Sustainability of Solar PV Institutions in Malawi
Dedicated Study

MREAP Strand: Institutional Support Programme (ISP)
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Abstract: The sustainability challenges of off-grid community energy projects using solar photovoltaics in Malawi have been widely acknowledged. However, little formal evidence has been produced regarding the factors that affect the sustainability of these projects. Under the MREAP, a study was commissioned to generate more conclusive evidence around the sustainability challenges of the current stock of schools, health centres, and other rural public institutions. An original data set consisting of performance data from 5 sustainability ‘pillars’, consisting of economic, technical, social, organizational, and environmental has been captured for 43 systems in rural Malawi. The results confirm existing anecdotal evidence and suggest that the majority of installed projects can be considered ‘unsustainable’ and at risk of failure in the near future. Many projects are now unsupported, are partially or completely non-functional, and are without reliable and effective means to resuscitate performance. Projects are ranked (relatively) in terms of overall sustainability and factors for improved sustainability are discussed. Our analysis demonstrates the complicated interactions between sustainability pillars and highlights the need for a holistic approach to project design and implementation.

MREAP is led by the University of Strathclyde and funded by the Scottish Government. For more information visit: http://www.strath.ac.uk/eee/energymalawi/
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Executive Summary

Background

The survey reported here was carried out in 2014/15 as part of an extension to the Malawi Renewable Energy Acceleration Programme. Through the initial scoping and evaluation stages of MREAP, sustainability of off-grid PV systems was identified as a major issue for community renewable energy development in Malawi. The distinct lack of an evidence base from which learning can be drawn to inform stakeholders deploying renewable energy systems in Malawi and wider policy making was also highlighted. MREAP sought to build on available knowledge to promote sustainability within community energy projects deployed by the Programme and also initiate more robust evidence gathering to grow the knowledge base available to the sector. The sustainability study is an action deriving from an MREAP Programme Steering Group discussion around the existing installed base of off-grid PV systems at schools and health clinics around Malawi and in particular the perceived poor sustainability and lack of learning from these deployments.

The motivation of the survey was to better understand the types of systems previously installed in Malawi, identify which systems were still functioning and to gain insights as to performance across all aspects of sustainability. The approach to survey design was based on the concept of sustainability pillars (technical, economic, social, organizational, and environmental) each of which has a distinct section in the survey with relevant indicators and questions.

Conclusions

Specific conclusions with respect to pre-defined study questions are outlined below.

To what degree are systems performing as expected?

Overall, the system technical performance is poor. There are numerous systems in a state of complete failure or not meeting expected performance. An interesting aspect of the data is that the expected performance of lighting systems is mainly described as either completely not meeting expectations or fully meeting expectations. It is difficult to say if this is a wholly accurate representation of the system or an indication of difficulty in the questioning process to articulate and capture varying degrees of satisfaction. Nevertheless, large numbers of systems can be said to be not meeting expectations.

Summary of system performance issues:

- 38% of the systems have completely lost all service
- 58% of room lighting is not fully meeting expectations
- 43% of batteries are showing ‘bad’ battery health indicator
- 31% of the mainly CFL installed bulbs are not working

What components are used in system design?

The standard components that comprise PV systems (PV panels, Batteries, Charge Controller and Inverter) are found to be prevalent in system design as expected. However, there are significant numbers of obscure brands and hence doubts over component quality. The poor practice of inverter direct connection to batteries is common. Light bulbs are primarily CFL and experience high failure rates.
Sizing and quality of PV system components is critical to appropriate design. Standards in this respect appear to be lacking. The analysis strongly infers that although the Malawian renewable energy sector is regulated and there is an accreditation process of installers and suppliers, there are still serious issues with the supply chain and design process. Design and installation is often below standard and the overall technical sustainability is poor. Specific suppliers and installers are not identified in the survey therefore this issue cannot be linked to the use of non-accredited suppliers.

The ultimate responsibility for ensuring appropriate technical standards for PV installations lies with MERA, however with numerous local and international organisations working with communities across Malawi there is significant chance of proper process being bypassed. In many cases this may be simply a case of the consumer being unaware of how to ensure they are purchasing an appropriate solution. Whilst it is not feasible for all consumers and communities to be fully conversant in PV system design methods and be able to verify their system has been designed properly, the MREAP community energy toolkit emphasises the importance of using MERA accredited suppliers and this should be sufficient in principle. It should therefore be the aim of the sector to ensure that all MERA accredited suppliers are using suitably robust design standards and components. Likewise efforts to better inform consumers (in this case purchasing agents for institutional level PV systems) on minimum quality requirements would allow for better choices during procurement.

**What factors are linked to high system performance?**

High system performance is assessed as the working state of the system and its ability to meet expectations. Performance overall has been identified as poor. There are no exemplar projects that allow a comparative analysis of factors linked to high performance. For the many systems in a state of failure, the multi-faceted nature of sustainability and the limited scope of this retrospective study makes identifying specific underlying reasons for that failure difficult in most cases. However, it is clear from technical analysis that system design, and battery bank sizing in particular, is a critical factor and can be linked to more robust and higher performing systems. Nevertheless, there is also evidence of systems that are technically weak that are maintaining a high level of performance through regular repair financed externally that quickly returns systems to working order after failure.

**Which systems can be described as “most” sustainable and why?**

We define the most sustainable projects as those scoring highest within the sustainability rankings. In essence, the ranking defines a project as highly sustainable if it meets usage expectations, has relatively strong financial performance, is embedded and accepted within the community, and has the skills available to manage the project. It is essential that the systems are sufficiently technically reliable to maintain a level of performance that available financial resources can support. i.e. project finance can fund the necessary life-cycle costs, and most critically, 3-5 year battery replacement. The encompassing sustainability issues of community engagement, social and organisational structures are also of importance, however in the surveyed systems, insufficient to guarantee sustainability on their own. Although there are a number of surveyed systems that rank highly in all respects, their long term outlook is limited due to the lack of sufficient revenue and forthcoming requirement for battery replacement. Based on the survey responses, even a highly trained, organised and motivated community will be unlikely to maintain their system in the long term without a high standard of technical installation and a degree of external financial support for life-cycle costs. Therefore, it is not clear that an equal weighting across the pillars is appropriate. Furthermore, there may be an absolute minimum requirement for each pillar depending on the particular operational model, a nuance we have only brushed the surface of.
Recommendations

Ensuring the use of 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 (GoM, MERA, funders, suppliers, communities, etc).

For Community Energy Practitioners

- (Timeframe: immediately) Project design should be based on a sustainability pillars approach. Best practice for all sustainability metrics should be referenced and used to justify a fully sustainable project design prior to implementation. To improve learning, a common set of sustainability indicators should be included within project monitoring and evaluation.
- (Timeframe: immediately) Project designers to consider the role of district authorities in the sustainability of PV systems for schools and health clinics. The study suggests that even projects with apparently good sustainability assessments begin to struggle without external support of some sort. District support has been helpful, but sporadic. It could be made more effective by formalizing respective roles between community and district. Furthermore, linking up and demonstrating the impact of interventions to district objectives could provide the district with more leverage to invest and support such initiatives more widely.
- (Timeframe: immediately) Projects must include long term maintenance costs in project design and explicitly include a facility for this. Even the most successful community led income generation schemes surveyed have not been able to generate and save sufficient revenue for 3-5 year battery replacement.

For Academic Institutions

- (Timeframe: next 3 years) The study shows that previous community solar PV deployment appears to be highly dependent on limited-time donor-based funding that has not been shown to be particularly sustainable. Promising variations on the ‘community energy’ model need to be robustly tested and conclusions drawn proving long-term sustainability performance of these models.
- (Timeframe: next 3 years) An interface of regular knowledge exchange and policy briefings should be led by academic institutions to ensure government is utilising best practice and can plan for systematic issues such as district management of rural infrastructure.

For Government of Malawi

- (Timeframe: next 3 years) MERA to consider approved component list and to publish on-line design standards that accredited suppliers must comply with.
- (Timeframe: next 3 years) Investigate models where district authorities can partner and support community energy projects for education and health infrastructure, taking into account the cost structure and technical support requirements of deployed PV systems.
- (Timeframe: next 3 years) Support and promote the supply chain for LED light bulbs for renewable energy systems.

For Scottish Government

- (Timeframe: next 3 years) Require a lifecycle costing approach and model in place for any community energy systems funded
• (Timeframe: next 3 years) Require a sustainability pillars approach to project design with appropriate M&E that enables analysis of sustainability performance for any community energy systems funded
• (Timeframe: immediate) Disseminate results from MREAP and encourage similar approaches to M&E that enable further evidence to be gathered on sustainability performance

Further Work
Despite the limitations of this retrospective survey, many insights as to the sustainability of off-grid PV systems in Malawi have been obtained. It is clear that a more systematic approach to monitoring technical and economic performance of off-grid projects in addition to social and organisational sustainability indicators from project inception, rather than retrospective one-off surveys, would allow more robust research into causes of poor sustainability and potential solutions. Given recent initiatives in Malawi to establish M&E systems for community energy projects and remote-monitoring for off-grid PV systems, the opportunity exists to establish, maintain and grow a valuable data set to serve as the foundation for the ongoing refinement of understanding on best practice for sustainable off-grid PV systems in Malawi.

Acknowledgements
This study was part of the Malawi Renewable Energy Acceleration Programme and was funded by the Scottish Government. The authors thank the field teams at WASHTED, Mzuzu University and Concern Universal Malawi and Renew’nable Malawi for their dedicated effort and input throughout all stages of the study process. We also acknowledge the motivation from the wider MREAP team in identifying the problem and inspiring this study. Finally, we thank the communities that contributed their time, information, and energy to answer all our questions!
1 Introduction

1.1 Energy Access in Malawi

Globally, nearly 1.3 billion people lack access to electricity. The sub-Saharan African country of Malawi currently supplies only 9% of its population overall [1]. Compared to other African countries, Malawi’s rural electrification ranks relatively low at only 5% (see Figure 1). Those with access currently experience blackouts on a regular basis. For public institutions such as primary schools, the situation is equally grim. UNESCO reported only 10% of primary schools and 52% of lower primary schools had access to electricity in 2012 [2].

