]

In spite of the recent decreases in PV modules price due to technology improvement and economy of production scale, the investment costs of stand-alone PV systems are still high. The main reasons are higher investment and replacement costs of batteries. Also the cost of off-grid inverters is still high, mainly that integrated with charge controllers.

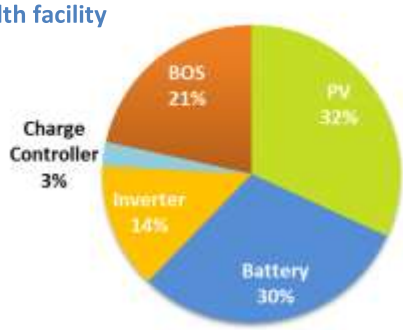
IEA indicates that the turn-key cost for a small scale stand-alone PV system is USD 6,000 per kW [6]. However, the investment costs of the systems vary, based on technology used and local economic aspects (i.e. taxes, transportation and installation costs). At Lugala Luthern Hospital, Tanzania, the investment costs of the installed PV systems vary from USD 7,480 per kW for the larger systems to USD 16,890 per kW for the smaller systems [7].

A breakdown of PV system components costs for Al-Mahwa, a small health facility based in Yemen, (see Table 3), shows that the major share of capital cost is in modules and batteries, which account for around 60%. As this analysis is based on local costs of 2010, the current costs of PV systems (mainly PV modules) can be considerably lower. For detailed analysis of the Al-Mahwa health facility, see Annex –A, case study one.

Table 3: Breakdown of a PV system costs for a small health facility

PV system components	Cost (USD)
PV panels (450W_p)	1,575
Batteries (600Ah)	1,500
Inverter (1,600W)	674
Charge Controller (30A)	130
BOS (Balance of system)*	1,065

* BOS includes transportation and installation costs.



The investment costs of PV systems vary in developing countries. The operation and maintenance costs of PV systems are low compared to the capital cost, estimated to be 1% of the capital investment per year [7]. However, it could be much lower also due to low wages of local technicians.

Hybrid systems (e.g. PV with diesel) could be economically attractive and reliable for medium and large facilities. A case study for a PV (Photovoltaic) and diesel generator (DG) hybrid system for the Lugala Lutheran Hospital in Tanzania shows that the PV systems contribute 40% of the total electricity generation for the hospital. More details about Lugala Luthern Hospital are presented in Annex-A, case study two.

Maintenance funds

Establishing a maintenance fund is the backbone of success for off-grid solar PV Projects. In spite of the importance of access to capital for covering the systems cost, allocating a sustainable finance for systems maintenance throughout the lifetime is the real challenge. Many projects have been successfully implemented by international donors in the past, but failed shortly after, because of lack of sustainable maintenance funds for replacement of the system components (mainly batteries, but also charge controllers and inverters).

→Maintenance funds are established in one of the following approaches:

i) Districts health offices:

Districts Health Offices may allocate maintenance budget annually to be financed by local authorities. The maintenance procedures are performed by local companies, and often managed by the facility. Therefore, districts health offices can supervise and monitor supply of spare parts as well as performance of the systems.

ii) Self-financing:

Health facilities sometimes have their own resources, so they by themselves can finance systems maintenance and parts replacement. However, most of off-grid health facilities are located in low income regions, and this option is feasible only in high income regions only.

iii) Donors:

Another mechanism is the allocation of a maintenance budget by project financers such as donors or interested organizations. The maintenance program in this case can be executed by the local maintenance company. Securing a co-financing for maintenance is highly recommended for the sustainability of rural health facilities.

3.3 International standards

PV systems for rural health facilities have to be procured according to the highest level of international standard. Several national and international standards and test laboratories exist for systems quality assurance. Concerning Technology, the world's leading organization for preparation and publication of international standards is the International Electrotechnical Commission (IEC) founded in 1906. There are also several national standardization organizations such as the German Institute for Standardization (DIN) or the American association for the advancement of technology (IEEE).

The World Health Organization (WHO) also has its own standard, called Performance Quality Standard (PQS). The WHO/PQS/E03/PV01.2/ 08:2007[2] addresses requirements for solar power systems that operate compression-cycle vaccine refrigerator or combined refrigerator and water-pack freezers.

Table 4 shows other international standards for stand-alone PV systems.

Table 4: International standards for Stand-alone PV systems

Standard No./Year	Title	Remarks
PV Modules		
IEC 61215	Crystalline silicon terrestrial photovoltaic modules - Design qualification and type approval	For procurement
IEC 61646	Thin-film terrestrial photovoltaic modules - Design qualification and type approval	For procurement
IEC 61730-1	PV module safety qualification - Part 1: Requirements for construction.	
IEC 61730-2	Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing	
IEC 60904-1	Photovoltaic devices. Part 1: Measurement of photovoltaic current-voltage characteristics PV Modules field test	For field test
Batteries		
IEC 60896-11	Stationary lead-acid batteries: Part 11: Vented types – General requirements and method tests; Part 21: Valve regulated types – Methods of tests; Part 22: Valve regulated types – Requirements,	For procurement
IEC 61427	Secondary cells and batteries for photovoltaic energy systems (PVES) – General Requirements and Methods of Test"	Long testing time ≥ ½ year for modified SLI[3] ≥ 1year for OGI & OPzS
IEC 62485-2	Part 2: Safety requirements for secondary batteries and battery installations: Stationary Batteries	For electrical and structural safety
IEEE 1361	Practice for determining performance characteristics and suitability of batteries in photovoltaic Systems- Field test	Field test

[2] http://www.who.int/immunization_standards/vaccine_quality/pqs_e03_pv1.2.pdf
[3] Lead acid battery types: SLI: starting, lighting, ignition; OGI: grid plate; OPzS: tubular plate.

Charge controllers		
IEC 62509	Performance and functioning of photovoltaic battery charge controllers	For procurement
IEC 62109-1	Safety of power converters for use in photovoltaic power systems. Part 1: General requirements	For procurement
Power converters (Inverters, Charge controllers,...)		
IEC 61683	Photovoltaic systems - Power conditioners - Procedure for measuring efficiency	For measuring efficiency
IEC 62109	Safety of power converters for use in photovoltaic power systems: Part 1: General requirements; Part 2: Particular requirements for inverters; Part 3: Particular requirements for electronic devices in combination with photovoltaic element	General standard
IEC 62093	BOS components - Environmental reliability testing - Design qualification and type approval.	Include inverters, charge controllers and batteries
Lights		
IEC 60969	Self-ballasted lamps for general lighting purposes - Performance Requirements.	For procurement
IEC 61347-1-4	Lamp control gear: Part 1: General and safety requirements; Part 3: Particular requirements for AC-supplied electronic ballasts for fluorescent lamps; Part 4: Particular requirements for DC-supplied electronic ballasts for general lighting.	For procurement
BOS/Systems		
IEC 60669-1	Switches for household and similar fixed-electrical installations. Part 1: General requirements.	For procurement
IEC 62124	PV stand-alone systems - Design verification	
IEC 60529	Degrees of protection provided by enclosures (IP Code)	For procurement
IEC/TS 62257 (All parts)	Recommendations for small renewable energy and hybrid systems for rural electrification	For procurement

4. International activities

The main focus of this chapter is to present, evaluate and analyse existing experience with PV systems for rural health facilities in developing countries. The main focus is on activities of international development organizations working in this field. Some organizations are presented in this report as examples of international organizations working globally, based on available data and published information.

4.1 International experience

PV systems for off-grid health facilities have been considered and implemented over the last decades in South and Central America, Africa and Asia. International development organizations have tested different power options to supply medical labs and other emergency first aid facilities with electrical power to cover essential needs. The implemented power options include off-grid solar PV systems, diesel generators, UPS[4] electrical storage and hybrid systems (e.g., diesel generators with PV systems or with wind turbine).

An overview based on available data about electricity access in some selected developing countries is shown in Figure 12. This survey statistics was conducted by the United States Agency for International Development (USAID), except for Bangladesh, India and Nigeria. It shows that, in Uganda for example, around 25% of health facilities have access to reliable electricity supply (i.e., without irregular or periodical interruptions).

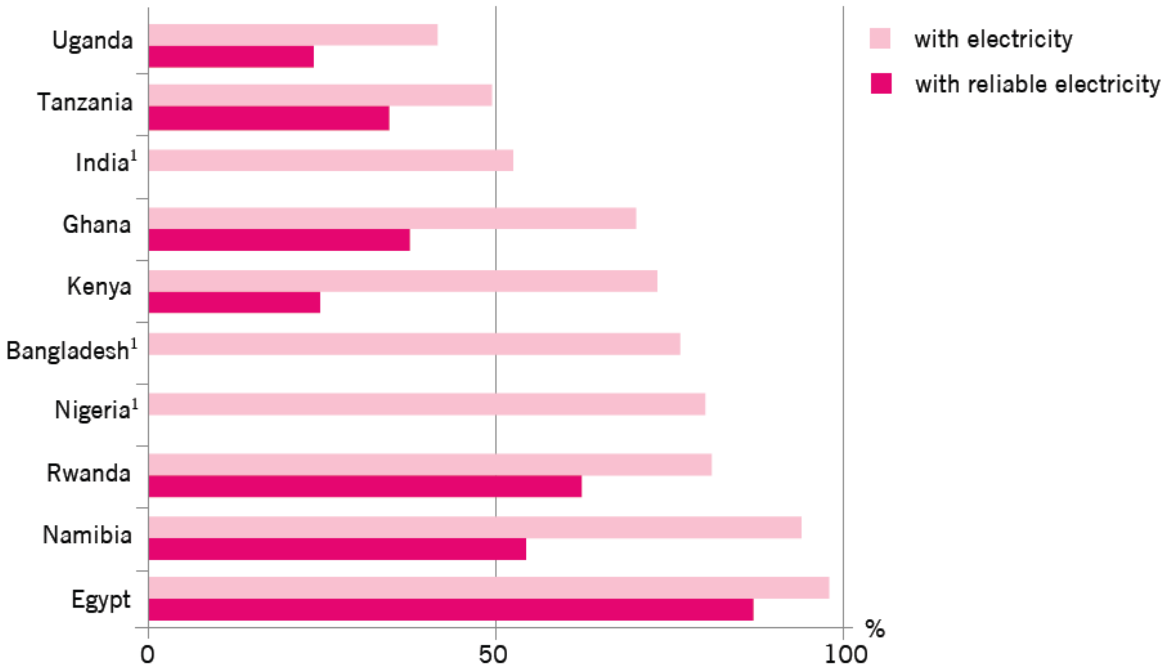


Figure 12: Electricity access rates in health facilities in some developing countries [15]

[4] UPS: uninterruptable power supply

4.1.1 Activities by organizations

World Health Organization (WHO)

The WHO is a major international agency working on health issues Worldwide. The main mandate of the WHO is directing and coordinating health issues within the United Nations system. It is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends [16].

