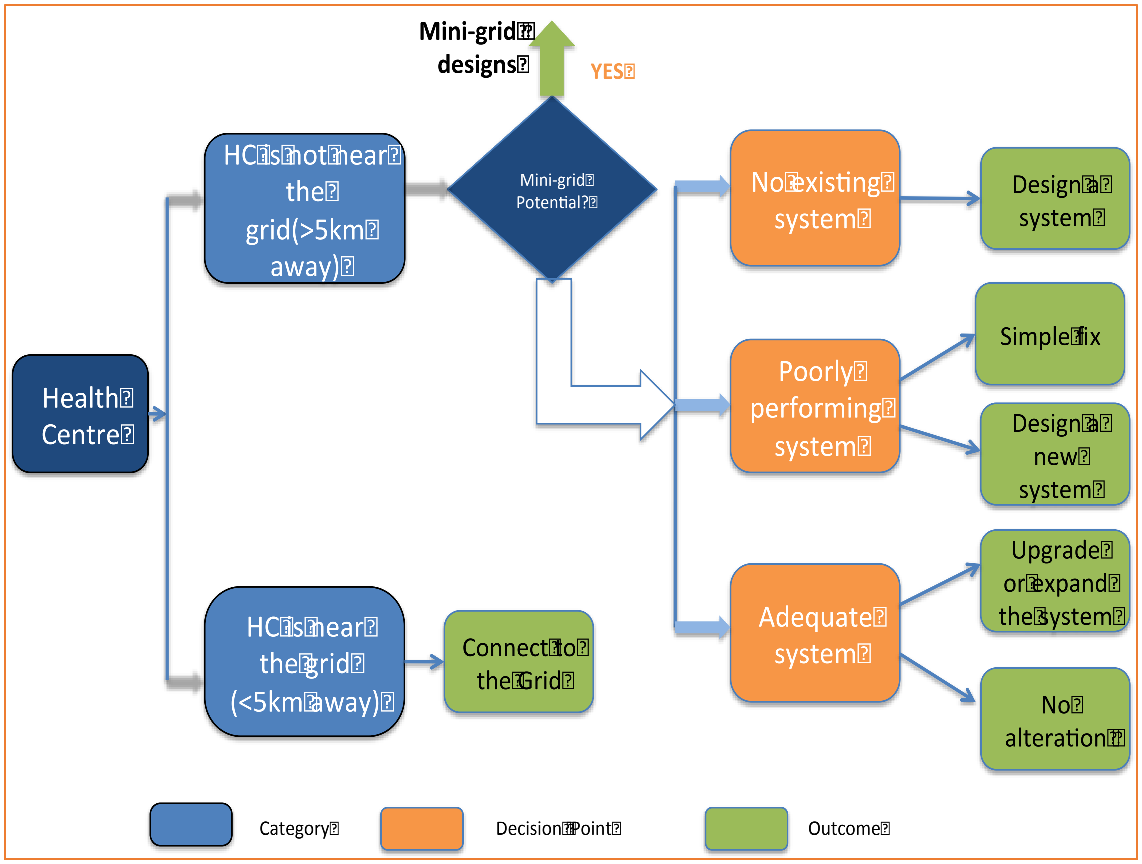
Annex 2: Site Analysis and System Design Methodology

System Designs

A standard process was used to design power solutions. The figure below shows the design decision tree used by ASD to arrive at the most appropriate solution.



As can be seen, if a system was within 5 km of the grid, a grid connection was recommended[14]. Where there was no system, a poorly performing system or need for system growth, the ASD team designed a new system. Based on the site audits, the team found that with load growth taken into consideration, all sites where grid connection was not viable would require a new solution.

Future Load Requirements

Information from a large sample of sites was reviewed and analyzed, in order to develop a model of the essential energy needs for rural health facilities. Site information was used to define the type and quantity of electrical appliances used at all different types of health facilities as well as their associated power and usage schedule.

The following six categories were identified as the essential energy demands that need to be taken into account for the future energy requirements.

[14] Five km was chosen as the cut-off for this study following discussions with stakeholders.

1. Lighting – Interior ambient plus security (exterior) and medical (bright task lighting)
2. Refrigeration
3. Water pumping
4. ICT – Mobile phone charging and computer access
5. Staff housing
6. Medical equipment –requirement decisions were based audit information, government advice and industry standards

Electric sterilizers are not recommended for use on off-grid power systems due to the high instantaneous power requirements as well as the lower inefficiency of electricity as an energy carrier for thermal applications compared to thermal fuels. Therefore, thermal fuel powered steam sterilizers are recommended for off-grid facilities.