![Figure 1: Sub-Saharan Africa Population without Access and Rural Electrification Rates (Source: [3], reformatted by authors)](image)

For many developing countries, where the extent of the grid is limited, off-grid solutions such as stand-alone PV systems are the only real near-term option for basic services such as lighting and charging of mobile phones. Although they do not match the quality of supply (in some cases) of a grid-connection, they nevertheless provide important benefits and often to the poorest. The provision of basic electrical services to remote schools and health clinics is a popular application of solar PV. The International Energy Agency (IEA) are expecting up to 70% of future energy access to come in the form of mini-grids and other off-grid systems [3]. This implies 840m people connected through off-grid¹. With this level of emphasis, it is critical to ensure the project-level sustainability of the new projects coming online and address weaknesses from existing projects.

¹ Though due to population growth, by the time they are connected, the number will be considerably larger.
1.2 MREAP perspective: motivation for studying sustainability

The Malawi Renewable Energy Acceleration Programme (MREAP) is a coordinated multi objective development Programme funded by the Scottish Government over 2012-2015 [4].

The issue of how to effectively address sustainability of off-grid community energy projects in Malawi has been a consistently recurring theme throughout MREAP. A scoping study for “support mechanisms for community energy” in Malawi, commissioned in 2010, strongly identified community engagement and support mechanisms as a sustainability measure though it did not identify research of sustainability factors as an explicit recommendation [5]. Building on this learning, MREAP’s approach (especially with respect to the Community Energy Development Programme) emphasized community engagement, capacity building, and support as elements deemed critical to a successful and sustainable community energy project [6].

As MREAP commenced, an evaluation of the sector was undertaken [7]. As part of the evaluation, 12 case studies were developed covering the 3 regions of Malawi and included a range of renewable energy technologies (RETs) that were being used at the community and household level. These case studies were complemented by key informant interviews and a round table with members of the Government of Malawi in March 2012. In addition, the evaluation piloted an inventory of RETs that collated information from more than 270 installation sites which were undertaken by more than 30 development programs or projects spread out across Malawi’s 28 Districts.  Though wide in scope, many projects included in the inventory had only high level descriptive information. The main findings from the inventory and case study analysis indicate that poor technical sustainability in the areas of design, agreed usage, maintenance process, and monitoring are compounded by a lack of appropriate community engagement and long term economic planning. In addition, it found a distinct lack of an evidence base from which learning can be drawn to inform stakeholders deploying RET in Malawi and wider policy making.

The technology and impact focus of community projects in MREAP were primarily determined via a thorough community engagement and needs identification process. Many of the projects chose solar PV applications for schools and health posts as community priorities. The potential benefits of such services are well accepted and evidenced by previous Government and donor initiatives to deploy solar PV in off-grid locations. However, as a public service with no obvious business model, ongoing support of such systems place an onerous burden on already stretched local government health and education burdens and much of the observed sustainability issues are evident in previous installations.

Following the consensus among the MREAP partners and sector colleagues at the Programme Steering Group Meeting in November 2013 that rural community based Solar PV projects continued to face sustainability challenges, a study was proposed to learn more about the factors behind project success and failure [8]. On the whole, attendees agreed that further exploration into all of the factors of the sustainability nexus would benefit the sector as a whole and develop a stronger evidence base than provided by the Scoping Study, Evaluation, and other anecdotes that were available. The focus was agreed to be school and health clinic systems. As a result, this study has been proposed under MREAP and was funded by the Scottish Government through an extension of the Programme in 2014.

1.3 Defining Sustainability

Due to its ubiquitous use, it is useful to adopt a working definition of “sustainability” here as: “the perceived potential for a system or project to endure, build a self-perpetuating capacity within a community, and ultimately reach the end of its predefined life span or evolve into another beneficial form” following [9].
Figure 2 outlines a general framework for consideration of sustainability and connects up the relative role of the project design and implementation phases. This represents the conception of sustainability used in this study. Because the project is strictly constrained by the project design phase, sustainability itself will be linked to the decisions made on the design earlier on. Finally, the whole project sits within a set of institutions (i.e. legal, governance, economics, etc.) that enable, detract, or constrain the project as the case may be.

**Figure 2: Sustainability Pillars and Project Design**

Within the Solar PV Sustainability Study it is used as the framework for analysis and evaluation of sustainability factors in retrospect, that is, after the project has been installed and is operational. The approach to survey design was to capture a set of indicators from included projects that were related to the various sustainability pillars that ultimately allows for comparison and further analysis. Each sustainability pillar (technical, economic, social, organizational, and environmental) has a distinct section in the survey with relevant questions. In analyzing the results we review responses for each indicator individually and then undertake a ranking process, scoring projects against each of the indicators.

A full discussion and background is provided in APPENDIX - Conceptualizing Sustainability.

### 1.4 Study Objectives

The motivation of the survey was to better understand the types of systems previously installed in Malawi, identify which systems were still functioning and to gain insights as to performance across all aspects of sustainability. With momentum growing for internal policy makers to encourage future off-grid projects, learning from past results is critical for their success.

Four key study questions were used to shape the survey:

1. To what degree are systems performing as expected?
2. What components are used in system design?
3. What factors are linked to high system performance?
4. Which systems can be described as “most” sustainable and why?

### 1.5 Report Structure

This report has been structured to present the results of the survey with respect to the sustainability pillars described above. Sections 2 and 3 will describe the methodology in further detail, Section 4
introduces the projects and provides some high level overview results, Sections 5 – 8 present detailed results for each sustainability pillar. Section 9 discusses social impact. Section 10 introduces a sustainability ranking for the projects and interpretations. The first three study questions are primarily addressed in the Technical Sustainability section (5). The final question is addressed by assessing the survey results for all sustainability pillars in Section 11. Sections 12 and 13 provide discussion and conclusions and set out recommendations and directions of future research.
2 Method

2.1 Data Sources

Data was gathered through interviewer led surveys held at 43 individual projects. The survey was developed through a collaborative effort between RENAMA and the University of Strathclyde. The survey consisted of 8 sections including basic project information, data sources available at the project, “sustainability pillars” (technical, economic, organizational, social, environmental), and impact data.

The survey was reviewed by the field partners (Washted, Mzuzu University, Concern Universal) and trialed by two field partners prior to deployment. Following the trial, the survey was revised with minor changes. Surveyors from all field organizations were trained to ensure questions and interpretations were well understood. Furthermore a guidance document was produced for surveyors.

Each field partner had a defined area of operation: North, Central or South. Field partners were responsible for conducting the survey at a mix of sites selected by the field coordinator (RENAMA) drawn from the Energy Project Database [21]. Projects from this database had only basic information recorded: name, location, contact number – so were relatively unknown. All sites were to involve off-grid solar PV electrification of either a primary school, secondary school, or health centre. Several locations could also be chosen by the field partner, but the intention was to diversify the selection of projects so no more than 3 could come from one specific area or implementing organization. Projects selected by the field coordinator were at random from the database.

The selection of projects that were surveyed unfortunately cannot be assumed to be a random sample. The objective of the selection approach was to balance the logistical and budget constraints with the desire to include a diverse portfolio of projects throughout Malawi. The Energy Project Database does not include the comprehensive set of projects in existence in Malawi, indeed MREAP had identified this issue during the 2012 evaluation [22]. Despite these limitations, the results do provide a depth of information previously unavailable on the sustainability of projects throughout Malawi. This information and analysis has both a direct value for community energy practitioners, and the approach itself can be considered for future analysis.

2.2 Survey Implementation

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 and a process for informed consent. During delivery, the surveyor would use a structured questionnaire while seeking answers from the respondent, typically a project lead on site. Elements of the survey which were purely observational (i.e. observed number of panels and manufacturer’s capacity rating) could be recorded without the respondent. In practice surveyor teams that included more than 1 individual split up to conduct the questionnaire with the respondent concurrent to gathering observational data.

Due to the length of the survey, it was suggested to surveyors to allow for up to 4 hours to complete the full survey. Respondents were offered refreshments and it was suggested that breaks between survey sections be provided, if needed. Surveyors were to attempt to complete the survey in full during a site visit but were allowed to follow up after the site visit concluded. In some cases this included following up with contacts provided by the main respondent, such as contractors involved or local non-governmental organization partners.
The surveying period was November 2014 in the central region and April 2015 in the North and Southern regions.

2.3 Data Entry

Following surveys of the 45 surveyed projects, 43 returned a completed questionnaire. Field partners were responsible for data entry into Excel based forms. Of these 43 projects, data quality issues prevented the inclusion of two secondary schools from the Northern Region and one TDC from the Southern Region resulting in the final data set consisting of 40 projects across the regions. The total number of systems assessed in the 40 projects was 113 and the total number of lit rooms was 219.

Although 40 completed surveys were taken forward for analysis, none were 100% complete across all data fields as, due to the natural variation between system types, the level of access granted to the surveyor and the knowledge of the respondent, not all data points were registered for each system. Throughout this report, the number of observations is provided alongside each statistic. For example, where a result is presented as a percentage of systems or percentage of rooms, this value is a percentage with respect to the total valid data entries for this data field, not necessarily a percentage of all systems or rooms.

2.4 Data Analysis

The completed survey data was entered into spreadsheet templates by the field partners. A regional surveyor report was also completed by each field partner based on their individual experience conducting the survey. This report was structured both to explore issues with the process of conducting the survey and to elicit analysis from the field partner that would ultimately be considered in the final analysis.

As a formal database design and build was not within the scope of this project, 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 some basic statistical analysis.

2.5 Limitations

This section discusses limitations to the study and expected implications. Limitations include the selection approach, capacity, logistics of enumerators, and potential respondent issues.

Firstly, the selection process was designed to select a variety of projects types such as: varying age, geographically distributed, size of system, and type of institution. Field partners were allowed to select a small number (less than three) projects, while the remainder were suggested by the field coordinator who populated a list from the CONREMA database. The suggested projects were separated by region (North, Central, and South) and passed to the respective field partner. This database is in a nascent stage and typically has only basic information on projects. The CONREMA database does not track all projects nationally, so we do not have the full population of projects to sample from. As such, the selection process is not randomized, though this limitation was known at the start of the study. The reader should be aware that conclusions can therefore only be drawn on the sample of selected projects.