The WHO has a long experience in leading the installations of PV systems for health facilities in developing regions worldwide. There is no accurate statistics on how many PV systems were implemented mainly for health facilities; however it is estimated that thousands of systems have been installed in isolated regions and communities where there is a lack of access to the electricity services. The main aim in the past was on solar PV projects for lighting of health facilities, powering refrigerators mainly utilized to store vaccines and a few projects taking power needs of medical appliances into consideration.

Vaccination is defined as an indispensable tool in fighting diseases like influenza, hepatitis, polio and rotaviruses. The WHO estimates that 2 to 3 million deaths get avoided each year due to vaccinations [1]. The WHO leads immunization programs globally in cooperation with UNICEF and other international organizations, research institutions, and governmental bodies.

The global network of immunization programs for developing countries is known as Expanded Program on Immunization (EPI) and was established in the 1970's.The main challenge is how to assure safe transportation of vaccines for immunization from the manufacturer to the beneficiaries at the required temperature, recently known as the “Cold Chain”. According to the WHO, and during 2012, about 110.6 million infants worldwide received three doses of diphtheria-tetanus-pertussis (DTP3) vaccine, protecting them against infectious diseases that can cause critical illness and disability or be fatal. By 2012 also, 131 countries had reached at least 90% coverage [17].

United Nations International Children’s Emergency Fund (UNICEF)

UNICEF, also calling itself Children's Rights & Emergency Relief Organization, is one of the United Nation organizations working in 191 countries worldwide. UNICEF's working areas are child survival and development, basic education and gender equality, HIV/AIDS and children, child protection, policy advocacy and partnership [18].

The immunization program for children is one of the main active programs executed by UNICEF in cooperation with the WHO. The program is part of the Cold Chain mechanism which aims at providing accessible vaccines for children and mothers mainly in developing regions. The Cold Chain mechanism, launched regularly in many developing countries, includes vaccines to reduce spreading of disease among children mainly in Africa.

Figure 13: Cold Chain Supply Journey [19]

The vaccine Cold Chain is the temperature controlled supply chain of vaccines. The mechanism of the Cold Chain is a long supply chain procedure passing through different stages as shown in Figure 13. The chain starts by shipment of vaccines from the manufacturers directly or normally from portals in the origin country of manufacturer. Then, the vaccine packages pass through testing, custom clearance issues and final approval. The next step is shipment of supplies between portals and central cooling stores at the host country, then to the health facilities' refrigerators.

The experience of UNICEF in energy for health facilities mainly focuses on solar PV systems for vaccine refrigerators. Many solar PV projects have been implemented in the past by UNICEF, in developing regions as well as in disaster areas. The purpose of PV systems projects is to supply power via battery storage to vaccine refrigerators. PV systems have been considered by UNICEF as an economic and reliable option for supply of energy to vaccine refrigerators particularly in remote regions.

While in existing UNICEF projects PV systems are experienced as reliable, the battery is the solar system's weakest component. While battery life cycles are different from one product to other, the average lifetime of batteries normally is 6 years. The life time of batteries depends on the number of charging and discharge cycles, DOD and temperature. The delay of replacing failed batteries might lead to damage of stored vaccine that must be stored in a temperature ranges between +2°C and +8°C [19].

Absorption refrigerators for vaccine storage, which work on kerosene, have been considered by UNICEF at the past with some difficulties. Lack of kerosene, maintenance problems, and higher capital cost are the main disadvantages of this type of refrigerators.

The lessons learned from existing projects show that the use of compression refrigerators is preferable over absorption refrigerators. Compression refrigerators operate on electrical energy generated by PV modules and stored in batteries, while absorption refrigerators operate on propane or kerosene. Fuel supply is interrupted in some rural areas, which results in spoiled vaccines.

The previous experience shows also that a dedicated PV system should be designed separately to supply energy only for vaccine refrigerators, and to make sure that the refrigerator has its independent power supply. Since a shortage in supply of power to the refrigerator leads to shut-down of the refrigerator for a period of time, which causes an increase in temperature of vaccines which might be spoiled.

U.S. Agency for International Development (USAID)

The USAID is an organization active in implementing PV systems for health facilities in many developing countries. Through its widespread offices, the agency works on the improvement and implementation of health facility infrastructures and blood banks. These include the provision of different energy options for powering health facilities and health posts.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ, German Agency for International Cooperation) works widely in many developing countries i.a. by enhancing off-grid energy services. Efforts include improved electrification of health facilities, social institutions, schools, and vocational training centers. Several projects have been implemented in this field, mainly in Africa.

We Care Solar

A new initiative developed by a NGO called We Care Solar aims at supplying solar suitcases for 250 health centers in Africa, particularly in Malawi, Sierra Leone and Uganda.

The system includes LED medical task light, cell phone charger, battery charger for AAA or AA batteries, and outlets for 12V DC devices. The system is equipped with a 40 or 80 watt solar panel and a 12Ah sealed lead acid battery [20] (See Figure 14)

Figure 14: "We Care Solar" Suitcase

4.1.2 Country experiences

Most PV system projects were implemented by international development organizations in close partnership with local authorities. This section presents key projects and existing experience in some selected countries based on available data and published information.

Haiti

In Haiti, the total installed power capacity is 216.11 MW and is managed by a governmental vertically integrated authority called *Electricité d'Haiti* (EDH). There are also other independent power producers (IPP). The total system losses in the energy sector range between 46-53%, while the technical losses reach 18 % [21].

The weakness of the public energy sector in the country highlighted the need to consider PV systems as an option to bridge the gap of power shortage. Management and operation of health facilities as well as maintenance of PV systems are done by the Ministry of Health in cooperation and with support from the President´s Emergency Plan for AIDS Relief (PEPFAR), a new project supported by USAID.

The PEPFAR, for instance, works for 45 Health clinics and blood laboratories across the country to enhance basic health needs and provide reliable service to local people. These include regular assessment of the different energy options for health facilities. PV systems, battery banks and diesel backup generators are considered in some projects as well.

Utilizing solar energy to power health facilities in the country has a long history, mainly in 1990s. The immunization program for example was extended by the WHO, mainly by designing and installing solar projects exclusively for powering vaccine refrigerators. Around 14 individual PV systems were installed in 1993 and were operational, according to the last assessment mission by USAID in 2008 [22].

→ ***Key success of the WHO projects in Haiti:***

- Accurate design of systems
- Professional installation
- Regular maintenance

The experience from existing PV projects shows that getting access to capital for projects and PV systems installation is not the main challenge, while ensuring sufficient funds to cover the maintenance and replacement cost of system components is a major component of success [22].

In addition, strengthening the capacity building of local staff and the availability of funds are crucial for keeping these projects running and sustainable on the long run. Tamper free mounting systems are used in some projects to protect solar panels from theft. The procurement of PV systems equipped with anti-theft screws was highly recommended to establish a sense of ownership and a feeling of responsibility among the community instead.

The USAID has carried out field assessment studies to improve the energy supply of health facilities for around 30 locations in Haiti. Up to 2013, 18 sites have been assessed recently and 12 new installation sites were supposed to be completed by the year, as shown in Figure 15.

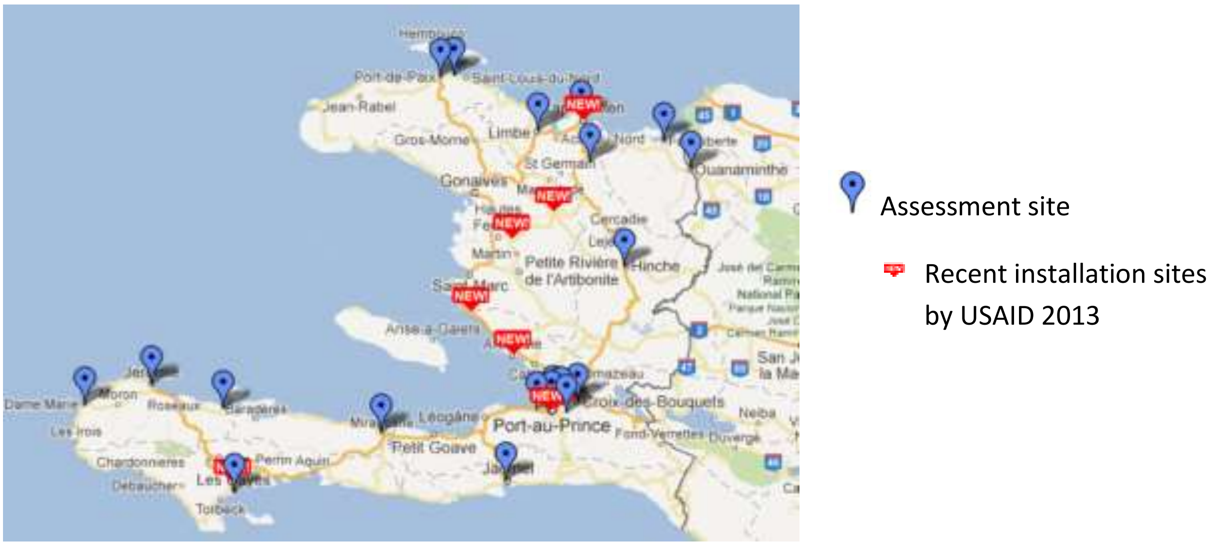


Figure 15: A Google map shows health facilities are served by USAID in Haiti [22]

To summarize, the main pillars for the success of solar projects in Haiti are: Proper design of PV systems, capacity building of local staff, and sustainable maintenance funds for regular maintenance and spare parts exchange.

