Technical Sustainability of Solar PV Institutions: Results from a field survey of 43 sites in Malawi

Authors: **Peter Dauenhauer**, Damien Frame, Scott Strachan
204 George St, Glasgow, Scotland, G1 1XW, UK
+44(0)141 444 -7266
peter.dauenhauer@strath.ac.uk

Introduction

Overall grid connection rates in Malawi is 9% (<1% for rural population) with an estimated 87% of primary schools lacking electricity. Potential for immediate connection to the grid looks unlikely so electricity access for a significant share of these facilities may occur through off-grid approaches such as solar PV [1,2]. However, historically sustainability of off-grid community energy projects at public institutions in Malawi is known to be low. Existing knowledge is anecdotal as quantitative data of any sort on energy supply systems and their performance has not been widely available. Although efforts to document project existence have mildly improved recently, this has not included an in-depth sustainability analysis [3, 4]. Despite these efforts, it is thought that many more systems and their performance go undocumented. In 2014 a study was funded by the Scottish Government within the MREAP programme to capture sustainability factors for 43 off-grid solar PV projects at public institutions dispersed throughout Malawi.

Purpose

The overall purpose of the sustainability study was to increase understanding of the importance of technical, economic, social, organizational, and environmental factors of off-grid PV systems in public institutions in Malawi. In this paper we discuss the results with respect to technical factors that are indicative for poor sustainability. With momentum growing for internal policy makers in Malawi to encourage future off-grid projects, learning from past results is critical for their success.

Method

The Solar PV sustainability study was designed to capture the impact of sustainability factors for public institutions with solar PV installed. Data was gathered through interviewer led surveys held at 43 individual projects. The survey consisted of 8 sections including basic project information, data sources available at the project, "sustainability pillar" (technical, economic, organizational, social, environmental), and impact data. There were three defined areas to be surveyed: North, Central or South. Field partners were responsible for conducting the survey at a mix of sites selected by the field coordinator drawn from the Energy Project Database [5]. **Error! Reference source not found.** provides a breakdown of the surveyed projects, detailing the type of project and the numbers per region. Due to space limitations, only the central data for 16 sites is analyzed.

No.	Type	Central	North	South
20	Primary Schools	8	8	4
5	Secondary Schools	2	1	2
18	Health Centers	6	4	8

Table 1: Project Types

Surveyors were given guidance on how to introduce the study objectives to the respondents with a script, in Chichewa, in order to reduce inordinate setting of expectations. The completed survey data was entered into spreadsheet templates by the field partners. A formal database design and build was not within the scope of this project, so data analysis was undertaken via Matlab and bespoke scripting. All spreadsheet data was read to Matlab and stored in a data structure that allowed querying of specific questions and statistical analysis. Each system is analyzed as a single entity and can range from a single panel and battery home system to a multi component system powering multiple classroom blocks.

Results and Discussion

There were 16 projects assessed in the Central Region with a total of 70 individual systems. System ages range from 1998 to 2014 (see **Error! Reference source not found.**) with 70% of systems installed prior to 2011.

Year	1998	2006	2007	2010	2011	2012	2013	2014
% Systems	6%	18%	11%	35%	8%	6%	5%	12%

Table 2: System Ages (number of systems observed = 66)

A summary of the components deployed within the systems is provided in **Error! Reference source not found.**. Quality brands dominate PV system components however high numbers of 'alternative' brands are also evident. 23% of battery brands and 25% of PV panel brands observed have been categorized as 'other'. In particular, Inverter brands appear to be a range of imported brands with unknown reputation and quality.

Component	Batteries	Panels	Charge Control	Inverter
Brand	Raylite	BP Solar	Steca	Power
% of Systems	50% (48)	41% (61)	67% (51)	48% (31)
Rating	96-102 Ah	75 - 110 Wp	8-15 A	150-300 A
% of Systems	51% (49)	50% (64)	62% (47)	71% (31)
Number in System	1	1	1	1
% of Systems	66% (53)	60% (53)	98% (53)	100% (33)
Missing	6.4% (47)	0% (64)	9% (54)	19% (37)
Health Indicator Bad	45% (38)		3% (33)	
Inverter connected direct to battery			64% (60)	
No Inverter				31% (60)

Table 3: Summary of System Components Characteristics (Parentheses indicate number of observations)

System ratings indicate a majority of single panel, single battery systems, implying a high penetration of home systems around school and health center installations. There is relatively low incidence of missing components, indicating that theft rates are low. The component most likely to be missing is an inverter which, as an easily removable component that can be utilized flexibly outside of the system, is an unsurprising result. Inverters are not ubiquitous across the systems, 31% of systems are DC only – implying a focus on lighting as the priority service. Battery health appears to be a major issue with 45% of the observed battery banks displaying a poor health indicator.