Second, the understanding of the survey by the enumerator may have resulted in error due to misinterpretation or mis-communication. The design team conducted at least 2 training sessions with each field implementer to clarify sections and come to consensus on question/response meanings. Furthermore, a pilot was completed by each implementation team. Despite these measures, after data entry there were some internal inconsistencies of data that required exclusion of parts of the
data set and furthermore suggest that enumerators required more training. One example was system usage information indicating a system is fully functional while follow up questions would otherwise indicate the system is in the state of a failure. After the first phase of data entry, any inconsistencies were discussed with enumerators and adjusted or, if we had low confidence, excluded.

Another prime example requiring clarification was during the interpretation of sections with missing data. Throughout the survey, many sections and questions did not have answers. Where appropriate options were given for “other” and “don’t know” to capture this possibility. However, enumerators tended to prefer to leave sections blank when there are no possible answers. For example, many projects lacked any sort of financial model so the whole section was left blank. Similar to the previous section, in these cases we confirmed the enumerator’s interpretation of and how it should be coded.

Accuracy of respondent answers is another area of potential limitation. The survey involves sections requiring the enumerator to directly gather data (e.g. recording system components) and sections where the enumerator asks question to respondents available on site. Several challenges were experienced here.

- First, availability of qualified respondents was not always secured. In this case we generally received sparser data sets when these respondents were not able to answer all the questions. In some cases, we followed up with several respondents to confirm an answer (such the technician who installed the project or a local NGO who kept records).

- Second, since many projects were relatively older, full project information was often unknown by current staff. Many rural facilities have staff that move frequently and replacements are unaware of inception information, in particular, capital costs, contractors, and funding sources. This could also affect time-sensitive answers such as whether theft or total system failure was ever experienced by the project.

- Third, respondents may have had difficult in recalling information even when they were present and could therefore provide an answer. We attempted to reduce this recall burden by optionally allowing respondents to estimate (i.e. what is typical monthly income? OR what was last month’s income?), or offering the option to not answer if respondents were uncertain. Furthermore, enumerators indicated that, in person, they felt reasonable confident in the accuracy of the responses we received.

- Fourth, it is possible that respondents may have answered questions to satisfy the surveyor. The survey took at minimum 2 hours to complete and for larger projects up to 4 hours. During design we identified respondent fatigue this as potential risk and designed the option to take breaks in between sections. It was also suggested that enumerators provide a light refreshment to the respondent if desired.

- Fifth, there is reason to believe that hidden biases could have influenced answers. For example, the respondent, assuming that funding opportunities would be forthcoming, could have provided responses that put the project in a better light. Likewise there could be an incentive of project managers for hiding thefts or abuse of position such as through not reporting financial performance. As the range of potential biases is quite high, we do not attempt to respond to the comprehensive list. The approach to minimize this included an opening statement clarifying the objectives (and limit of involvement) of the study. Sections often had more than one questions that would allow for consistency checks of the answers. Finally, enumerators were asked whether they thought, in person, there was any indication of respondent deception; which returned as negative. As a result we have assumed that answers were truthful and free of bias.
Third, as a result of the physical distance between field surveyors and the analysis team, an enumerator reports was designed to capture specific feedback from the enumerators. This was meant to better understand the study process as well as capture the enumerator’s analysis for their regional data.

Finally, the environmental sustainability section had to be excluded from all data sets as we suspected, based on qualitative answers and enumerator reports that it was misinterpreted to mean “global” environmental sustainability rather than specific local effects as intended.

2.6 Availability Survey Instruments and Data

Annexed to this report are several useful tools as well as the survey instrument that is shared for other researchers to extend and improve the approach taken here. Users are encouraged to contact the corresponding authors for questions and to explore potential collaborations.

Available tools:

- Solar PV Survey (Annex 1)
- Survey Guidance (Annex 2)
- Excel based Data Entry form (Annex 3)
- Field coordinator Report (Annex 4)

Data will be available for research purposes upon request from the authors and is also available via the CONREMA database managers.
3 Overview of Projects Surveyed

3.1 Projects, Systems and Rooms

Table 1 provides a breakdown of the surveyed projects, detailing the type of project and the numbers per region. The projects are mainly Primary schools and Health Centers, this is deemed to be representative of the national picture of off-grid PV installations. The three ‘Other’ projects were two Teacher Development Centers and a Youth Club.

Two southern health centers are actually Mission Hospitals that also utilize ESCOM power with PV as a switchable standby power source. As such, most data was not relevant for comparison with the other projects.

<table>
<thead>
<tr>
<th>No.</th>
<th>Type</th>
<th>Central</th>
<th>North</th>
<th>South</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Primary Schools</td>
<td>8</td>
<td>6</td>
<td>3</td>
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<tr>
<td>5</td>
<td>Secondary Schools</td>
<td>2</td>
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<td>1</td>
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<td>18</td>
<td>Health Centers</td>
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<td>Other</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

*Table 1: Project Types*

The term ‘project’ refers to the site location where a PV installation has taken place, e.g. at a primary school. In most cases there are numerous individual PV systems within a project that provide a range of services to the stakeholders. The majority of systems are installed on a per building basis.

In addition, each system may provide a range of services to a number of rooms within that building. The questionnaire was therefore designed to capture data at project level, system level and room level, as shown in the questionnaire extracts for a school with one classroom and three staff houses (see Figure 3, Figure 4).

*Figure 3: System Data Entry Example*
<table>
<thead>
<tr>
<th>System #</th>
<th>Room #</th>
<th>Classroom / Maternity Wing</th>
<th>Office</th>
<th>Staff House</th>
<th>Other</th>
<th>AC</th>
<th>DC</th>
<th>Total # of light sockets/ fittings</th>
<th>Number of working lights</th>
</tr>
</thead>
<tbody>
<tr>
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<td>1</td>
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<td>3</td>
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<td></td>
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<tr>
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<tr>
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<td>1</td>
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<tr>
<td>3</td>
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<td>1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

*Figure 4: Room Data Entry Example*
4 Technical Sustainability

In this section, the results drawn from analysis of the technical sustainability data are presented and discussed. Technical sustainability is the ability of the system to operate reliably and provide the expected level of energy service for the planned system life-span. The initial design of the system is critical. It must be based on an accurate understanding of expected service requirements and robust assumptions around solar resource and component efficiency. For example, should the solar resource be over-estimated, the daily energy demand under-estimated and PV panel and battery efficiency over-estimated, the system will quickly fail to meet expected service standards and battery degradation is likely. Quality and reliability of components is also a major factor for technical sustainability.

Each project has a variable number of systems that include classroom blocks, delivery rooms, offices and staff homes. 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.

4.1 Overview of Technical Issues

Off-grid solar PV systems follow a common design and component choice format. Solar PV panels are connected to Battery Storage via some protection and control electronics usually in the form of a Charge Controller unit. Lighting and other electrical loads will normally be connected to the system via the charge controller. If AC power (grid style supply) is required, an inverter will be required to change from DC supply to AC supply.

**PV Panel Orientation**: The solar PV panels must be positioned at the correct angle and facing in the correct direction to achieve maximum conversion of the solar energy into electrical energy. For static systems in Malawi, panels should be facing north with a tilt angle of approximately 25 degrees\(^2\).

**Battery Health**: Batteries commonly used for PV systems are quoted to have lifespans from 5-15 years\(^3\), however this is highly dependent on the operating temperature and how heavily the batteries are used\(^4\). Protection from the environmental conditions and appropriate ventilation are the essential minimum requirements for a lead acid battery bank. 3 years could be a realistic expected lifespan for batteries in PV systems in Malawi.

**Component Choice**: PV Panels, batteries, charge controllers and inverters are imported and distributed in Malawi by regulated suppliers\(^5\). Imports of established brands from Europe, South Africa and China are well established. The importance of reliable, high-quality components is paramount to the technical performance of the system.

**PV system design**: The first stage in the design process is to estimate the average daily energy requirement (load) in Watt-hours (Wh). Using this ‘design load’ the PV array and battery bank are sized using the appropriate design equations. The PV array sizing aims to meet the average daily load whilst accounting for system losses and inefficiency. The battery bank sizing aims for a battery capacity that can deliver the average daily load (adjusted for losses) without dropping below a chosen level of charge, for a chosen number of days without being recharged (days of autonomy).

\(^2\) Optimum Tilt Angle for Photovoltaic Solar Panels in Zomba District, Malawi
http://www.hindawi.com/journals/jse/2014/132950/


\(^4\) http://solararray.com/TechGuides/Batteries_T.php

varies between design approaches are the assumptions made on solar PV resource, required days of autonomy and system efficiencies. The balance to be made is between cost (increased size of system) and sufficiently robust assumptions.

A simple PV system design process is summarized below.

1. Estimate the average daily load in Watt hours
2. Find the required PV panel array daily output by multiplying daily load by an efficiency factor (assumed as 1.3 here)
3. Find the required Watt peak output of the panel array
   a. Divide the required panel Watt hours by the local Panel Generation Factor\(^6\) (PGF assumed to be 3.7 for Malawi).
4. Find the required battery bank capacity in Amp hours
   a. Divide the average daily load (Wh) by the system voltage to obtain Amp hours
   b. Include efficiency factor (multiply by 1.3)
   c. Scale by the maximum discharge rating of the batteries (assumed 80% here)
   d. Scale by the chosen number days of autonomy (3 days)

Solar PV design resources contain a range of approaches and assumptions. The assumptions made here are those recommended and used within the MREAP program, adopted from the more conservative, high standard design methodologies available [20]

4.2 System Age

Systems were established over a considerable range of dates from 1998 to 2014 (Table 2). A third of these were installed in 2010 (due to 4 particularly large school and health clinic projects in 2010 with numerous systems). 70% of systems included in the survey were installed prior to 2012. As such, 70% of the surveyed systems could expect to have experienced, or be currently experiencing battery issues.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Systems</td>
<td>4%</td>
<td>2%</td>
<td>14%</td>
<td>7%</td>
<td>3%</td>
<td>2%</td>
<td>33%</td>
<td>5%</td>
<td>8%</td>
<td>8%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Table 2: System Establishment Date (number of systems observed =94)

4.3 System Components

The initial sections of the questionnaire capture basic information on system technical characteristics. The results from these sections indicate that the most basic requirements of a PV installation (secure PV panel mounting and correct orientation along with secure and well ventilated battery bank enclosures) are not ubiquitously met.