Guyana

The power sector in Guyana is managed by the Guyana Power and Light (GPL), a governmental vertically integrated utility. The power management includes generation, transmission and distribution, and additionally the management of isolated power producers.

Due to high energy cost in Guyana, the increasing transmission losses and the poor reliability of the provided power in general lead to GPL's inability to collect service payment and to work efficiently. As result of the unreliable service and the instable electrical network, grid-connected health appliances such as x-ray machines, lights and other laboratory equipment have been damaged. Therefore end-users prefer to have their own independent power sources.

Health facilities in Guyana are divided into different categories based on energy supply options: grid connected quasi grid, and off-grid.

The President´s Emergency Plan for AIDS Relief (PEPFAR) project, for instance up to 2007, has been working on 42 health facilities across the country which provide HIV/AIDS care, treatment and prevention activities. Each one of these facilities has its own power supply for operating medical appliances, blood banks, vaccine refrigerators (for pediatric anti-retroviral drugs as well as immunization medicines).

Guyana has a long experience with solar energy systems for health facilities since 1980's. PV systems have been installed for 20 health facilities in different categories by the Ministry of Health in Guyana and democratic council in cooperation with and support from the Pan American Organization.

Although the installed PV systems are widespread across the countryside, their sustainability on the long run was considered, neither by the projects financers nor by the operators (end-users). Assessment studies by international development organizations, such as the USAID, revealed that many of the PV systems installed were not working properly, or having technical problems.
According to the significant evaluation study recently published by the USAID in Guyana, referring to the cold chain assessment report, 13 of 21 systems installed between 1982 and 2004 were not functioning well.

→ The main reasons for failure some PV systems in the country:

- Poor design of systems. This includes over or under-sizing of system components, such as batteries, charge controllers, etc.
- Improper installation carried out by untrained technicians in some cases.
- Poor maintenance.
- Lack of capacity building programs in parallel to the system installation.

A new project launched by the USAID in 2012 in Guyana "Improving Health Facilities Infrastructure (IHFI)" aims at improving energy access, reliability, and cost reduction for health facilities and posts in Guyana. Around 12 sites of health facilities and posts were assessed, in order to be electrified by photovoltaic systems. Two different capacities were launched in an open tender for the twelve health facilities: The first system (1.25kWp) was designed mainly for lighting and operation of a vaccine refrigerator, by providing 1.7kWh/day of energy needed. The second system (1kWp) was designed mainly for lighting, by providing 1.3kWh/day.

Ethiopia

Ethiopia has one of the lowest rates of electricity use per capita of the world, which is 45kWh per capita in 2009 [23]. The electricity capacity of the country is about 929MW, and expected to be doubled after launching the ongoing hydro power projects. About 86 % of the population is living in rural areas, and less than 20% are connected to the national grid [25].

There is much experience in Ethiopia with PV for health facilities and posts. The overall coverage of health services in Ethiopia in 2008 is about 89.6% [26] . Many international organizations are active in the country by extending health services, including the provision of energy access for rural infrastructure projects. Rehabilitation health facilities with medical appliances and energy sources have so far taken the priority.

A study conducted by the USAID team in Ethiopia shows that small to medium sized health facilities in the country required PV systems with a PV array capacity of 3kWp to 6kWp. The cost of this equipment, including batteries and inverter, would be between $60,000 and $120,000 [27].

Access to Modern Energy Services (AMES) project [28]

The AMES project is based in Ethiopia and financed by the GIZ. The main objective of this development project is to supply health facilities with solar PV systems. Up to date, 50 PV systems have been installed for off-grid health facilities at the countryside.

→ **The project seems to have an economic impact on the targeted areas**. Some of the PV system components have been produced locally, such as table frames and the solar panels support structure. Additionally, system installation has been carried out by five local companies. The installation companies in this project have been obliged by GIZ to maintain the PV systems for a period of 9 months after the installation or according to request. Increased capacity building was taken into consideration by training local technicians for doing maintenance and replacing spare parts.

→ **The project seems to have considered diverse cultures at planning and implementation stages**. Considered criteria include the cultural diversity in the country, as well as economic and topographical aspects, through selecting 18 different regions. Sustainability of the project was considered early by provision of a service contract, for the training of local technicians, and for providing system maintenance for five years. Raising capacity building, through training of local technicians, empowers the management staff of health centers to sustain PV systems operation and maintenance on the long run. Main aspects are presented in Table 5.

Table 5: Main aspects considered by GIZ in Ethiopia

Considered Aspects	Applied Actions
Economy	• Local production of PV system parts locally • Systems installation by local companies
Sustainability	• Designed capacity building program covers system installation, operation and maintenance • Maintenance chain mechanism provided for 5 years
Topography	• Selected 18 different regions cover large parts of the country

The Ethiopian government has an ambitious plan to build many health facilities, 50 % of them will be off-grid. Figure 16 shows the rapid growing number of health posts in the country. Recently, the government planned to launch a strategy which aims at calling for a health post to serve 5000 people, and health centers to cover an area inhabited by 25,000 people [29].

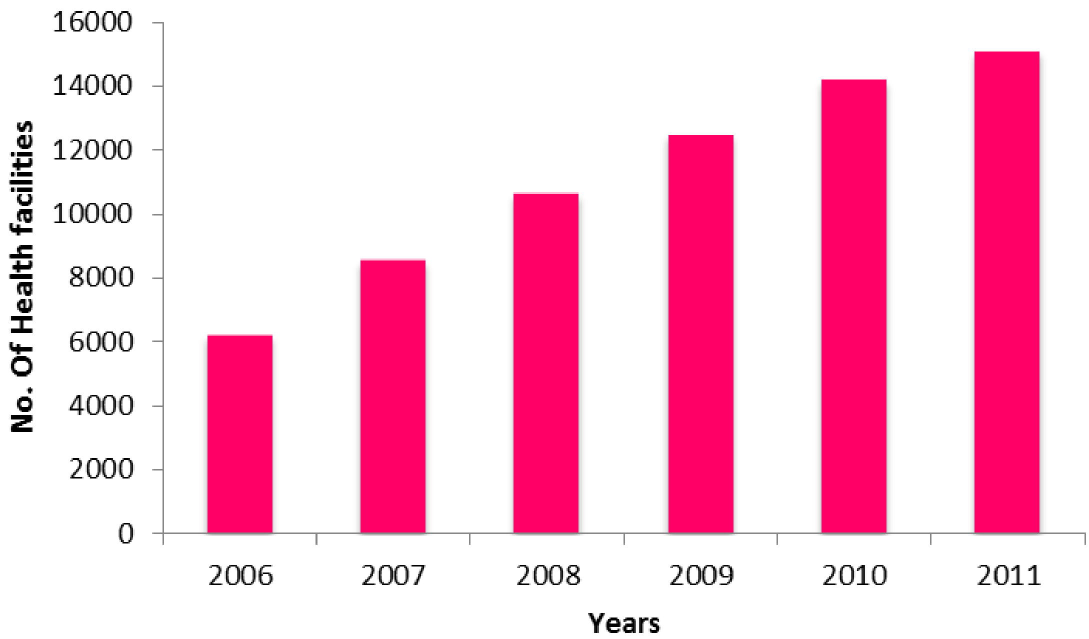


Figure 16: Growth in the number of health posts in Ethiopia (adapted [29])

The Stiftung Solarenergie (Solar Energy Foundation) recently announced to provide 100 solar lighting in Ethiopia and Kenya. Another 50 solar systems for lighting and refrigeration were installed also by the foundation in the last few years.

Tanzania

The power sector in Tanzania is a mix of hydropower (560MW) and thermal generation (300MW), in addition to the independent power producers. In 2009, the electricity access rate in the country was only 13.9%, and the energy consumption per capita was 85kWh [30]

In terms of receiving international aid per capita, Tanzania is ranked on top of the list of African countries. Due to the political stability of the country, many international organizations are active in the implementation of development projects, such as providing energy for health facilities and schools.

Energy contributes to accessibility: Most health services are closer to the rural dwellers in Tanzania. Provision of health services halted in most of the rural areas due to the lack of lighting. Experience of local people and private companies involved in energy sector shows that pregnant women are prompted to go for health services in health facilities carrying their own kerosene lamps or torches. Attending an emergency case during the night is difficult, as long as the health facility has no access to electricity. Most laboratory tests, including minor ones like malaria screening, are not being done in most rural health facilities in the country, due to unavailability of electricity. Moreover, energy availability plays a big role in keeping rural health workers from providing health services at night.

Experience of ENSOL, a solar PV company in Tanzania, shows that health workers prefer to stay in places where electricity is available. There are health facilities with no single health worker (a nurse, midwife or doctor), and one of the contributing factors is the unavailability of energy. Recorded cases show that health workers choose to even quit employment when they are assigned to work in remote rural areas where energy is a problem [31].

USAID has recently supported a project in four regions in Tanzania: Dodoma, Singida, Morogoro and Iringa. Over 50 health centers were equipped with PV systems of a total capacity of 3.4kW each. The systems are mainly designed to provide energy for lighting, lab equipment, computer, printer and TV set of CTC, as well as lights and TV for staff houses. The lab equipment consists of some medical equipment (a microscope, a hematology analyzer, a biochemistry machine, a centrifuge, a refrigerator and a suction machine).

Uganda

Uganda is a country with an estimated population of 35 million and a population growth rate of 3.3%. Malaria, malnutrition, HIV/AIDS, acute respiratory and tuberculosis are the main serious diseases spread out in the country. Around 80% of health facilities have no access to reliable electricity, see Figure 17.