The following site specific characteristics were determined for each site, (and used in conjunction with the above essential needs) to determine the future energy requirements:

<u>The health facility is assigned to a category</u> depending on its country and level. This allows for generalizing about the typical or prescribed type and number of medical appliances and staff energy requirements at a given site.

Country – Uganda, Malawi or Ghana

Health Facility Level – This definition depends on the country. In some Uganda, the equipment and services offered at each level are relatively consistent. In Ghana and Malawi, less so. Further explanation of health facility levels are included in each country report.

Uganda health facility levels are clearly defined (HC II, HC III, and HC IV).

Malawi health facilities included in this study are all Tier 1 and therefore a decision informed by the services offered was made to break them into sub-categories of Tier 1 – Basic (resembling Ugandan HC II and Ghanaian CHPS / Clinics) or Tier 1 – Advanced (resembling Ugandan HC III and Ghanaian Health Centers)

Ghana health facility levels are Community-based Health Planning and Services (CHPS) posts, Clinics and Health Centers. From survey information and communication with the Ghana Health services, it was decided that CHPS and Clinics have similar energy needs, whereas Health Centers have higher energy needs.

<u>Numerical parameters individual to each facility</u> were taken in order to calculate the required energy for certain energy applications.

Number of Buildings – this determines the lighting energy requirements at the facility. Medical buildings, guardian shelters and toilet blocks were included. Where possible, the number of rooms and size of each building was considered and where more lighting was required, the number of building was increased appropriately.

Number of Staff Units - this determines the staff housing energy requirements. A base staff unit energy requirement was calculated on the assumption of 2 lights bulbs, 1 TV and 2 mobile phones per unit. This value has been increased or decreased depending on the country and health center level as differences in staff housing energy requirements is seen.

Number of Staff – this determines the mobile phone charging energy requirement. It is assumed that one out of two staff members charged their phone every day.

Water Storage Capacity – this determines the water pumping energy requirements. Where the on-site water storage capacity was given, this was taken as the daily pumping requirement. If the storage capacity seems too large for the daily demand or if there is no on-site storage at present, an assumption of future needs was made. Standard assumption = 10m^3/day.

The table below details the appliances associated with the six essential energy demands outlined above, and details on how the site specific parameters are incorporated to calculate the future energy demand.

Energy Demand Category	Appliance	Daily energy require-ment [kWh/day]	Uganda			Malawi		Ghana	
			HC 2	**HC3**	**HC4**	**Tier 1 basic**	**Tier 1 advanced**	**CHPS and Clinic**	**Health Center**
			Number of lights/appliances required						
Lighting	Interior lights	0.16	3 interior lights per building						
	Security lights	0.36	2 security lights per building						
	Operation lights	0.48	0	1	3	0	1	0	1
Refrigeration	Refrigerator	1.14	1	1.5	2	1	1.5	1	2
ICT	Mobile phone	0.02	1 phone per 2 staff members each day						
	Computers	0.96	1	2	4	1	2	1	2
	Printer	0.20	1	2	4	1	2	1	2
Medical equipment	Microscope	0.16	1	2	3	1	2	0	2
	Oxygen concentrator	1.05	0	1	2	0	1	1	2
	Air conditioner	3.00	0	0	1	0	0	0	0
	Centrifuge	0.40	0	1	2	0	1	0	1
	CD 4 machine	0.30	1	2	4	1	2	0	0
	Suction Machine	0.75	0	1	2	0	1	1	2
	Anesthesia machine	2.00	0	0	1	0	0	0	0
Staff housing	Staff unit		0.6 kWh/day	0.7 kWh/day	0.9 kWh/day	0.5 kWh/day	0.6 kWh/day	0.6 kWh/day	0.8 kWh/day
Water supply	Water pumping		0.14 kWh/day per m^3						

NOTE: The system has been sized as to account for all loads. For example, where there is an existing solar water pump, this has not been removed from the modelled energy loads. The aim of the system sizing is to account for all possible future energy demands. Sterilization has not been modeled as it is too electricity-intensive for a stand-alone or facility-level micro-grid system to power.

System Sizing

Once the future electric load requirement is determined from the table above and the site specific parameters, the system size is determined according to the following steps:

1. Twenty percent (20%) is added to future load in order to capture any unseen growth or energy requirements.
2. A further 25% is added to account for inefficiencies and losses in the power system generation, storage and distribution. The kWh obtained from here is the final future energy demand used to size the systems.