The number of unventilated battery banks should be of particular concern as is the level of suspected tampering.

Summary of Basic Installation Measures

- 77 of 82 systems are north facing
- 79 of 81 systems are roof mounted
- 56 of 66 battery banks have a solid enclosure, 20 of these are unventilated
- 23 of 71 systems show signs of tampering

\(^6\) The PGF is a function of the site location’s ‘peak sun hours’ and assumptions on system efficiency

MREAP - Malawi Renewable Acceleration Programme

Solar PV Sustainability Study
**Component Details**

A summary of the components deployed within the systems is provided in Table 3. Number of observations are shown in parenthesis.

The results indicate that well-known, quality brands are the most prevalent PV system components, however high numbers of ‘alternative’ brands are also evident. The judgement of brand quality is based on the survey team’s combined experience of solar PV installation. In addition to the 36% Raylite and 30% BP Solar results shown in Table 3, 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.

<table>
<thead>
<tr>
<th>Component</th>
<th>Batteries</th>
<th>Panels</th>
<th>Charge Control</th>
<th>Inverter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand</td>
<td>Raylite</td>
<td>BP Solar</td>
<td>Steca</td>
<td>Power</td>
</tr>
<tr>
<td>% of Systems in bin</td>
<td>36% (73)</td>
<td>30% (83)</td>
<td>45% (77)</td>
<td>36% (47)</td>
</tr>
<tr>
<td>Rating</td>
<td>96-120 Ah</td>
<td>75-120 Wp</td>
<td>8-15 Amps</td>
<td>200-300 W</td>
</tr>
<tr>
<td>% of Systems in bin</td>
<td>58% (74)</td>
<td>43% (95)</td>
<td>52% (67)</td>
<td>52% (46)</td>
</tr>
<tr>
<td>Number</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>% of Systems in bin</td>
<td>50% (92)</td>
<td>53% (104)</td>
<td>79% (99)</td>
<td>46% (113)</td>
</tr>
<tr>
<td>Missing</td>
<td>8% (49)</td>
<td>0%</td>
<td>1.1% (55)</td>
<td>19% (37)</td>
</tr>
<tr>
<td>Health Indicator Bad</td>
<td>43% (40)</td>
<td>3% (33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter connected direct to battery</td>
<td></td>
<td>67% (70)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Inverter</td>
<td></td>
<td></td>
<td></td>
<td>53% (113)</td>
</tr>
</tbody>
</table>

*Table 3: Summary of System Components*

Component ratings indicate approximately half of systems are 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, 47% of systems are DC only – implying a focus on lighting as the priority service. Battery health appears to be a major issue with 43% of the observed battery banks displaying a poor health indicator.

**4.4 Performance of Lighting Systems**

For every system 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 usage of lights in that room (hours per day and days per week)

Good quality deep cycle batteries have a ‘Magic-eye’ window built-in that provides an indication of state of charge for one of the battery cells. This is an approximation, but a good first pass test of battery health.
• Expected usage of lights in that room (hours per day and days per week)

The results are summarized in Table 4 below. Of 598 installed bulb fittings, 416 (or 70%) contain working bulbs. As would be expected, LED lights as an emerging technology have a low penetration and most lights are CFL technology. Bulb power ratings are in the expected range for energy efficient CFL bulbs. Interestingly, not all systems have utilized the standard DC lighting approach, with 20% supplying lighting with AC power via an inverter. Although this may have implications in the power quality and reliability required from the inverter (i.e. higher cost), AC powered light bulbs are more widely available from non-specialist retailers.

<table>
<thead>
<tr>
<th>Lighting Data</th>
<th>Number of Observations (rooms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulb Type CFL</td>
<td>95%</td>
</tr>
<tr>
<td>Bulb Type LED</td>
<td>5%</td>
</tr>
<tr>
<td>Bulb Power Type DC</td>
<td>81%</td>
</tr>
<tr>
<td>Bulb Power Type AC</td>
<td>19%</td>
</tr>
<tr>
<td>Bulb Rating (W) &lt;8</td>
<td>13%</td>
</tr>
<tr>
<td>Bulb Rating (W) 8 to 11</td>
<td>75%</td>
</tr>
<tr>
<td>Bulb Rating (W) &gt;11</td>
<td>12%</td>
</tr>
<tr>
<td>Bulb Working 0%</td>
<td>44%</td>
</tr>
<tr>
<td>Bulb Working 1-99%</td>
<td>8%</td>
</tr>
<tr>
<td>Bulb Working 100%</td>
<td>48%</td>
</tr>
<tr>
<td>Expected Days per Week 5</td>
<td>5%</td>
</tr>
<tr>
<td>Expected Days per Week 6</td>
<td>1%</td>
</tr>
<tr>
<td>Expected Days per Week 7</td>
<td>96%</td>
</tr>
<tr>
<td>Expected Hours per Day &lt;2</td>
<td>6%</td>
</tr>
<tr>
<td>Expected Hours per Day 2 to 4</td>
<td>54%</td>
</tr>
<tr>
<td>Expected Hours per Day 5 to 11</td>
<td>10%</td>
</tr>
<tr>
<td>Expected Hours per Day 12</td>
<td>20%</td>
</tr>
<tr>
<td>Expected Hours per Day &gt;12</td>
<td>10%</td>
</tr>
<tr>
<td>Bulbs Working 0%</td>
<td>6%</td>
</tr>
<tr>
<td>Bulbs Working 1-99%</td>
<td>54%</td>
</tr>
<tr>
<td>Bulbs Working 100%</td>
<td>10%</td>
</tr>
<tr>
<td>Number of Bulbs Installed</td>
<td>598</td>
</tr>
<tr>
<td>Number of Bulbs Working</td>
<td>416</td>
</tr>
</tbody>
</table>

Table 4: Lighting statistics for all rooms in all systems

Comparison of the numbers of bulbs working versus installed fittings on a per room basis produces an interesting result (Figure 5). It appears 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, it has been observed by the project team that 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. 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 6 displays data for the expected weekly house of lighting. These values are derived by multiplying expected days per week by expected hours per day for each room. This approach is common to the established methods used in PV system design to calculate average daily usage. Excepting the security lighting (84 hours), an approximate bell curve is produced with a mean around 21 hours (7 days at 3 hours).

7 days at 3 hours of use is a fairly common design assumption. However, electrical design standards often utilize at least a 90% confidence factor for load estimation. As a point of interest, for our data, it appears that roughly half of the systems would be considered undersized when compared to the standard design assumption for PV lighting of 7 days x 3 hours.

Any design assumptions that imply working week (5 day) usage for e.g. school blocks, offices, health posts, should be carefully qualified. This data would suggest that a more robust lighting load estimate would be 7 days at 5 hours per day.
As a measure of system functionality, we compared the expected weekly usage with the recorded actual usage on a room by room basis (Figure 7). The results reflect the statistics for rooms with bulbs working, in that performance is mainly polarized as either entirely meeting expectations or completely failing to meet expectations.

When plotted against age (Figure 8), a trend of poorer performance in older systems is observed. 70% of systems were installed prior to 2011 – 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 sustainable system performance.
4.5 Analysis of System Sizing

The survey data provides the expected usage (or electrical loading) of the system as well as the installed components that are attempting to meet that load. By applying established PV system design methods, as described in Section 5.1, an estimate of the required system sizing can be obtained from the expected usage data. The actual installed system size can then be compared to the estimated requirement and the ‘fitness for purpose’ of the systems can be assessed.

Figure 9 and Figure 10 display 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. In both cases there are systems that appear to have dramatically oversized or undersized capacity. Given the data for this estimation is based on a respondent response and subject to the limitations presented earlier, there is a fair likelihood of error in the provided data. Nevertheless, the majority of results appear sensible and it is a significant finding that large numbers of systems appear to be undersized.

As a result, 44% systems have undersized PV arrays and 83% of systems have undersized battery banks.

---

8 In the most extreme cases the entered data is incomplete or incorrect (entered as a voltage rating rather than a power rating for example).
9 For the purposes of this analysis, consistent respondent overestimation of expected use would bias the result towards the systems being considered “under sized”. In many cases it is also likely that expectations over time have increased. However we argue that the current usage expectations are now most relevant to the sizing exercise and a good design process should have properly assessed future expectations.
In addition to data on system components and system usage, the survey also sought to capture particular symptoms of poor technical sustainability as an additional insight to the user perception of their system performance. The symptoms are described below and the results are summarized in Table 5.

**All service lost**: System is in a complete state of failure.

**All lights lost/All power lost**: Option to identify partial loss of service. This indicates a fault specific to a particular load type.

**Lights/Power in day only**: Some services work, but only during sunlight hours. This indicates that the PV panels are supplying power, however a failure in battery storage means no energy available at night time.
**Lights/Power for short time at night:** As above, however the battery failure is not complete and can provide a limited service.

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>% Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>All service lost</td>
<td>38%</td>
</tr>
<tr>
<td>All lights lost</td>
<td>7%</td>
</tr>
<tr>
<td>Lights in day only</td>
<td>7%</td>
</tr>
<tr>
<td>lights for short time at night</td>
<td>12%</td>
</tr>
<tr>
<td>All power lost</td>
<td>4%</td>
</tr>
<tr>
<td>Power in day only</td>
<td>5%</td>
</tr>
<tr>
<td>Power for short time at night</td>
<td>5%</td>
</tr>
<tr>
<td>% Systems with any Symptom</td>
<td>45%</td>
</tr>
<tr>
<td>Number of systems observed</td>
<td>74</td>
</tr>
</tbody>
</table>

**Table 5: Technical Sustainability Symptoms for Central Projects**

45% of systems have experienced some kind of symptom with their lighting or power service, however most significantly, 38% of systems have lost all service.
5 Economic Sustainability

In this section the survey economic data is presented and discussed. Economic sustainability concerns the continued financial well-being of the off-grid project. This is determined by understanding the full cost and income structures and assessing the ability to meet operation and maintenance costs (short-term and long-term) in addition to respond to unexpected system failures. As a qualitative survey without access to retrospective financial accounts, the key factors for assessing economic sustainability were identified as the presence of any financial management structures or process and a qualitative estimate of typical monthly income, operation and maintenance costs.