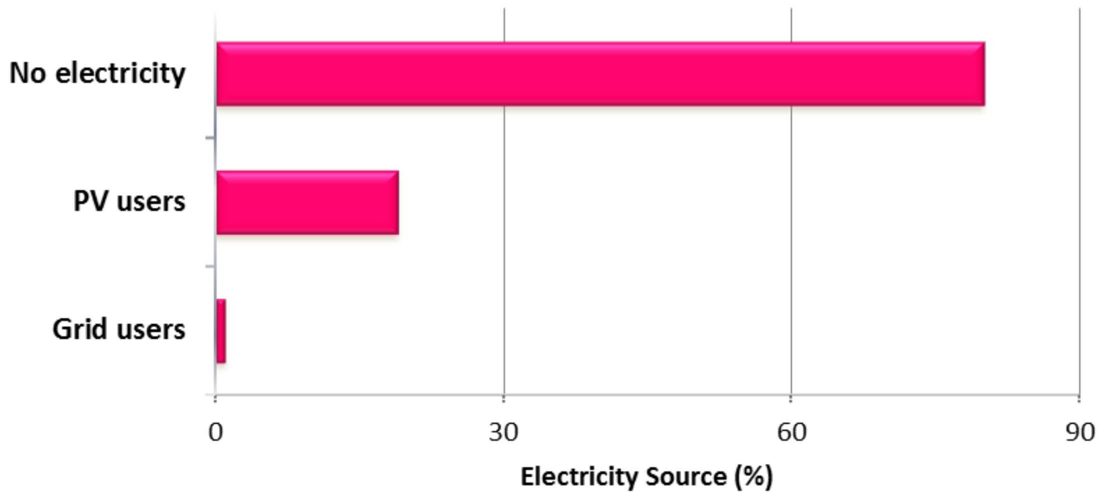


Figure 17: Electricity sources used by health centers in Uganda (adapted [31])

The GIZ Promotion of Renewable Energy and Energy Efficiency Programme (PREEP) in Uganda has set up the following criteria for supplying PV systems for new health facilities [28]:

- The facility should be located in the geographic working area of the project.
- The expected impact of the health center includes the number of beneficiaries which are served or receive benefits, and the amount of of medical equipment in the facility.
- The facility should be located not less than 5km from the nearest low voltage electrical grid and there should be no plan to be connected to the grid during the next 5 to 10 years.
- The Regional Health Office should be able to contribute 20% of the total PV system cost. This includes capital cost of the equipment, installation cost, maintenance, and battery replacement.
- So far, bigger facilities are prioritized.

Even when electricity is available through PV systems, in some of the health facilities, some difficulties still exist. For example, lack of accommodation for health staff, lack of clean water, and insecurity problems due to absence of fences surrounding the health facilities. Keeping solar panels safe from theft is a real challenge faced in some areas in Uganda.

The existing experience in Uganda shows that providing lighting for health centers to be utilized at night is as important as providing main service to patients within day. A survey done by GIZ in some targeted districts shows that the lack of electricity is the second problem of non-electrified health centers. Monitoring of projects while implementation process started is very crucial to ensure that PV systems are installed properly.

4.2 Financing approaches

PV systems projects for health facilities are financed and executed by a range of stakeholders include the following [30]:

i) **Government funded projects**

Financed locally from the central government through the Ministry of Health, local district councils, and Rural Energy Agency. These projects are often executed based on open competitive tendering procedures. Accordingly, procurement is done based on specific technical standards according to the energy needs of the targeted facilities. Most of these projects target the public infrastructure in developing regions such health facilities, schools etc.

→ Government funded projects cover a wide range of geographic locations as well as economic, political and financial aspects. These projects could also take a long time to be realized due to existing bureaucratic systems. Transparency is sometimes not considered.

ii) **Donor funded projects**

Financed by a range of international development organizations and multilateral agencies. The procurement mechanisms could be based on selective open competitive tenders or through financing of non-governmental organizations or research institutions that act as agencies for implementation.

→ The availability of assigned funds for such projects is a relevant question where international donor organizations work. Strict criteria and procedures are often put in place by international development organizations for financing such projects. The criteria include consultant assessment studies with regards to the expected socioeconomic impacts.

Co-finance projects

The co-finance is a mix of donor finance coupled with community contribution. The co-financing strengthens the sustainability of projects. Contribution of local districts, or even communities, if applicable, will increase the feeling of local project ownership, which makes proper systems maintenance more likely. The mechanism starts by an initial socio-economic and technical survey, and ends with the signing up of a partnership agreement between a main donor and other involved parties, usually regional health offices or local relevant associations.

→ Sustainability is more likely established with this financial approach. The existing experiences of such initiatives in some developing countries show that the contributions of local communities strengthen the feeling of local project ownership. Contribution of local communities is measured by ability and willingness of end-users to participate in financing of projects.

Grant funded projects

These include projects financed by international donors that provide grants directly to the official bodies and relevant ministries. For instance, the Tanzanian Rural Energy Agency in 2010 and 2012 has carried out grant proposal competitions called "Lighting Rural Tanzania Competition" and was financed by the World Bank. The 2012 competition was specifically focused on the electrification of rural public facilities (schools and health facilities). Winning proposals were awarded a maximum of US$ 100,000 to implement their projects.

→ Grant project has advantages of spreading up, or "ice-breaking" for, new technology. This kind of approach motivates governments and other stakeholders to finance and invest in new projects. However, co-financing approach is a more sustainable way, compared to the grant model.

iii) Religious institutional funded projects

These projects are financed by religious institution in limited locations. The geographical coverage of these types of projects is limited in some developing countries.

iv) Private funded Projects

Private health centers are spread out in off-grid regions where there is a lack of public health facilities. These facilities are privately owned by a local investor or family. The main function of these facilities is the provision of first aid, basic surgery and emergency services. Lack of financing of capital cost of these facilities, including the installation of a reliable energy source does not allow this mechanism to take place widely in developing countries.

An analysis of, and comparison between, the different approaches is shown in Table 6.

Table 6: Overview of financial Approaches through different stakeholders

	Geographical coverage	Bureaucratic process and delay	Access to finance capital	Ownership feeling
Government Finance	High	High	Low	Low
Donor Finance	Medium	Low	High	Medium to low
Co-finance	Medium to high	Medium to low	High	High
Grant Finance[5]	Medium	Medium	Medium	Medium
Religious Finance	Low	Medium	Low	Medium
Private Finance	Low	Low	Low	High

[5] Grant finance is given directly to the official authorities

5. Lessons learned

The international experience on PV systems for rural health facilities was discussed in the previous chapter. This chapter presents main conducive factors, sustainability key pillars, and practical lessons learned.

5.1 Conducive factors of PV supply for health facilities

In line to a local renewable energy strategy, conductive factors are considered to be the main framework towards successful PV supply programs for health facilities. These factors are: regulatory framework, institutional framework and business models, see Figure 18. It is in this document's scope to give a brief overview about existing policies, typical business models, and corresponding lessons learned.

5.1.1 Regulatory framework

While the international experience in building up clear policies and institutional regulatory frameworks is rich, a ‘one size fits all’ approach is not adequate. Establishing a local solar energy program policy is crucial, taking into consideration successful models of other countries, to be locally tailored. The political commitment also motivates private sectors to invest in off-grid PV projects.

A national off-grid renewable energy strategy is the cornerstone of the regulatory framework. The strategy draws the dimension of the solar energy program and identifies the locations of off-grid health facilities, criteria of involvement, and the geographical area covered. The political commitments and transparent policies are important to assist in expanding the off-grid PV market. In some countries, governments have launched a wide range of policy instruments to support off-grid rural electrification development programs. This includes financial and fiscal incentives (e.g. soft loans, exemptions from import duty) and reduction of overall subsidy of fuel [33].

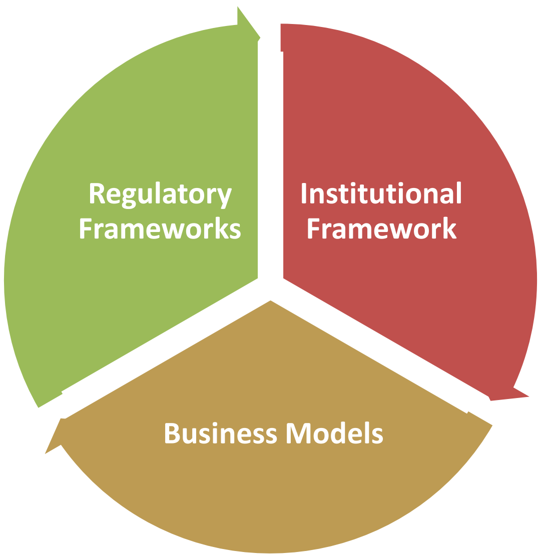


Figure 18: Conducive factors of PV supply for health facilities

5.1.2 Institutional framework

Building up a strong institutional framework is the key success factor for PV projects. This factor can be achieved through establishing an efficient management system, assigning clear roles, tasks and responsibilities to working staff and specialists. Administrative procedures can be minimized by using modern administration tools and software networks, and avoiding administrative routine. A transparent institutional set-up assists in expanding the PV markets in off grid areas, and in attracting PV manufacturers to invest in local markets and to create new jobs.

Effective coordination and cooperation should take place between relevant sectors and parties. These include building up open cooperative channels between main players, speeding up project financing, survey and implementation, and reducing operation cost. Often, the main stakeholders are district health offices, local government, the Ministry of Electricity and Energy, local NGOs, and end-users. In this context, a top-down centralized management approach is not recommended as much as a decentralized bottom-up approach [33].

5.1.3 Business models

Business models and also financial schemes significantly contribute to expanding off-grid PV markets. Through designing adequate financial mechanisms, a large number of health facilities will have access to solar energy services.

Donor financing funds are necessary in the early stages of off-grid solar programs. This finance can be reduced gradually until a solar market reaches a certain stage. The PREEP project in Uganda, which was implemented by the GIZ, is an example of a co-financing business model. The contribution of the GIZ in this project reached 80% of the total cost, while the Districts Health Offices share 20% [28]. Figure 19 shows the schematic diagram financial and operational model of the PREEP project.