For every system with that included a lighting service, the following information was recorded for every room that contained lighting: Room Type, Power supply (AC or DC), Number of installed light fittings, Number of working lights, Bulb type (CFL or LED), Bulb power rating in Watts, Actual and Expected usage of lights per room.

Comparison of the numbers of bulbs working versus installed fittings on a per room basis shows that rooms will mainly have either all bulbs working (48% of rooms) or no bulbs working (45% of rooms). This can partially be attributed to household installations with small numbers of light fittings where an all or none situation may be likely. In addition, where light failures start to occur within a project, working bulbs will be repositioned in priority rooms to provide a good quality service in at least one room as opposed to partial service in multiple rooms.

The data on expected usage reveals that lighting is almost always expected to be utilized 7 days per week. Any design assumptions that imply working week (5 day) usage for e.g. school blocks, offices, health posts, should be carefully qualified. Hours per day usage figures are concentrated in the range of 2-4 hours and around 12 hours. This aligns well with standard design of lighting for 3 hours in the evening for social and business use and 12 hours a night for external security lighting. Figure 1 displays the data for expected weekly hours. Excepting the security lighting (84 hours), an approximate bell curve is produced with a mean around 21 hours (7 days at 3 hours). An interesting point to take from this is that 7 days at 3 hours is a fairly common design assumption, however electrical design standards often utilize at least a 90% confidence factor for load estimation and although the analogy is not perfect, the point can be made that the common design assumption will be wrong 50% of the time. This data would suggest that a more robust lighting load estimate would be 7 days at 5 hours per day.

When plotted against age (Figure 2), a trend of poorer performance in older systems is observed. 70% of systems were installed prior to 2011 and more than half of these (65%) are not meeting expectations. However, a significant portion of older systems are still meeting expectations, indicating that age is perhaps not the main factor in

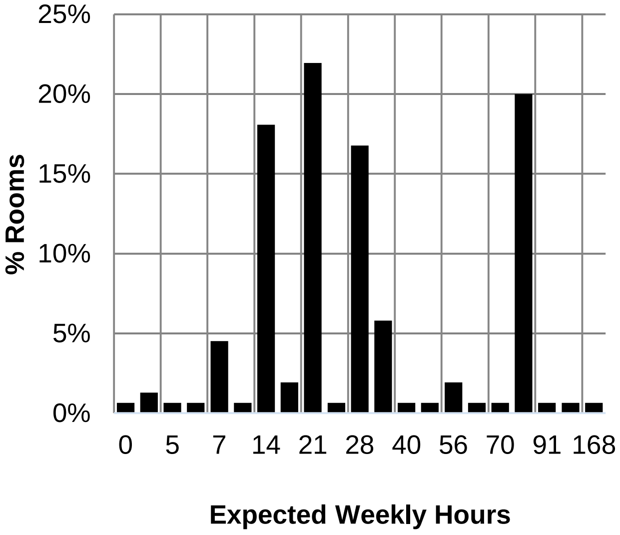

Figure 1: Expected Weekly Hours of Lighting Usage

sustainable system performance.