The survey asked, at a project level, for an estimate of typical monthly income and expenditure. Figure 11 shows the headline economic sustainability indicators. Only 11 projects (27%) have any kind of income at all. Of these only 6 (15% of all projects) also have a bank account.

![Figure 11: Project Economic Sustainability Indicators (blue = yes)]

5.1 Project Income

For the full 40 projects, the mean and median monthly income was 1,832 MW, and 0 MWK respectively. We restrict the data set to projects which have a recorded income. 11 projects provide detail on income, a similar number of projects provided data on monthly operation and maintenance costs, although not necessarily the same set of projects in each case. Some of the projects report significant costs but little or no income; an interesting observation which either points to a hidden income source supporting the project or a sustainability risk.

From the restricted data set, a representation of the monthly finances is provided below (Figure 12-Figure 14). Monthly income and costs range from 0 to near 20,000 MWK. Mobile phone charging dominates income generation sources and expenditure on equipment is primarily on light bulbs and inverter replacement.
The data available does not support a particularly robust statistical analysis, therefore some specific case studies are used here to discuss sustainable economics for these types of system in Malawi.

**Project 10**

Project 10 is a rural full Primary school in Dedza district with a solar PV system installed in 2013, providing lighting and power in the Headmaster’s office. The system has been operating reliably since installation. An energy committee manage the system and operate a formal income generation scheme from mobile phone charging with a formal logbook system to record sales. The 2014 records of income and expenditure are shown in Table 6. All income for the year is generated from approximately 5000 mobile phone charging sales. Core costs to the income generation scheme are security guard salary and phone charger replacements. It is also evident that the funds also support more general school activities. With revenues healthy and a positive balance obtained for the year, economic sustainability appears to be good. However, even for this relatively economically healthy project, there still remains some cause for concern in that creating a suitable level of reserves is not fully prioritized. Reserves of approximately 100,000 MWK will be required for a battery replacement and more immediately should the inverter fail, insufficient funds remain to replace the unit and all income generation would stop.
<table>
<thead>
<tr>
<th>Income</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>mobile phone charging</td>
<td>security guard</td>
</tr>
<tr>
<td>149,680.00</td>
<td>60,000.00</td>
</tr>
<tr>
<td>phone chargers</td>
<td></td>
</tr>
<tr>
<td>24,000.00</td>
<td></td>
</tr>
<tr>
<td>Buckets</td>
<td></td>
</tr>
<tr>
<td>1,750.00</td>
<td></td>
</tr>
<tr>
<td>Refreshments</td>
<td></td>
</tr>
<tr>
<td>2,000.00</td>
<td></td>
</tr>
<tr>
<td>Transport</td>
<td></td>
</tr>
<tr>
<td>8,000.00</td>
<td></td>
</tr>
<tr>
<td>Paper</td>
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</tr>
<tr>
<td>8,000.00</td>
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<td>Notebooks</td>
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<tr>
<td>1,000.00</td>
<td></td>
</tr>
<tr>
<td>Land</td>
<td></td>
</tr>
<tr>
<td>5,000.00</td>
<td></td>
</tr>
<tr>
<td><strong>149,680.00</strong></td>
<td><strong>109,750.00</strong></td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td><strong>39,930.00</strong></td>
</tr>
</tbody>
</table>

Table 6: Project 10 Financial Summary 2014

**Project 22**

Project 22 is a rural full Primary school in Mzimba district with a solar PV system providing lighting to a school hall installed in 2011. A school committee manages the system and undertakes income generation activities. Logbook records were not being kept and only estimated monthly figures were available, as shown in Table 7. Based on these figures, the school should have an annual surplus of MWK 48,000. With over 3 years in operation the system should have built up approximately MWK 150,000 in reserves. In fact the committee report a bank account with a balance of “above MWK 100,000”. Despite a fairly onerous cost burden for lightbulb replacement, this system appears to be approaching economic sustainability, however the lack of financial records is a cause for some concern. The diversification of income sources is critical, if TV/Stereo/Radio shows were not offered, monthly net income would be zero.

<table>
<thead>
<tr>
<th>Income</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobile phone charging</td>
<td>security guard</td>
</tr>
<tr>
<td>9,000</td>
<td>6,000</td>
</tr>
<tr>
<td>TV/Stereo/Radio shows</td>
<td>Replacement light bulbs</td>
</tr>
<tr>
<td>4,000</td>
<td>3,000</td>
</tr>
<tr>
<td><strong>13,000</strong></td>
<td><strong>9,000</strong></td>
</tr>
<tr>
<td><strong>Balance</strong></td>
<td><strong>4,000</strong></td>
</tr>
</tbody>
</table>

Table 7: Project 22 Average Monthly Financial Summary
6 Social Sustainability

Although the social sustainability pillar for energy projects can encompass many potential indicators, the key factors for the PV systems surveyed in this work were identified as the level of community involvement and contribution with the inception and ongoing management of the project i.e. ‘buy-in’ and ‘engagement’. Incidence of theft was adopted as a measure of the wider community sense of ownership. Finally, the projects inception activities were tracked to understand how communities are engaged by implementing organisations.

6.1 Inception Activities

![Figure 15: Inception Activities]

Figure 15 shows the level of engagement by implementing organisations was provided prior to project inception. Our data indicate that 27% of the communities were not consulted prior to installation of the project. Respondents were asked whether a needs assessment was completed with the community with just over half responding ‘yes’. Of these, roughly half of the needs assessment specifically identified an energy need. While it is possible that current respondents simply do not recall the pre-installation activities (some projects are quite old), it is clear that a significant number of projects have a limited pre-project community engagement process.

6.2 Community Engagement

![Figure 16: Community Contribution]

Community engagement levels in terms of involvement and contributions is shown Figure 16. Contributions of any sort of by the community to establish a new project are found to be extremely low. This is perhaps surprising given it is commonly thought that most project require at least some form of even nominal community contribution to show it is committed to the prospect.

6.3 Ownership

Ownership of the surveyed PV systems is primarily via community committees (50% of projects) (Figure 19). 20% of projects are dominated by one individual and 18% of projects have no management structure at all. Management meetings (Figure 18) are monthly if at all (80% of projects have no meetings). Only 22% of projects have oversight by local district government (Figure 17).
In addition to the management structure, the involvement of local stakeholders was tested as an indication of wider community engagement. A large number of projects (21) have no stakeholder representation in the ongoing management of the project. Where stakeholder representation occurs, there is mostly only one stakeholder group (Figure 20, Figure 21).
6.4 Theft and Breakdown

The survey attempted to capture the decision making process by which the owners would respond to major events: theft and complete system breakdown. Unfortunately, data on the process of decision making following these major events was very limited and therefore cannot be presented. However, respondents did provide high level information on prevalence of theft and perception of whether it was resolved (Figure 22). There is a low but significant number of equipment thefts: 28% of all projects. Of these, only 18% of respondents felt it was resolved adequately (i.e. thief brought to justice).

![Figure 22: Theft](image)

Figure 23 shows the responses on whether the system in the project have ever failed and, if it was repaired. We interpreted the results to correspond to the main/largest system in the project (i.e. primary school or health system), given a project could incorporate multiple asynchronous electrical systems. As we would expect, the systems identified as “completely failed” and “not resolved” are comparable to breakdown rate in the technical sustainability section. This question is useful however as it has a historical element: over the lifetime of the surveyed projects nearly 80% had at least 1 total system failure and a fair number do not get fully repaired (28%).

![Figure 23: Breakdown](image)
7 Organisational Sustainability

The organisational sustainability pillar is primarily concerned with the capacity of the organisation (or individuals) that is managing the system. The presence of Technical, Management and Financial skills along with appropriate training strategies are necessary throughout the project lifetime and as a result capture the essence of organisational sustainability. Suitable maintenance skills and practical resources are also core components.

Figures 24-26 highlight that the required skill sets are lacking in many projects. Training at install was received by less than half of the projects and very few have any ongoing training. Financial skills and training are particularly limited.

As shown in Figures 27-29 nearly half of all projects have no ongoing maintenance arrangements in place. This would incorporate both internal and/or external maintenance provision such as through a PV contractor. More than half have no process of handover training should a management team member leave. The simplest maintenance requirement for a PV system is to replace light bulbs. 31% of systems have no spare bulbs on hand and have no knowledge of where to obtain bulbs. 50% of projects are aware of where bulbs may be purchased, however the location is greater than 20km away.
Figure 27: Handover Training

- Trained by Departing Staff: 45%
- Trained by External Party: 2%
- No process or training provided: 53%

Figure 28: Spare Bulb Availability

- >20km: 50%
- 5-20km: 19%
- None: 31%

Figure 29: Maintenance Arrangement in Place

- Yes: 52%
- No: 48%
8 Social Impact

The surveyed PV systems were all community-based projects with an objective of achieving a positive impact on the local community. In the majority of cases, the objective is improving infrastructure at primary schools and health centres, where the implicit assumption is that lighting and power will improve educational attainment and health outcomes in the community. In the surveyed projects, no specific monitoring of the impact was being undertaken. Although measuring impact was not specifically within the scope of this study, understanding the level of social impact where possible was deemed a valuable additional exercise to provide insight as to the value a community may attach to a system.

Data was requested from Primary schools regarding educational attainment in terms of numbers of students performing well enough in leaver exams to be offered places at secondary school. At health centres, records of birth rates and mortality of mothers going into labour were requested. The information returned has allowed some insights to be drawn regarding school performance, however health centre data was insufficient to allow any meaningful analysis.

For each primary school, the records were examined to find the total number of children going on to secondary school each year and the total number of children who sat leaver exams. These figures were used to provide an annual percentage of students going to secondary for each surveyed primary school. Each school’s annual data set was arranged with respect to the year of PV installation in order to allow a standard comparison of results before and after PV installation. With the data aligned around Year 0 (PV install) the total percentage of students going to secondary across all schools was found for each year relative to PV install and plotted in Figure 30. Not all schools had records available and those that did had varying numbers of years available. In addition, some of the schools have retained a working system for years after PV install while some have been in a state of failure for many years. With such incomplete data derived from a small set (13) of primary schools, no robust statistical analysis on the impact of solar PV on educational attainment is possible. The results for six of the most complete data sets is shown in Figure 30.
The data, unfortunately, do not enable any strong conclusions to be drawn. Some schools do exhibit a gradual increase in secondary school enrollment rates, yet others have confusing trends. It was out of scope in this study to examine causal factors to improvement in academic achievement. However, some insight as to the interaction between access to lighting and impact can be drawn out as case studies for discussion.