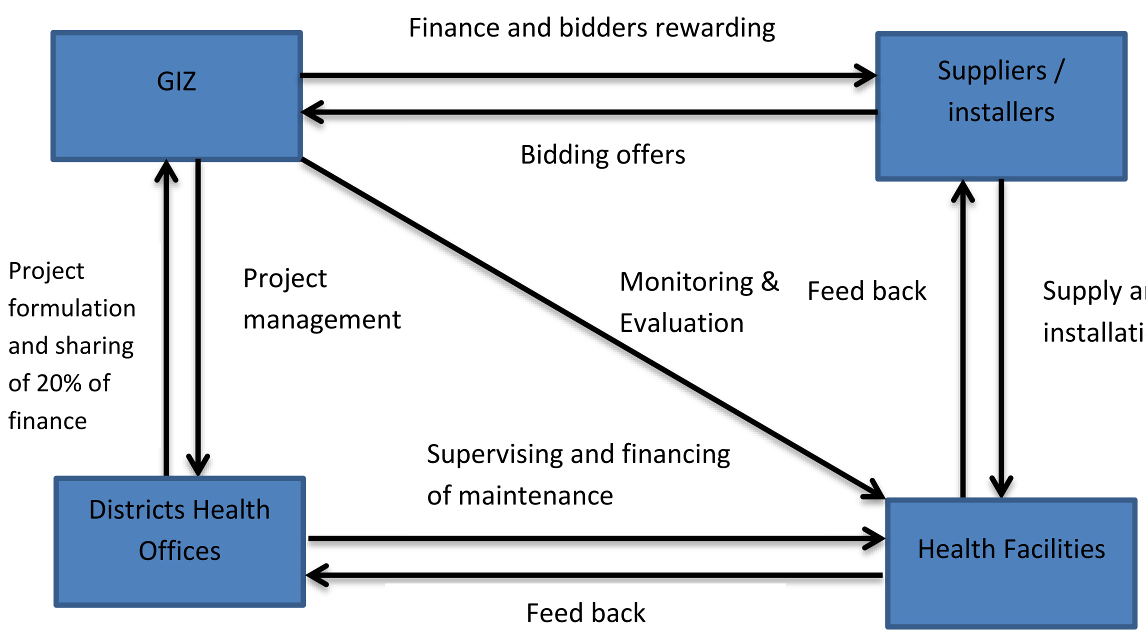


Figure 19: The financial and operational model of the PREEP project in Uganda

A similar financial model was applied by Solaraid in Tanzania. This model provided PV systems to district councils with, as a pre-requisite commitment, a contribution of 40% of the installation cost by the district councils. The contribution was supposed to be paid over a period of one year after installation [31].

5.2 Factors enhancing the sustainability of PV systems

PV systems can contribute considerably towards realizing sustainability in health facilities. The main challenge, however, is how to keep installed systems properly working and efficiently utilized throughout their lifetime. Lessons learned, and crucial pillars of success, which significantly enhance the sustainability of PV systems, are shown in Figure 20.

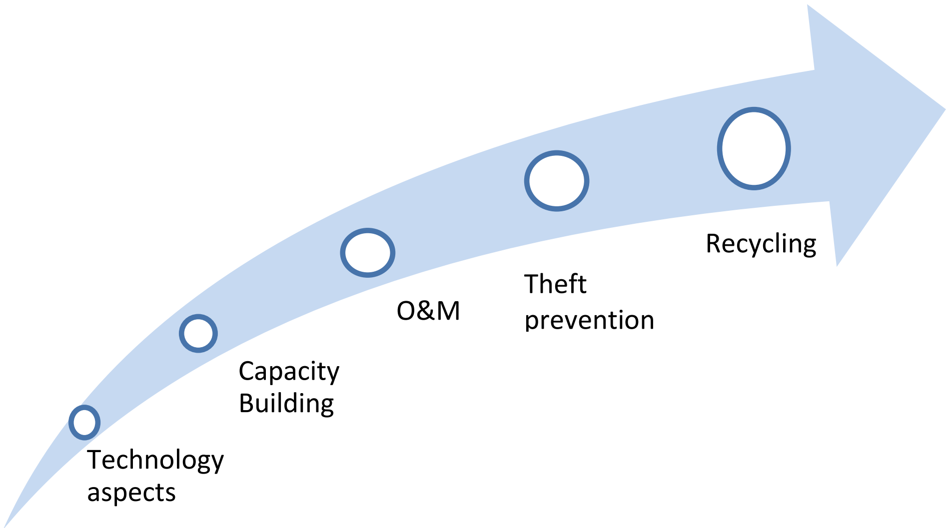


Figure 20: Main factors towards enhancing sustainability of solar PV systems

5.2.1 Technology aspects

While PV systems are meanwhile a mature technology, many projects failed in the past due to the poor quality of system components including batteries, charge controllers and inverters. PV system components should comply with one of the recognized international standards (e.g. IEC, DIN, IEEE). For instance, the WHO has its own standard PQS, which represents a technical-assurance reference for the WHO and UNICEF regular supplies. More details about international standards are illustrated in the chapter three.

System design is also a crucial task. Generally, it is recommended to procure the systems based on the actual energy demand in kWh, and not only based on a nominal power capacity in kW-peak. Accordingly, the technical specifications of the designed systems have to be precisely adjusted.

A proper sizing of electrical cables is also important. Undersized cross section of cables leads to increased internal resistance and overall losses. To avoid short-circuit currents, it is advisable to use proper terminals for connecting cables with the system components. Furthermore, the electrical connections should be kept as short as possible, to reduce overall loses.

To avoid unhealthy battery bank depths of discharge (DOD), it is advisable not to connect the battery directly to an inverter without battery deep discharge protection. An adequately controlled electrical relay can be a solution to connect the inverter to the batteries, or to the output of a charge controller. A proper schematic diagram for an electrical circuit of the PV stand-alone system is shown in Annex-1, case study one.

5.2.2 Capacity building

A specific training program on operation and maintenance of PV systems for local working staff is required. The training program can be launched in parallel with the installation of the PV systems. In addition, training of local staff on management of energy stored in batteries is necessary; including the operation of critical, important and non-important loads.

A user manual should be delivered to end-users of health facilities and technicians. For instance, a user manual should illustrate battery water level measurement and shows also a caution of misusing batteries. This will help technicians in remote monitoring or reporting a problem might occur.

5.2.3 Operation and maintenance

Most PV systems are designed by independent consultants in developing regions. The task of consultants includes system design, field survey, and preparing the technical specifications of PV systems. Existing experience shows that most health facilities in rural areas are owned by district councils. Hence, it is their responsibility to operate and maintain the installed systems. This is a challenging situation, as most of the district councils do not have a maintenance budget set aside. This leads to premature failure as the systems are not attended in time when there is a problem.

Only a few donor organizations support maintenance funds for implemented projects. The Clinton Foundation in Tanzania, for instance, has put a maintenance plan in place to carry out the maintenance of all of their supported installations through contracted PV companies. Table 7 shows the type of maintenance recommended, and the corresponding lifetime of system components.

Table 7: Main PV System components, life time and maintenance recommended [9]

System Components	**Life-time (years)**	**Type of Maintenance**
Solar Panels	20	• Clean dust on modules regularly (once a month) • Check PV array output current, voltage and connections (once a year)
Batteries (lead-acid type)	3 - 10 years	• Clean batteries poles regularly (once a month is recommended) • Check the voltage of the battery (twice a month), e.g. at noon it should be 14V for a 12V battery • Check level of electrolyte of cells6 (once a month) • Fill distilled water when needed4
Charge Controllers	10	• Inspect connection of wiring to and from charge controllers (once a year) • Check charging current and voltage
Inverters	10	• Inspect connection of wiring to and from inverters (once a year) • Check output current and voltage
Wiring, , connections, etc.	20	• Check fuse, connections between system components regularly (once a year)

[6] Sealed batteries are excluded

One of the main common problems is inappropriate system design, or misuse of it through connecting other loads, often heavy loads, which were not intended to be supplied by the system.

If installations follow international standards, the PV system components are long lasting (i.e., guaranteed to work over a period of 10 to 20 years) except for the batteries. Depending on the type of battery chosen, battery replacement is the major item that contributes to higher lifecycle cost of the systems. Long-life type batteries are available, but are also very expensive. It is recommended to work with good quality batteries lasting for a minimum of 5 years.

5.2.4 Recycling

Batteries are the main components in stand-alone PV systems that need to be recycled. Basically, they contain toxic materials which have negative effects on the environment if disposed of inadequately. Therefore, recycling of batteries should be considered mainly when designing maintenance mechanisms.

5.2.5 Theft prevention

The investment costs of PV systems are high; therefore systems can be stolen in remote areas. Some health facilities lack the safety of fences or other measures that prevent installed systems from being stolen. Anti-theft screws can keep the PV modules secured. Another option to secure the PV modules is through the welding of module frames together, if possible with a fixed foundation.