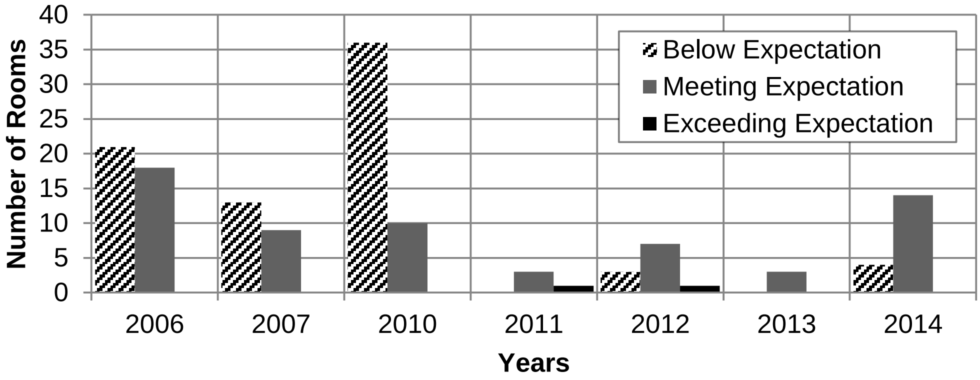

Figure 2: System Performance by Year

Figure 3 displays the estimated ‘fitness for purpose’ of the PV array size and battery banks for each system as the ratio of installed capacity to estimated required capacity (based on observed system loading). In both cases, there are systems that appear to have dramatically oversized or undersized capacity. This is thought to be due to data capture inaccuracy rather than actual design flaws, however further verification of the data set is required to establish this. Nevertheless, the majority of results appear sensible and it is a significant finding that large numbers of systems appear to be undersized. For the PV arrays, 59% are undersized. 89% of systems have undersized Battery Banks.

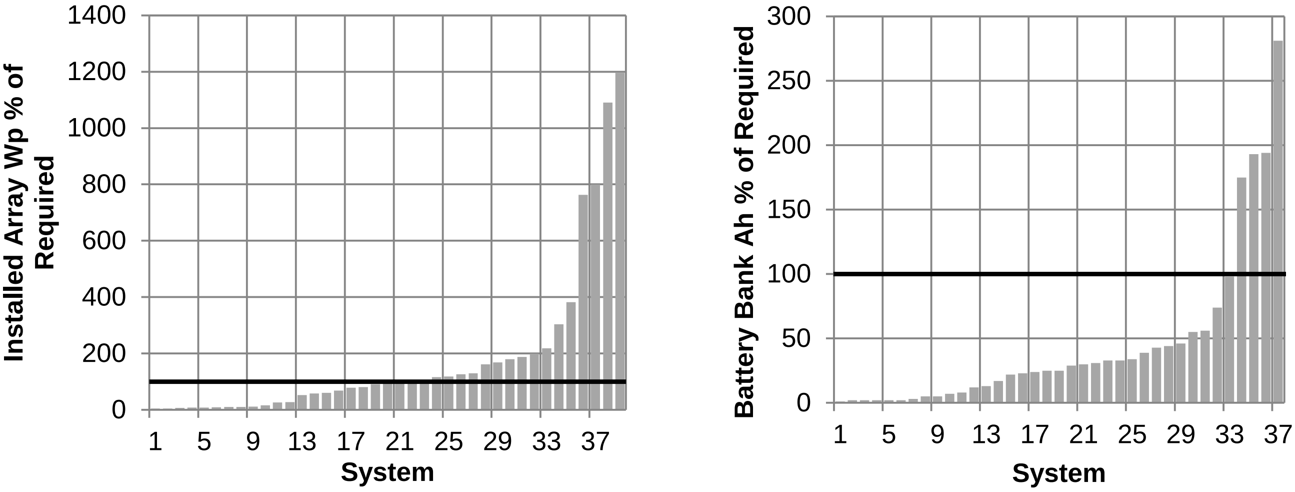

Figure 3: Ratio of installed battery bank size (amp hours) and installed PV array size (Watt peak) to estimated required size

Conclusion

The data presented in this paper indicates a poor standard of technical performance in the surveyed systems. Although some initial work has been done to seek the underlying issues linked to the poor sustainability performance observed, further analysis of the data set is required. System design practices appear to be erring on the side of optimistic/minimum (budget) assumptions rather than preference towards technically robust specifications. Chronic under-specification of battery banks appears to be a particular issue. Typical design assumptions of room lighting usage as 3hrs/7days are valid but should be treated as a minimum, 5hrs/7days is closer to a 90th percentile design standard. Systems older than 4 years old have a high failure rate however system age is also not a complete indicator of failure likelihood, since some older systems are still performing.

Sustainability is clearly multi-faceted and as more comprehensive analysis of all the sustainability pillars is undertaken, further insight into the critical factors behind poor sustainability is likely to be obtained. However it is no major leap of logic that ensuring the use of more technically robust design standards and component choice is required for improved technical sustainability. Mechanisms to achieve this should be a priority for the sector and the role of all stakeholders in this should be considered. The ultimate responsibility for ensuring appropriate technical standards for PV installations in Malawi lies with MERA, the energy regulator, however with many local and international organizations working with communities across Malawi there is significant chance of proper process being bypassed. A strong conclusion based on this research indicates that the aim of the sector should be to ensure that all MERA accredited suppliers are using suitably robust design standards and components.

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