School 6

School 6 is a rural full primary school in Lilongwe district. Records are available from 2006 to 2013. Solar PV lighting was installed to a classroom block and Headmaster Office in 2010. For the 4 years prior to PV installation, performance was relatively stable at around 60%. Following PV install, performance jumps to 88% then decreases year on year to 49% in 2013. The system is currently in a complete state of failure as of 2014. Prior to this, the survey indicates regular evening study classes and a healthy revenue generation scheme from mobile phone charging. The survey reports regular theft of lightbulbs and reliance on the original contractor (>20km distant) to supply spares. Interestingly, in the years that follow PV install, overall school attendance goes up. From the quantitative and qualitative data for this school, the following narrative appears reasonable: “A well organised and reasonably well performing school prior to PV install. PV services provide an immediate benefit to staff and student performance resulting in a boost in exam results. Attendance starts to increase. PV system reliability issues start to occur. Benefits from PV reduce and exam performance

10 One would expect that availability of a school feeding programme, availability of sanitation facilities, and household economic situation may all be critical factors towards a pupil’s educational performance. Literature reviews from 1990-2010 and notes that availability of desks, low teacher absence rates, and teacher knowledge in taught areas improve educational outcomes [23]. In Sri Lanka, Aturupane et al [24] examine and find a number of key factors such as education of parents, nutrition levels and, notably, availability of electric lighting.
decreases. With increased attendance and dropping performance, overall percentage of students going to secondary drops sharply”.

**School 2**

School 2 is a rural full primary school in Balaka district. Records are available from 2005 to 2012. Solar PV lighting was installed to an office block and staff houses in 2010. For the 4 years prior to PV installation, performance fluctuates between 8% and 30%. Following PV install, performance ramps sharply for 2 years until records stop in 2012. Although recent problems have arisen with the system batteries, system reliability is reported to have been good from 2010 to 2012 and an active committee with health income generation schemes are evident. The lack of data from 2012 makes further interpretation difficult, however, although performance fluctuated prior to PV install, a pronounced rise in performance of students is evident post PV install. Interestingly this has occurred without lighting a classroom block, only office and houses that facilitate staff preparation time and a small amount of evening student study.

**Additional Impact**

The survey also investigated the community perception of services that the PV systems were providing (Figure 31 Figure 32). From these responses we can see that in addition to the expected acknowledgement of improved education and health services, improved communications is the most widely perceived benefit (65% of projects).

![Figure 31: Perceived New or Improved Services in the Community provided by PV system](Image)
Figure 32: Perception of local lifestyle improvements as a result of PV
9 Sustainability Ranking

In order to consider the overall sustainability of a system or project with respect to others, a ranking process has been applied to the surveyed systems. For each of the sustainability pillars a set of the indicators described in Sections 3-6 above are used for ranking.

Each indicator has been normalised to a range between 0 and 1 and then combined with equal weighting to form a total score for each pillar. All pillars are also then combined with equal weighting to form an aggregate sustainability score between 0 and 1.

9.1 Ranking metrics

Technical sustainability:
Actual usage versus expected usage has been chosen as the critical indicator of technical sustainability as this best represents the current technical performance of each system. Battery Health, Panel Design and Battery Design have also all been used where available. If usage meets or exceeds expectation, the score is 1, otherwise the score is the percentage of actual vs expected usage (0-1). The same rule has been applied to the design metrics. For the binary indicators (good/bad, yes/no) the score is either 0 or 1.

Economic sustainability:
The net income of each project has been arranged from highest to lowest and each project given a score between 0 to 1 based on its position in the list. Bank account existence has also been used as a binary yes/no indicator scoring 1 or 0 respectively.

Social sustainability:
The social sustainability ranking includes yes/no scores (1 or 0 respectively) for existence of a needs assessment, existence of community contributions, whether the district governance is involved in the project, whether there are any stakeholders or not (1 or 0 respectively) and indecent of Theft (scoring 0 if it has occurred and 1 if not). Management Meetings were simplified to score 1 if they were reported to occur at all, and 0 if not.

Organisational sustainability:
The indicators relating to the presence of Technical, Financial, Management skills and training, plus the presence of a maintenance arrangement have been used as binary scores for this pillar.
9.2 Ranking Results

Results are summarised in Figure 34. The aggregate ranking is shown for each system along with the ranking for each pillar. In addition, the observed status of the system is also provided. System rankings are colour coded based on their score of 0-1. Red=0, green=1. System rankings are colour coded as follows: Green=working, amber=partial failure, red=total failure, grey=unknown.

In Figure 34, the systems are ordered based on the aggregate ranking. Each sub-indicator within the pillar is equally ranked and then the pillars themselves are equally ranked. We would expect a higher aggregate score to correspond, at least, to whether on inspection the technical components are functioning normal. However when comparing the “aggregate rank” to the “status” it is clearly possible for a system to have a very poor ranking in one pillar, yet achieve a reasonably good aggregate ranking. Nonetheless, using the current observed system status as a point of comparison it can be seen that those systems ranked least sustainable are generally experiencing failure and those ranked most sustainable are mostly observed to be working well.
In some cases, a weakness in a particular sustainability pillar could imply no actual weakness in sustainability. For example, based on the way the ranking design, lack of district involvement confers a lower social sustainability score. However, according to the actual operational model, district involvement may be not required which would make the sub-indicator actually irrelevant for scoring. Another example is with respect to existence of a bank account, which again is part of the economics scoring. The existence of a bank account is meant to indicate seriousness of the economic model, imply improved organization and financial oversight. However, it is conceivable that a project is serious, organized, and has oversight even without an account at a bank to store funds. Thus when viewing each project through the ranking lens, it could be argued that the ranking approach itself prescribes a particular model, meanwhile devaluing other models. However, we argue, based on experience taken from the case studies and literature sources, that on the whole they are relevant to these types of project: off-grid community energy systems. Since the pillars and sub-indicators do not get scored on any one metric, than any individual quirks of the operational model should not be entirely irrelevant for each indicator. Following the previous examples, in the social pillar existence of stakeholders to own the project is relevant even without significant district involvement; in the economics pillar existence of an income to backstop the project is relevant even without a bank account.

There are some anomalies with several systems ranked highly for sustainability also currently in a state of failure and vice versa. If the systems are re-ordered based on technical sustainability ranking (Figure 33) a closer relationship between ranked sustainability and status is observed. This is due to the fact that Technical Sustainability ranking is partly influenced by the current technical performance and hence the metrics are linked. Re-ordering in a similar way with any of the other symptoms does not have a similar effect. We examine some case studies within the next section to interpret these results.
10 Discussion

10.1 Technical Sustainability

There are significant indications of poor design and installation practice that indicate poor technical sustainability.

- PV panel orientation and mounting is not always correct
- Battery bank enclosures are often not secure and well ventilated
- Although quality brands dominate the main PV system components utilized, there are still high numbers of what could be deemed to be ‘inferior’ components being installed in large numbers.
- Uncontrolled inverter load is common (inverter connected directly to batteries). Given the low end spec of inverters used, this method of operation risks regular battery deep discharge, i.e. damage and reduced lifespan
- 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
- System design practices appear to be erring on the side of optimistic/minimum (budget) assumptions rather than preferring technically robust specifications, and chronic under-specification of battery banks appears to be a particular issue

10.1.1 Linkage between system design and technical sustainability

The sustainability metrics of lost service, battery health and performance against expectation have been assessed for all systems against design ‘fitness for purpose’ parameters. The results are shown in Figure 35.

For systems that are judged to have an undersized PV array, 15% have completely lost service, and 60% are not meeting lighting expectations. For systems judged to have an oversized array only 4% have lost service, however 62% are not meeting lighting expectations.

For systems judged to have an undersized battery bank array, 17% have completely lost service, 31% have a bad battery health indicator and 67% are not meeting lighting expectations. For oversized battery arrays, lost service and bad battery indicator are 4%, however 40% are not meeting lighting expectations.

There appears to be a reasonably strong link between system under-sizing and the symptoms of lost service and bad battery health, especially for battery bank under-sizing. There is less of an association between system sizing and meeting of lighting expectations.
10.2 Economic Sustainability

From the available financial data from the projects, economic sustainability is very poor in the majority of projects. Only 11 projects (28%) have any kind of income at all. Of these only 6 (15% of all projects) also have a bank account. Within the small group of projects that are managing to generate income and had a bank account, there are some case studies available that indicate a community managed financial model could achieve a degree of economic sustainability in terms of meeting running costs if the systems were technically robust and did not experience an unduly high degree of fault. Even in the best performing system in the data set, in terms of finances, it is impossible to expect that it could save enough to replace the likely capital expenses as the system ages. As has been documented in many other sources, it is the lead acid batteries which tend to fail and require replacement.

Given the role of the public institutions themselves it is perhaps not unusual that there is not significant emphasis on revenue generation. Obviously, their primary purpose is not rural electrification, but provision of education and health for the local communities. In this case, electrification is a mean for these other ends. We found little evidence of external sources of ongoing funds supporting the PV infrastructure such as NGOs or district education or health offices. In our sample only 22% of projects cited any sort of district involvement and 7% citing NGO involvement, it is unlikely that these source provide much financial support after inception.

During our study, no projects were able to identify savings targets that would be required to support the maintenance or replacement of system assets or current progress against these targets. Only a token few projects could produce log books or accounting for sales of any goods/services associated with their energy projects. This is a particularly worrying result and raises a host of issues from system design to ongoing implementation of community energy projects. Ideally, capacity building efforts as well as business model design should reinforce the long-term asset management model and develop effective approaches to ensuring funds are available when they are needed to replace failing equipment. Once operational, a structure should be in place to transparently manage funds and ensure discipline when saving.
Without external financial support or sufficient local revenue generation, it is unlikely that many of these projects will endure to reach the full lifecycle of the equipment. In the right environmental and operational conditions, PV projects can last for 10+ years with periodic replacement of the battery array and even cope with the costs of replacing of an inverter or charge controller.