Table 8: Recommendations for a successful PV supply projects for health facilities

Categories	Recommendations
Regulatory frame work	1. Establish a local policy for an off-grid PV program, taking international successful models into consideration. A regulatory model should be adapted locally, since no "one size fits or all". 2. A national off-grid solar energy strategy is the road map for health facilities and other public infrastructure with solar technologies. The strategy should identify off-grid areas, public infrastructure, number of beneficiaries, income, etc. 3. Political commitment of the government is important for successful energy projects. This commitment should be applied on the ground, by measures such as soft loans, subsidies or guarantee.
Institutional framework	4. Build up a transparent institutional set-up for program management, and identify rules, duties and responsibilities of working staff. 5. A decentralized bottom-up management approach is recommended more than a centralized top-down approach. The decentralized bottom-up approach speeds up project implementation and avoids routine procedures or delays. 6. Build up a partnership agreement or cooperation with relevant official bodies such district health offices, local government and local NGO, which is crucial to facilitate implementation procedures, to tackle barriers and to guarantee project sustainability.
Business models	7. Establish local business models with relevant partners. Financial channels accelerate the number of health facilities that get supplied by PV systems. These channels may be established in form of partnerships concerning capital cost of projects, operation and maintenance cost, loans, subsidies, etc. 8. Donor funding is necessary at the early stages of programs, and could 'break the ice' for local investors and development banks to support such a new technology.
Technology aspects	9. Procure system components strictly according to the requested specifications, and store batteries in suitable environment and appropriate temperature. 10. Design the PV system based on actual or anticipated demand of the health facility. Consider critical, important and non-important loads to enable a 'graceful degradation scheme' in case of scarce energy supply). 11. Install PV systems professionally, considering solar azimuth angle, inclination angle, shadow etc. 12. To avoid battery related problems, a direct-drive vaccine refrigerator could be an option for small size health posts (in immunization programs). While this technology was recently approved by WHO, pilot projects still need to be monitored and evaluated.
Capacity building	13. Train local staff in installation and regular maintenance, replacing spare parts, checking of the electrolyte in batteries, corrosion cleaning, checking and replacing protection fuses, and short-circuit problems. 14. Prepare a user manual of the PV system for the health facility staff. The manual should illustrate operation, monitoring and energy management of the system.
Operation and maintenance	15. Establish a sustainable maintenance fund for regular maintenance and for replacing defect components of the PV system along the lifetime. 16. On the long run, system maintenance is the backbone of the sustainability of off-grid systems.

Annex-A:

Case study one: Al-Mahwa health facility, Yemen

Source: Adnan Al-Akori, personal observation, February 2014

Project overview: The project is located in the Al-Mansoria district, Al-Hodeida city, Yemen. Latitude is 14° 66’ North and longitude is 43° 43’ East. The project was implemented by the local government in 2010 with aims to provide basic health services to around 4,000 people living nearby.

Main services provided by the facility are:

- Provision of simple diagnostic treatments and blood tests ;
- Support of vaccine campaigns, each month approx. 13 children get benefit from vaccine services each month;
- Provision of emergency first aid treatments.

Solar radiation

The solar irradiation in Yemen is very high, as the country is located under the ‘Sun Belt’. Figure 21 shows the mean irradiance of the site. The highest solar irradiance is in April, it reaches 7.40kWh/m^2/day. The global horizontal solar irradiation of the site is 2270 kWh/m^2/year.

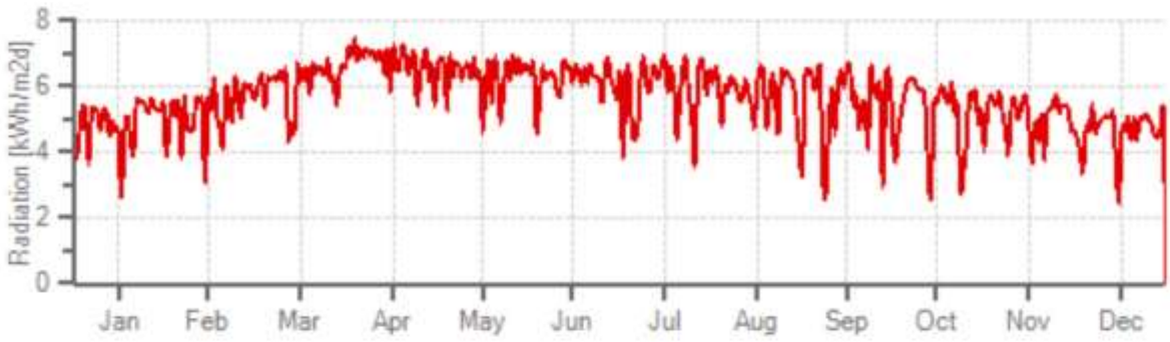


Figure 21: The horizontal solar irradiation of the site

Loads

The facility has a small lab which contains very limited medical equipment. The lab is equipped with an LED microscope and a centrifuge, in addition to lights and fans. Table 9 shows the list of medical and non-medical appliances working with a PV system. Due to the lack of a solar vaccine refrigerator, the facility is equipped with an absorption thermal operated refrigerator, RGE 400 model, with a volume of 224 liter and 308 Watt of power.

PV array

The total power output of PV modules is 450W_p. The PV array consists of six panels, SLSM-080D model from LONG energy, 75W each, and is expected to produce 4.44A each in a full sun shine. Out of that, only five modules were functioning. The PV array power output estimated to be 1300Wh/day considering the voltage of system is 12V, and the peak solar hours equal to 5hrs. The total load was calculated, equal to 1444Wh/day which exceeds the PV array power output, see Table 9.

Battery
The system includes three 12V sealed lead acid batteries with a capacity of 200Ah each (MF210H52 model from AURORA). The batteries are connected in parallel to yield 600Ah at 12V. At the time of the field visit, the existing batteries failed and were replaced by new batteries.

Charge controller
A 30A series type charge controller was installed to protect the batteries from overcharging. The charge controller model is SOLARIX PRS 3030 from Steca Electronic GmbH, Germany.

Inverter
The distribution voltage is designed to be AC as the overall load works on the AC voltage. A 1600W inverter from SCIENCE Company converts the current from 12V DC to 220V AC. The inverter was directly connected to the batteries.

Project cost
The local cost of the PV system is high compared to the international market. A few dealers provide PV system components. The overall cost of the installed system, which includes the capital and installation cost, is USD 5,000 or 11USD/Wp.

Field observations
Within the field investigation mission to the installed PV system, the following observations were made:
System installation: Poor installation of the system was clearly noticed, see Figure 22. The inclination of the PV panels was not adjusted to be at the optimum angle. As a rule of thumb, PV panels are installed with a tilt angle equal to the latitude of the site (unless optimization needs to prefer winter or summer situation, or adapt to local climatic circumstances). In other words, the PV array receives less solar irradiation and produces less power than would be possible.

The inverter was directly connected to the battery, which most probably damaged the batteries (due to deep discharge) that were replaced recently. Excessive discharging the batteries decreases their lifetime considerably. The wiring connections between panels or between the system's components were not carried out properly. There also were no fuses.


Figure 22: Poor installation of the installed PV system

***Power shortage**:* The existing PV system does not cover the actual load of the facility and is not able to operate additional loads, such as a water pump or essential medical appliances which local people are looking for (e.g. X-ray, diagnostic devices).

Training: The regular maintenance of the system was carried out by local volunteers. Often, the costs of spare parts were covered partially by the facility itself. However, as there is no sustainable finance allocated for the maintenance, some spare parts in the system were replaced with lower quality parts, such as batteries with lower capacity.

PV system and diesel gen set: The working staff had a positive attitude towards the PV system, rather than towards a diesel gen set. However, the field survey investigation showed that the capacity of the installed PV system does not cover the actual energy needs of the health facility. A small diesel generator was available and might be used for the operation of the autoclave.

Vaccine refrigerator: A 220L vaccine absorption refrigerator was located in the facility. As the existing PV system cannot supply the vaccine refrigerator with the required energy, the existing refrigerator is operated with liquefied petroleum gas (LPG).

End-user experience: The working staff of the facility was in favor of the installed PV system, but not satisfied about its capacity which does not cover the actual load. Lack of finance was seen as the main barrier against upgrading the existed system or replacing spare parts. As the health facility supports occasional vaccination campaigns, the working staff looks forward to replace the vaccine refrigerator that works with LPG by a new one working with PV.

Recommendation:

- A comprehensive load demand assessment must be conducted in the planning phase of projects;
- Installation of PV system should be carried out through skilled technicians;
- Allocating of a sustainable finance for maintenance and replacing of spare parts;
- Upgrading the existing PV system by installing an additional one mainly for a new vaccine refrigerator.
- Replacing of the absorption vaccine refrigerator powered with LPG by a compression refrigerator powered with PV either via electrical battery storage or as direct-drive version with internal thermal storage, e.g. with additional 330W of PV panels.

Box 2: Re-designing the system

The existing PV system could be redesigned to work efficiently. Simple calculations show that the optimized design based on existing load (1444Wh/day) suggests upgrading the PV modules to 700Wp and reducing number of batteries to be two units, each 6V-225Ah (Trojan T-105 model). The autonomy would be 33 hours and the battery replacement cost would be lower. A 500 W inverter could be adequate to operate the existing loads. The existing absorption refrigerator (powered with LPG) also could be replaced by a direct-drive refrigerator, powered by an additionally required 330W PV array.

Box 3: Avoiding battery damage by inverter

Because of cost reasons, in many systems the charge controller is not able to handle the high DC input current of the inverter. This means that the inverter is directly connected to the battery without a deep-discharge protection for the battery. For example, many 12V inverters operate until a low input voltage of 10V, which is too low to prevent deep-discharge of the battery. The result is in many cases a premature failure of the battery. To avoid this, an inverter should have an input to switch it off by an external contact or a signal, which could be a control relay which is connected to the output of the charge controller, see Figure 23.

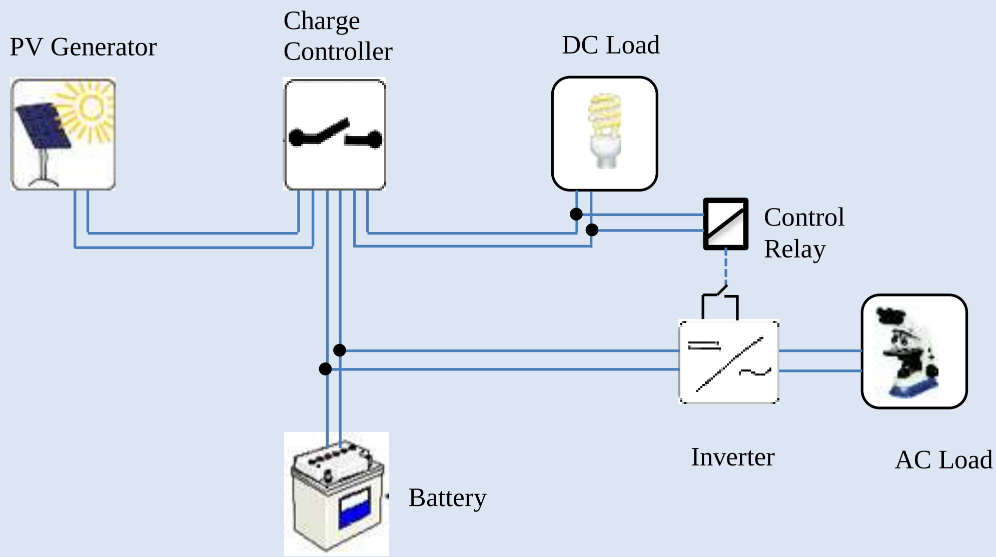


Figure 23 : Proposed schematic diagram for electrical connections of a PV system (with a control relay)

A DC power relay in the DC power line of the inverter can be used, see Figure 24. The disadvantages of this solution are the higher price and higher power demand of such a DC power relay.