3. The number of equivalent hours of peak insolation is calculated for that sub-national region using industry standard online databases. The European PV GIS radiation database system is used and both databases are considered (Climate-SAF and Helioclim) and the minimum value is taken in order to be conservative.
4. The system size requirement is determined from the final projected future energy demand and the equivalent hours of peak insolation for that region. It is then rounded up to the nearest size category which has already been assigned (i.e 2.7 kWp system would fall in the 3 kWp category)
5. For sites where the system size is marginally greater than a system category, an objective decision is made whether to round it down or up (i.e 3.08 kWp would be rounded down to 3 kWp rather than up to 5 kWp). This is to avoid over-sizing systems as the 20% electricity growth allocated ensures that the size will account the sites basis needs in any case.

The systems have been sized according to appliance total kWh usage, with inefficiency factors and storage included in the overall design.

System Configuration

Designing, supplying and installing individual systems for scores of sites would be extremely time-consuming (and impractical to tender and procure). Instead the team designed 6 standard systems which can solve general needs of a site. In order to address the varying supply and demand needs of the audited sites, the team has designed and recommended a number of "standard systems" that allow for load growth and have the capability to power a number of standard appliances.

Two possible configurations are proposed:

Stand Alone Systems – For scenarios where only one building is required to be connected to the Solar PV power unit. This occurs rarely, for example when there is only one medical building.

Facility-wide System (clinic level micro-grid) – One centralized solar PV power unit with all buildings connected in a micro-grid configuration. Appropriate for facilities were there are more than one building and all building are close. On-site distribution costs are assumed to be USD14/m accounting for distribution cable and poles. Where the site dimensions are available from satellite imagery, distances between buildings are calculated. If the price of on-site distribution is greater than 15% of the approximate system cost (country dependent), the micro-grid configuration is not considered financially appropriate.

Decentralized vs Centralized Power Delivery

When considering the implementation of power solutions in off-grid health centers (and rural sites in general), there are two general engineering solutions for supply of power. The first is to independently power devices (and/or buildings) with separate systems that are independently operated and designed. The second approach is to design a facility-wide power system that powers all equipment on site with a single power source and distribute power to each of the appliances/buildings. Both approaches can and do work - and there is considerable debate among practitioners about which approach is more desirable.

The consultants have, in a large majority of the sites surveys, opted to recommend centralized 240 VAC "facility-wide micro-grids because these systems:

- Enable HC administrators to use standard 240VAC lights and appliances (which are lower cost and widely available) rather than non-standard DC devices (which are more expensive and harder to replace).
- Are easier to manage and maintain than multiple small systems.
- Are more economical with regard to electricity cost.
- Are easier for PV system suppliers to quote for because most PV equipment is designed for AC supply.
- Prepare the site for eventual connection to the grid. Appliances in centralized systems will not become redundant when the grid arrives.

We note that smaller low voltage decentralized systems are more appropriate in certain applications. For example:

- Very small clinics and dispensaries are often best served by pico-lighting systems and dedicated vaccine fridges.
- In extremely remote sites where central technical capacity is extremely limited, smaller, more simple systems may be better.
- When there is a need for portable power, or
- Where demand is limited to lighting only and buildings are far apart.

Grid Connection, Off-Grid Power Systems and Power Back-Ups

Even though it is recognized that sometimes the grid performs poorly, grid connection for grid-proximate sites was recommended for the following reasons:

- All governments prioritize grid connection for rural electrification;
- Grid electricity is much lower cost than off-grid solutions – between half and one-third the cost in most cases;
- It is a more flexible supply option and allows more appliances to be powered (i.e. electric sterilizers);
- Even poor grid solutions are generally better than poorly managed off-grid solutions.

For small demand (less than 1-2 kWh/day) solar solutions may be viable and actual designs can be re-assessed on a case by case basis. The cost of grid connection is not estimated in this study as it is very difficult to gauge without on-the-ground assessment. A rough estimate of USD 10,000 - 20,000 per km, plus transformer costs, may be used – but the actual distance to a site versus the “as the crow flies” distance must be taken into account. A grid connection, of course, benefits an entire community – and its costs are borne by the larger community – and not only the health facility.

Because of the confusion between the two, it is important to distinguish between off-grid power systems (which supply primary power) and back-up power solutions (which provide power when the grid fails). Either battery-back-ups or generators are used as power back up equipment, but not usually solar. Back-ups present a <u>different</u> technical solution than remote off-grid solar power supply. Because of varying power sources and voltages, there are numerous issues with back-up systems (safety, maintenance, grid connect issues, net-metering). In this solution set back-up power systems have not been designed.