10.3 Social Sustainability

The data gathered from the projects paint a picture of relatively limited involvement by social actors in many cases. While this does not mean necessarily that a project cannot survive without involvement from local or district community, it is also difficult to imagine models for off-grid energy for institutionally sized PV systems in Malawi without a support network.

The most startling figure is the lack of ownership over projects. On one question, nearly half of projects identified no stakeholders involved in the project. Another similar question identified that 18% of projects had no ‘decision maker’. Without ownership, one has to assume that a sufficient restoration following a breakdown is unlikely. The difference between these two responses can be interpreted to mean that in some cases ‘custodians’ of projects step in to make decisions without fully owning the projects.

The public institutions from our sample show that types of project stakeholders can vary quite considerably from project to project. If one assumes that current ownership structure is by design, then it can be noted that there was no conclusive evidence that any particular ownership model was more successful than others. The complete lack of private ownership or involvement is noticeable; though the result is not surprising given that infrastructure public institutions are by default considered the domain of a public department or the community to provide.

Community consultation at project inception is around 60% and equally for whether a needs assessment was completed. This is an unsatisfactory figure since securing community consent (and indeed engagement) and the existence of an identified need prior to inception is good development practice. As a gauge of community ownership or buy-in at inception, almost no projects have any sort of community contribution that was provided (and no monetary contributions at all). This suggests that even when the community is consulted, the community has only token involvement. Furthermore, community engagement is not sustained after inception; only 18% of the projects stakeholders meet on a regular basis (at least monthly). Any oversight or management by district governance (such has Health or Education offices) occurred in only 22% of projects. When it occurs, district involvement is inconsistent; it does not guarantee that systems are fully functional.

Finally though theft was present it can be considered low, occurring in 28% of projects. However, of the projects which experienced theft only 18% were considered resolved adequately. An open question is the adequacy of rule of law to protect the solar PV project. Introduction of the relatively expensive equipment provides an incentive for theft. It is apparent that alternative means of security such as cages and existence of a security guard are required. Future areas of research could investigate whether higher levels of community engagement and ownership can provide an alternative or complementary measure of security where rule of law is ineffective.

10.4 Organizational Sustainability

Due to the size of the investment, relative complexity of equipment and requirement to embed the PV equipment into a business model (even for public institutions), it is unrealistic to expect that projects can be installed without first assessing the capacity of the prospective owners and operators. Solar PV at rural institutions is currently not ‘plug and play’. The skill levels and human resources
currently available for project management is extremely low across the set of projects, particular in the area of financial management. The other key capacities of technical skills and managerial skills are similarly not adequately addressed.

For projects that are meant to be self-sufficient, lack of skills will undermine overall project performance as managers are unprepared to make informed decisions on their projects. This suggests that the development process for similar energy projects place higher priority on training of project owners and operators or better identification of qualified personnel. Given the lack of technical skills (and systems to provide skills) in this context, substantial training is the more likely immediate solution.

Project design needs to be more aware of the skills retention problem that this study has documented for community energy PV projects. We found that half of all projects have no ongoing maintenance arrangements in place and more than half have no process of handover training should a management team member leave. It is also well known that health facility personnel and teachers are quite mobile, so ongoing training arrangements either internal or through an external provider are realistically necessary to ensure that personnel on-site are capable of managing the projects. If an internal arrangement is desired, then projects need to consider hand-over training and how to encourage a permanent local knowledge base.

### 10.5 Sustainability Case Studies

The survey results and analysis indicate significant sustainability issues across the projects. Many of the systems are in a state of complete failure and those that are not have weaknesses across the sustainability pillars. The overall performance of the systems in terms of maintaining the designed for, or expected quality of service is poor. Although the quantitative nature of these results provide many insights into the current state of off-grid solar PV systems in Malawi, further analysis of the relationship between sustainability indicators and the current and future performance of the system will provide a more complete picture of sustainability. For instance, from the ranking analysis it appears that the single most important factor for the system to be maintaining working order is the technical robustness of the system. In the main, systems with poor economic, social and organizational sustainability rankings show good current working status as long as the technical sustainability ranking is high. Conversely, systems may have a high ranking in one or more of the other categories but still be in a state of system failure. Why this is so, what causes the exceptions and whether the working systems can be expected to remain so are questions arising from the results so far.

In order to explore these issues, case studies drawn from the ranking results are set out below

#### 10.5.1 Top ranked project

This project is a small health clinic in Chikhwawa that supports a refrigerator and three rooms with lighting. The system was installed in 2009. The project scores highly on all sustainability metrics (Figure 36). The Social score is lesser due to the absence of district involvement or the presence of any other stakeholders. However, there is an active management committee with a good range of skills and training. There is a project bank account and a positive cash flow from income generation through mobile phone charging and selling cold drinks. The system is reported to be fully meeting performance expectations. However, partial failure is reported in that lighting will sometimes cut out after a few hours at night. This indicates that the batteries are not holding sufficient charge, although a major fault is not apparent as yet. It is also noted that the refrigerator is directly connected to the batteries so is free to drain battery charge with no control. Although a small positive cash flow is
observed (MK 3,000 per month) the surveyor reports that the bank balance is not available and also notes that last year MK 35,000 was spent on cement and bricks to repair the building infrastructure. In this case, not only does the project lack support from local government for the PV system, the PV system is subsidising basic maintenance costs that should be met by the district health office. Although this project has many positive sustainability aspects, the current bank balance is critical. With potential battery failure on the horizon and hence loss of service and lack of further income generation opportunity, the sustainability is under threat in the near term.

<table>
<thead>
<tr>
<th>SYSTEM</th>
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<th>ORG SCORE</th>
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<td>1.00</td>
<td>0.98</td>
<td>0.67</td>
<td>0.90</td>
<td>0.89</td>
<td>Partial Failure</td>
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*Figure 36: Sustainability Metrics for Top Ranked Project*

10.5.2 Bottom Ranked Project

This project is a primary school in the Northern Region that comprises of a classroom lighting system (sys 76) installed in 2012 and a teacher’s house system (sys 77) installed in 2014. The newer system is currently working and meeting all expectations. The classroom is in a state of failure and has the lowest overall ranking of all systems. The project as a whole ranks very poorly across Economic, Social and Organizational Sustainability. Despite no apparent income generation, the project has spent significant sums in the last year replacing light bulbs and paying a security guard. This appears to be sourced from the school committee. There is no recorded external involvement, community engagement, management structures or evidence of training. The battery container is noted to be unventilated. Based on these results it would be expected that the new installation at the teacher’s house will operate successfully for a short time, however there is no capacity to repair or maintain the system.

<table>
<thead>
<tr>
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<th>TOTAL</th>
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<td>1.00</td>
<td>0.04</td>
<td>0.17</td>
<td>0.00</td>
<td>0.30</td>
<td>Working</td>
</tr>
<tr>
<td>76</td>
<td>21</td>
<td>0.00</td>
<td>0.04</td>
<td>0.17</td>
<td>0.00</td>
<td>0.05</td>
<td>Total Failure</td>
</tr>
</tbody>
</table>

*Figure 37: Sustainability Metrics for Bottom Ranked Project*

10.5.3 Project with multiple systems and range of rankings

This project is located at a health clinic with multiple staff houses and was installed in 2007. The overview of the project sustainability is shown below. It can be seen that the projects all have relatively low scores for Economic, Social and Organisational Sustainability. Technical sustainability ranges from good to bad with 3 systems currently in a working state and 4 in a state of total failure.

<table>
<thead>
<tr>
<th>SYSTEM</th>
<th>PROJECT</th>
<th>TECH SCORE</th>
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<td>6</td>
<td>1</td>
<td>0.82</td>
<td>0.30</td>
<td>0.56</td>
<td>0.30</td>
<td>0.50</td>
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<tr>
<td>5</td>
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<td>0.30</td>
<td>0.56</td>
<td>0.30</td>
<td>0.48</td>
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<tr>
<td>4</td>
<td>1</td>
<td>0.51</td>
<td>0.30</td>
<td>0.56</td>
<td>0.30</td>
<td>0.42</td>
<td>Working</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.50</td>
<td>0.30</td>
<td>0.56</td>
<td>0.30</td>
<td>0.41</td>
<td>Total Failure</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>0.30</td>
<td>0.30</td>
<td>0.56</td>
<td>0.30</td>
<td>0.36</td>
<td>Total Failure</td>
</tr>
</tbody>
</table>
The systems that are currently working have their technical score boosted by the current level of performance. All systems have a poor design rating that brings the tech score down. However, as system 6 is currently managing to fully meet expectations, it maintains a high technical score.

On reviewing the project questionnaire in further detail, along with the surveyor’s notes, it is apparent that the District Health Office continue to support this large health clinic. This is the main factor that drives up the social sustainability score, which would otherwise be very low. The DHO is noted to occasionally respond to maintenance requests. The system is however completely reliant on this sporadic external support.

Based on this analysis it would be expected that the systems will regularly fail and will only be restored if district support is forthcoming.

10.5.4 Highl Ranked System in State of Failure

The project that places 4th in the overall sustainability ranking is a Youth Club building providing lighting, phone charging and TV shows in Mulanje District. It is however in a state of total failure. Due to the technical design and other factors ranking highly, it maintains an overall high score. A positive cash flow of MK 10,000 ranks highly against other projects and the social structures also rate well. However, there has been little in the way of organizational training. It appears that a recent incidence of panel theft is the cause of the system failure. The bank account balance is unknown and it appears that the youth group do not have the resources or external support to repair the system. There is a suggestion in the surveyor’s notes that the available funds have been spent on a variety of activities. Even with a significant available bank balance, the panels are the most costly system component and would not normally be expected to be a maintenance cost. This project’s sustainability has suffered due to its vulnerability to theft.