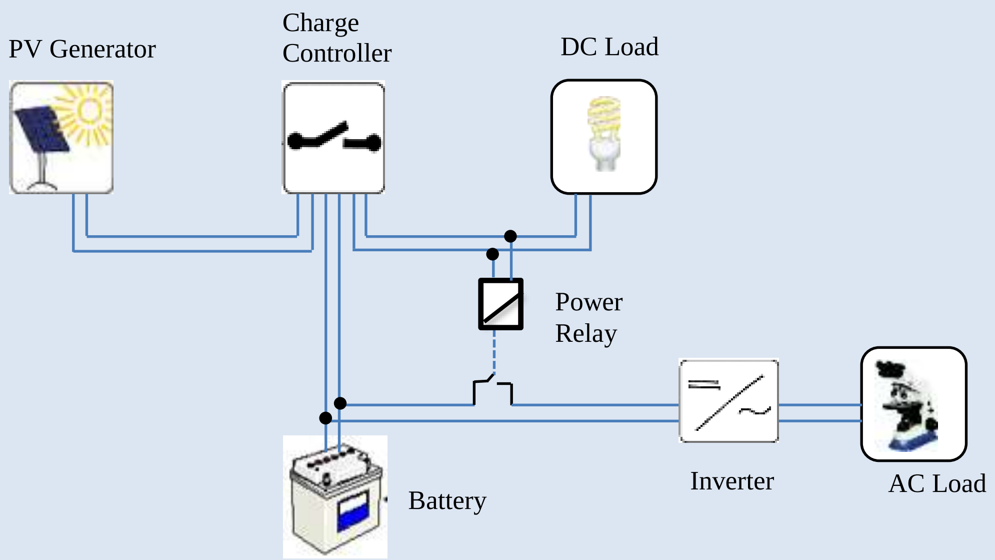


Figure 24: Proposed schematic diagram for electrical connections of a PV system (with a power relay)

Table 9: Daily load of the Al-Mahwa health facility

Power Consumption	**Qty.**	**Power (Watts)**	**Hours/ Day and Night**		**Watt-Hours/Day and Night**		
			Day	Night	Day	Night	Total
Lighting (CFL)	3	18		2	0	108	108
Exam light	1	18		2	0	36	36
Microscope	1	20	1		20		20
Centrifuge	1	40	0,5		20	0	20
Fans	3	80	5		1200	0	1200
Radio	1	10	4	2	40	20	60
Total		382			1260	184	1444

Case study two: Lugala Lutheran Hospital, Tanzania [7]

Source: This case study was contributed from Sofia Sparr and Mona Norbäck, a master thesis investigation study was carried out under a theme of "A sustainable, economical and reliable off-grid energy system", Lunds University, May 2014.

Project overview: Lugala Lutheran Hospital is situated in poor and rural region, at 8o 56' south and 36o 8' east in the Ulanga district of South Tanzania. It is located 115km from the national electricity grid. The hospital, a non-profit facility with 157 beds, covers a geographical area with a population of 164,000 people.

The hospital consists of the following departments: maternity ward, female and pediatric ward, male ward, theatre with X-Ray department, laboratory and pharmacy department. Furthermore, there is a care and treatment clinic (CTC), outpatient department (OPD), reproductive and child health clinic (RCHC), nursing school, and workshop. In addition, the hospital provides housing for some of the working staff members and patient relatives. Connected to the hospital are also a hospital church, a restaurant and an incineration site.

Energy system: The current energy system at the hospital consists of PV panels and diesel generators (DG) for electricity, solar thermal collectors and solid bio fuel for water heating and cooking. Figure 25 summarizes the energy system of the Lugala Lutheran Hospital. In this case study, the main focus is on the installed PV systems. The schematic diagram shows that the total installed capacity of the PV array is 18kW which provides about 40% of the electricity generated for the hospital. The capacities of the two diesel generators are 33.6kW and 23kW respectively. Some of the PV systems are connected to the diesel building in a PV–DG hybrid system with batteries. In this way, the DG is set to be the master. However, most of the PV systems are not connected to the generator, and autonomously supply energy to some of the hospital wards.

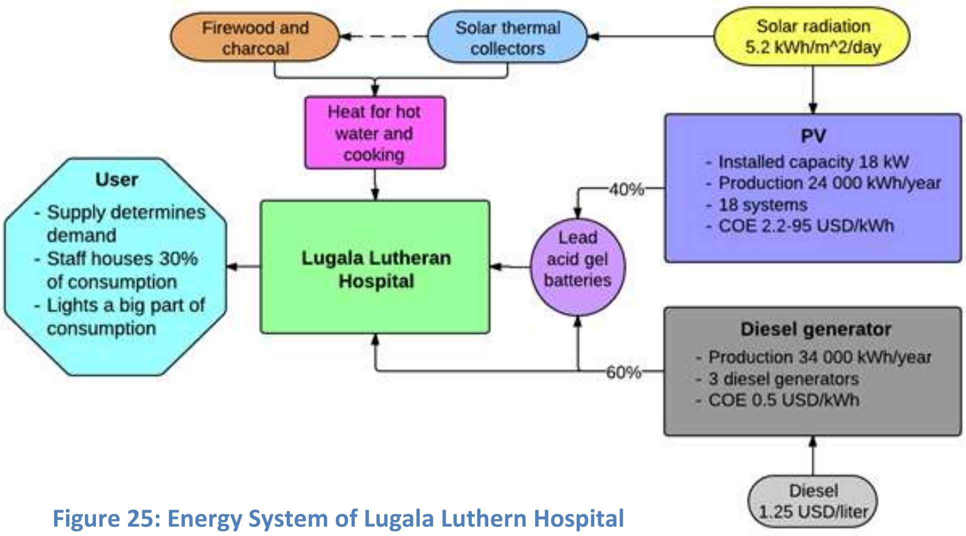


Figure 25: Energy System of Lugala Luthern Hospital

Electricity consumption

The current total electricity consumption of the hospital is 160kWh per day (58,000kWh per year), of which the largest part (39% of the total consumption) is used for lights, mostly for staff houses. Among the light load there is also outdoor security light that is switched on or off from dusk to dawn. The majority of the lights are energy saving bulbs with a power input range of 7-35 W. The second largest consumption part is by personal electronics and appliances. Medical equipment (e.g. X –ray, oxygen concentrators and other equipment) shares only 11% of the total load consumption. Furthermore, the autoclaves that are used daily require electricity from diesel generators. Figure 26 shows the total electricity consumption divided per type of load.

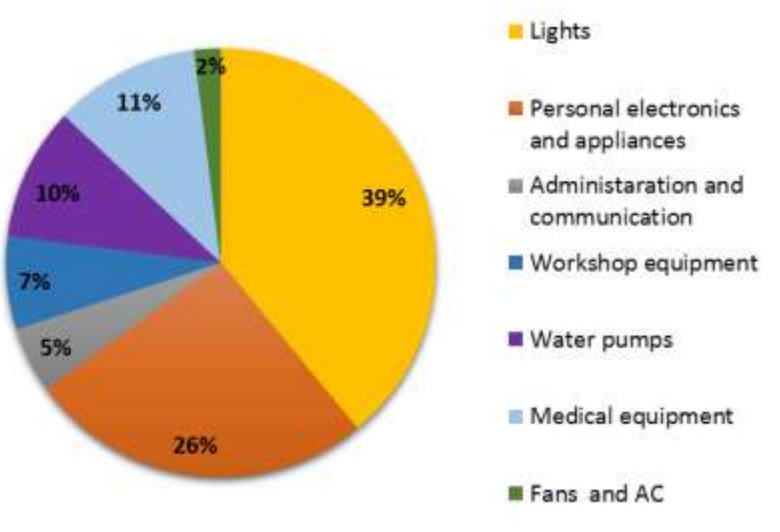


Figure 26: Electricity consumption divided per type of load

Investigation results

Regarding the installed systems, the loads could preferably be redistributed. According to modeling results on HOMER, some of the systems showed a high excess of electricity, while others seem to suffer from shortage. For instance, the excess capacity in the staff houses reaches 75% of the system. However, it is preferable to keep some excess electricity rather than to risk a shortage, since this will prevent the batteries from being destroyed in case of a large demand peak.

Batteries were the weakest components of the installed solar systems, and the users are not always aware of how premature failure can be avoided by changing the user behaviour. At the time of the field investigation to the hospital, the batteries in some of the systems were in bad condition due to repeated deep discharge, which sometimes led to premature battery failure. Therefore, it is important to keep track of the battery status and to make sure that the users know which loads are compatible with PV systems. The charge controllers used at the hospital shows the battery status which could easily be checked regularly. The gel batteries are proven also at the hospital to be suitable for hot climates, where batteries which required refills of distilled water had been used earlier, and failed due to insufficient refilling.

For water pumping, batteries are not needed; hence the PV system used for pumping water at the hospital seemed to be working satisfactorily. An increase of PV capacity for water pumping can moreover reduce the use of diesel, since additional pumping is often performed during the day.
The electricity generated from diesel at the hospital will be hard to be substituted in the near future. The diesel generator is currently more or less used as a base load supplier. Most of the staff houses only have access to diesel-generated electricity. An aim to reduce reliance on diesel would be important. A decrease in the usage of diesel can be achieved by optimizing the loads and operation of diesel generator.

During the case study, it was difficult to get an understanding of the question of how well the maintenance of the energy system components was implemented. Although preventive maintenance was implemented according to the staff members, one of the diesel generators was unable to operate for several weeks due to problems caused by the usage of oil fitted for different types of diesel generators. The other diesel generator was leaking oil, which implied that preventive maintenance was not working properly.

At Lugala Lutheran Hospital, the investment varies from 7,480 USD per kW for the larger system to 16,890 USD per kW for the smaller systems. This shows that larger systems are more economical, since the cost per kW is decreasing with increasing size. Economic calculations show that levelized cost of energy (LCOE) from PV systems varies between 2.2 and 95 USD per kWh. The most important reason for this big variation is to what degree the available capacity is utilized.

Annex-B:

Typical load estimation sheet for Al-Ja'adh Facility, Yemen (adapted [1]).

	Area	Qty	Load	Power (Watts)	Hrs/ Day		Watt-hours			KWh/ day
					Day	Night	Day	Night	Total	
S/no	**lighting and Fans**									
1	Entry and Corrids	10	CFL light	22		12	0	2640	2640	2,6
2	PTMTCT Lab	2	CFL light	22	2	4	88	176	264	0,3
3	Partial	2	Fan	80	5	3	800	480	1280	1,3
4	Blood lab	1	CFL light	22	2	4	44	88	132	0,1
5	Male ward	3	CFL light	22		4	0	264	264	0,3
6		1	Fan	80	5	3	400	240	640	0,6
7	Exam Room	1	CFL light	22	1	4	22	88	110	0,1
8	Post Natal	2	CFL light	22		4	0	176	176	0,2
9		1	Fan	80	5	3	400	240	640	0,6
10	Maternity Dorm	5	CFL light	22		4	0	440	440	0,4
11		2	Fan	80	5	3	800	480	1280	1,3
12	Delivery room	4	CFL light	22		4	0	352	352	0,4
13	Kitchen	2	CFL light	22		2	0	88	88	0,1
14	Offices (5)	5	CFL light	22	4	4	440	440	880	0,9
15	Other Lights	4	CFL light	22		4	0	352	352	0,4
16	Security Lights	4	CFL light	22		10	0	880	880	0,9
	Total lighting						**2.994,0**	**7.424,0**	**10.418,0**	**10,4**
	Lab Equipment									
17	Blood Lab	3	Microscope	20	2	2	120	120	240	0,24
18		1	Radio	30	4	4	120	120	240	0,24
19	PTMTC Lab	1	Rotar	60	1		60	0	60	0,06
20		1	Refrigerator-	500	1	1	500	500	1000	1
21		1	centrifuge	400	1		400		400	0,4
22		1	Water Bath	400	1		400		400	0,4
23		1	Spectrophotometer	63	1		63		63	0,063
24		1	Autoclave	630	1		630		630	0,63
25	Dental Suite	1	Chair	710	0,5		355		355	0,355
26		1	Compressor	370	2		740		740	0,74
27		1	Jet Sonic Cleaner	45	2		90		90	0,09
28		1	Amalgam	80	1		80		80	0,08
29		1	X-Ray	200	0,5		100		100	0,1
	Total Lab Equipment						**3.658,0**	**740,0**	**4.398,0**	**4,4**
	Other Equipment									
30	RHO Office	1	Refrigerator	500	1	1	500	500	1000	1
31	Admin Office	2	Computers	150	4		1200	0	1200	1,2
32	Vaccine	1	Vaccine	60	12	12*	108	108	216	0,216
33	Water Supply	1	Water Pump	100	6		600	0	600	0,6
34		1	CB Radio	10	10	12	100	120	220	0,22
35		1	Stand by	2	12	12	24	24	48	0,048
36		1	Transmiting	30	4		120	0	120	0,12
	Total Other Equipment						1.700,0	500,0	3.404,0	3,4
	Grand Total						**8.352**	**8.664**	**18.220**	**18**

* duty cycle about 15%

Bibliography

[1] Powering Health, “Load Analysis and Example Calculations,” USIAD, [Online]. Available: http://www.poweringhealth.org/index.php/topics/management/load-analysis-and-example-calculations. [Accessed 10 09 2014].

[2] WHO, “Prequalification of immunization related equipment and devices,” 14 07 2014. [Online]. Available: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/. [Accessed 16 07 2014].

[3] NREAL, “Renewable Energy for Rural Health Clinics,” National Renewable Energy Laboratory, Colorado, 1998.

[4] “Comparison Chart between ILB, CFL and LED (modified),” [Online]. Available: http://www.designrecycleinc.com/led%20comp%20chart.html. [Accessed 17 07 2014].

[5] Powering Health, “Load Analysis and Example Calculations,” USIAD, [Online]. Available: http://www.poweringhealth.org/index.php/community/stories/item/350-world-immunization-week-the-cold-chain-energy-and-the-environment. [Accessed 10 09 2014].

[6] Mona Norbäck and Sofai Sparr, “A sustainable, economic and a relieble off-grid energy system Master Thesis,” Institutionen för Energivetenskaper, Lunds Tekniska Högskola, Lunds Universitet, Lund, 2014.

[7] Mark Hankins, Stand-Alone Solar Electrical Systems, One ed., London: Earthscan, 2010.

[8] USAID, “Photovoltaic (PV) Systems,” [Online]. Available: http://www.poweringhealth.org/index.php/topics/technology/solar-pv. [Accessed 04 03 2014].

[9] Dr. P. Jayakumar for APCCT, “Solar Energy Resource Assessment Handbook,” APCCT, 2009.

[10] Deutsche Gesellschaft fü rSonnenenergie (DGS), Planning and Installing Photovoltaic Systems, Third ed., New York: Earthscan, 2013.

[11] S.R Wenham, M.A Green, M.E. Watt, R.Corkish, Applied Photovoltaics, Earthscan, 2007.

[12] Know Your Planet, “DC LA Battery Voltage Drop Under Load,” [Online]. Available: http://www.knowyourplanet.org/off-grid/batteries/DODdischargeVoltageLoad_.png/view. [Accessed 06 02 2014].

[13] IEA, “Lead-Acid Battery Guide for Stand-Alone Photovoltaic Systems,” IEA-PVPS, 1999.

[14] IEA, “Technology Roadmap Solar photovoltic energy,” IEA Publications, Paris, 2010.

[15] Practical Action, “Poor People's Energy Outlook 2013,” Practical Action Publishing., UK, 2013.

[16] WHO, “About WHO,” [Online]. Available: http://www.who.int/about/en/. [Accessed 10 11 2013].

[17] WHO, “Immunization coverage Fact sheet N°378,” 02 2014. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs378/en/index.html. [Accessed 14 03 2014].

[18] unicef, “About unicef: Who we are,” [Online]. Available: www.unicef.org. [Accessed 15 11 2013].

[19] unicef, “Supply Annual Report,” unicef, 2012.

[20] W. c. Solar, “Solar Suitcase,” [Online]. Available: http://wecaresolar.org/solutions/solar-suitcase/. [Accessed 22 10 2013].

[21] USAID, “Powering Health, Options for Improving Energy Services at Health Facilities in Haiti,” USAID, 2008.

[22] USAID, “Powering Health, Options for Improving Energy Services at Health Facilities in Haiti,” USAID, 2008.

[23] USAID, “Haiti Updates,” [Online]. Available: http://www.poweringhealth.org/index.php/countries/haiti. [Accessed 15 11 2013].

[24] IRENA, “Renewablwe Enenrgy Country Profile,” [Online]. Available: http://www.irena.org/REmaps/countryprofiles/africa/Ethiopia.pdf#zoom=75. [Accessed 15 01 2014].

[25] World Bank, “Ethiopia Receives US$180 Million for Energy Access Project,” [Online]. Available: http://www.worldbank.org/en/news/press-release/2010/06/29/ethiopia-receives-us180-million-for-energy-access-project. [Accessed 13 12 2013].

[26] GIZ, “PV System for Rural Health Center - "AMES-E" Project,” GIZ, 2009.

[27] USAID, “Powering Health, Options for Improving Energy Services At Health Facilities In Ethiopia,” http://www.poweringhealth.org/index.php/resources/media/publications, 2008.

[28] GIZ, “Electrification of Social Institutions with Solar Photovoltaic -Lessons Learned from Uganda and Ethiopia,” [Online]. Available: https://energypedia.info/wiki/Electrification_of_Social_Institutions_with_Solar_Photovoltaic_-Lessons_Learned_from_Uganda. [Accessed 17 12 2013].

[29] FMOH , “Health Policy of the Transitional Government of Ethiopia,” Addis Ababa, 1993.

[30] IRENA, “Renewable Energy Country Profile,” [Online]. Available: http://www.irena.org/REmaps/countryprofiles/africa/tanzania.pdf#zoom=75. [Accessed 06 30

2014].

[31] P. R. Magali, Interviewee, *Director of projects and business development in Ensol-Tanzania.* [Interview]. 11 November 2013.

[32] GIZ, “Impact Assessment of The Solar Electrification of Health centers in Uganda,” GIZ, 2009.

[33] IRENA, “IOREC 2012, Iternational Off-Grid RE Conference, Key Findings and Recommendations,” 2013. [Online]. Available: http://www.iorec.org/conference.php?page=conference-presentations-nov2. [Accessed 15 12 2013].

[34] unicef, “Cold Chain Procurement Reference Guide,” [Online]. Available: http://www.unicef.org/supply/files/Cold_Chain_Procurement_Reference_Guide.pdf. [Accessed 10 22 2013].

[35] Arnaud De La Tour, Matthieu Glachant, Yann Ménière, Interdisciplinary Institute for Innovation, “What cost for photovoltaic modules in 2020? Lessons from experience curve models,” Interdisciplinary Institute for Innovation, Paris, 2013.

[36] Adnan Al-Akori, “Photovoltaic Systems for Off-Grid Infrastructure in Developing Areas with Main Focus on Health Facilities: Evaluation, Design and Simulation,” Universität Kassel , Kassel, 2014.