10.5.5 Low Ranked System in Good Working Order

This project is a large health clinic with 8 systems serving treatment rooms and staff houses. The systems were installed in 2010. Only two systems had sufficient data to be ranked. Overall the project performs poorly in the rankings. System 26 places 78th in the ranking table, however the system is observed to be still working. There are no indications of any resource or capacity in place to maintain and operate the systems. Inspecting the surveyor’s additional notes the following observation is made “Maintenance costs were once handled by the DHO but they stopped when at a point in time realised that the maintenance that was needed was too big for them to manage”. From this it seems reasonable to assume that systems have been regularly falling into a state of failure due to the poor
sustainability. The presence of external support and finance allowed the systems to be returned to working status, however this support has been withdrawn and the sustainability outlook is now quite negative.

<table>
<thead>
<tr>
<th>SYSTEM</th>
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<td>4</td>
<td>0.76</td>
<td>0.30</td>
<td>0.22</td>
<td>0.10</td>
<td>0.35</td>
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<tr>
<td>26</td>
<td>4</td>
<td>0.44</td>
<td>0.30</td>
<td>0.22</td>
<td>0.10</td>
<td>0.27</td>
<td>Working</td>
</tr>
</tbody>
</table>

Figure 40: Sustainability Metrics for Low Ranked System in Good Working Order
11 Conclusions

The sustainability picture is bleak across the surveyed set of projects. Elements such as detailed needs assessment, community engagement, establishment and training of management structures, good technical design, quality components, maintenance and operation structures, financial management and a business plan are lacking in many of the projects. Even those systems that rank relatively highly in a sustainability assessment and are currently in good working order have an uncertain outlook.

Specific conclusions with respect to the study questions are outlined below.

To what degree are systems performing as expected?

As noted above, the systems technical performance is poor. There are numerous systems in a state of complete failure. An interesting aspect of the data is that the expected performance of the lighting systems are mainly described as either completely not meeting expectations or fully meeting expectations. It is difficult to say if this is a wholly accurate representation of the system or an indication of difficulty in the questioning process to articulate and capture degrees of satisfaction. Nevertheless, large numbers of systems can be said to be not meeting expectations.

Summary of system performance issues:

- 38% of the systems have completely lost all service
- 58% of room lighting is not fully meeting expectations
- 43% of batteries are showing 'bad' battery health indicator
- 31% of the mainly CFL installed bulbs are not working

What components are used in system design?

The standard components that comprise PV systems (PV panels, Batteries, Charge Controller and Inverter) are found to be prevalent in system design as expected. However, there are significant numbers of obscure brands and hence doubts over component quality. The poor practice of inverter direct connection to batteries is common. Light bulbs are primarily CFL and experience high failure rates.

Sizing and quality of PV system components is critical to appropriate design. Standards in this respect appear to be lacking. The analysis strongly infers that although the Malawian renewable energy sector is regulated and there is an accreditation process of installers and suppliers, there are still serious issues with the supply chain and design process. Design and installation is often below standard and the overall technical sustainability is poor. Specific suppliers and installers are not identified in the survey therefore this issue cannot be linked to the use of non-accredited suppliers.

The ultimate responsibility for ensuring appropriate technical standards for PV installations lies with MERA, however with numerous local and international organisations working with communities across Malawi there is significant chance of proper process being bypassed. In many cases this may be simply a case of the consumer being unaware of how to ensure they are purchasing an appropriate solution. Whilst it is not feasible for all consumers and communities to be fully conversant in PV system design methods and be able to verify their system has been designed properly, the MREAP community energy toolkit emphasises the importance of using MERA accredited suppliers and this should be sufficient in principle. It should therefore be the aim of the sector to ensure that all MERA accredited suppliers are using suitably robust design standards and components. Likewise efforts to better inform consumers (in this case purchasing agents for institutional level PV systems) on minimum quality requirements would allow for better choices during procurement.
**What factors are linked to high system performance?**

High system performance is assessed as the working state of the system and its ability to meet expectations. Performance overall has been identified as poor. There are no exemplar projects that allow a comparative analysis of factors linked to high performance. For the many systems in a state of failure, the multi-faceted nature of sustainability and the limited scope of this retrospective study makes identifying specific underlying reasons for that failure difficult in most cases. However, it is clear from technical analysis that system design, battery bank sizing in particular, is a critical factor and can be linked to more robust and higher performing systems. Nevertheless, there is also evidence of systems that are technically weak that are maintaining a high level of performance through regular repair financed externally that quickly returns systems to working order after failure.

**Which systems can be described as “most” sustainable and why?**

We define the most sustainable projects as those scoring highest within the sustainability rankings. In essence, the ranking defines a project as highly sustainable if it meets usage expectations, has relatively strong financial performance, is embedded and accepted within the community, and has the skills available to manage the project. It is essential that the systems are sufficiently technically reliable to maintain a level of performance that available financial resources can support. i.e. project finance can fund the necessary life-cycle costs, and most critically, 3-5 year battery replacement. The encompassing sustainability issues of community engagement, social and organisational structures are also of importance, however in the surveyed systems, insufficient to guarantee sustainability on their own. Although there are a number of surveyed systems that rank highly in all respects, their long term outlook is limited due to the lack of sufficient revenue and forthcoming requirement for battery replacement. Based on the survey responses, even a highly trained, organised and motivated community will be unlikely to maintain their system in the long term without a high standard of technical installation and a degree of external financial support for life-cycle costs. Therefore, it is not clear that an equal weighting across the pillars is appropriate. Furthermore, there may be an absolute minimum requirement for each pillar depending on the particular operational model, a nuance we have only brushed the surface of.
12 Recommendations

Ensuring the use of 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 (GoM, MERA, funders, suppliers, communities, etc).

For Community Energy Practitioners

- (Timeframe: immediately) Project design should be based on a sustainability pillars approach. Best practice for all sustainability metrics should be referenced and used to justify a fully sustainable project design prior to implementation. To improve learning, a common set of sustainability indicators should be included within project monitoring and evaluation.
- (Timeframe: immediately) Project designers to consider the role of district authorities in the sustainability of PV systems for schools and health clinics. The study suggests that even projects with apparently good sustainability assessments begin to struggle without external support of some sort. District support has been helpful, but sporadic. It could be made more effective by formalizing respective roles between community and district. Furthermore, linking up and demonstrating the impact of interventions to district objectives could provide the district with more leverage to invest and support such initiatives more widely.
- (Timeframe: immediately) Projects must include long term maintenance costs in project design and explicitly include a facility for this. Even the most successful community led income generation schemes surveyed have not been able to generate and save sufficient revenue for 3-5 year battery replacement.

For Academic Institutions

- (Timeframe: next 3 years) The study shows that previous community solar PV deployment appears to be highly dependent on limited-time donor-based funding that has not been shown to be particularly sustainable. Promising variations on the ‘community energy’ model need to be robustly tested and conclusions drawn proving long-term sustainability performance of these models.
- (Timeframe: next 3 years) An interface of regular knowledge exchange and policy briefings should be led by academic institutions to ensure government is utilising best practice and can plan for systematic issues such as district management of rural infrastructure.

For Government of Malawi

- (Timeframe: next 3 years) MERA to consider approved component list and to publish on-line design standards that accredited suppliers must comply with.
- (Timeframe: next 3 years) Investigate models where district authorities can partner and support community energy projects for education and health infrastructure, taking into account the cost structure and technical support requirements of deployed PV systems.
- (Timeframe: next 3 years) Support and promote the supply chain for LED light bulbs for renewable energy systems.

For Scottish Government

- (Timeframe: next 3 years) Require a lifecycle costing approach and model in place for any community energy systems funded
• (Timeframe: next 3 years) Require a sustainability pillars approach to project design with appropriate M&E that enables analysis of sustainability performance for any community energy systems funded
• (Timeframe: immediate) Disseminate results from MREAP and encourage similar approaches

Further Work
Despite the limitations of this retrospective survey, many insights as to the sustainability of off-grid PV systems in Malawi have been obtained. It is clear that a more systematic approach to monitoring technical and economic performance of off-grid projects in addition to social and organisational sustainability indicators from project inception, rather than retrospective one-off surveys, would allow more robust research into causes of poor sustainability and potential solutions. Given recent initiatives in Malawi to establish M&E systems for community energy projects and remote-monitoring for off-grid PV systems, the opportunity exists to establish, maintain and grow a valuable data set to serve as the foundation for the ongoing refinement of understanding on best practice for sustainable off-grid PV systems in Malawi.
13 References

19. Watson, Jim, Byrne, Robert, Morgan Jones, Molly, Tsang, Flavia, Opazo, Jose, Fry, Caroline and Castle-Clarke, Sophie (2012) What are the major barriers to increased use of modern energy services among the world’s poorest people, and are interventions to overcome these effective? Project Report. Collaboration for Environmental Evidence, Bangor.


14 List of Annexxes

1. Solar PV Survey (Annex 1)
2. Survey Guidance (Annex 2)
3. Excel based Data Entry form (Annex 3)
15 APPENDIX - Conceptualizing Sustainability

Due to its ubiquitous use, it is useful to adopt a working definition of “sustainability” here as: “the perceived potential for a system or project to endure, build a self-perpetuating capacity within a community, and ultimately reach the end of its predefined life span or evolve into another beneficial form” following [9].

From the documented sources in Section 1, a stylized story can be constructed that highlights the challenge of sustainability of off-grid community energy projects. Sustainability is complex and multifaceted. Technical issues such as inferior components, bad design, and insufficient maintenance can lead to the project quickly dying out as a key component is broken and goes unrepaired. Many projects have insufficient financial performance to expect long-term sustainability which results in lower performance versus expectation, and then outright failure. As projects are often run with a community or organization that takes on the role of management, its capacity, coherence, and adaptability are also important. Socially, when a (relatively) large project is installed in a remote community and intended to address local needs, it is critical that community has buy-in, support, and oversight to avoid outcomes like elite capture and/or theft. In order to capture the breadth of scenarios and factors that are at play the concept of sustainability must also include corresponding details for it to be operational.

We frame the concept of sustainability using two main sources: indicators framework for evaluating sustainability and (off-grid solar PV) project design guides and toolkits. Though many other potential sources do exist, such as individual case studies or field reports, there is also a high degree of fragmentation of knowledge and experience which makes it difficult to simply adopt a framework that must be both applicable to projects but also provide a systematic basis for comparison. Therefore, our approach is to start from a few well known sources and refine so it is relevant at the project-level, comprehensive in coverage of sustainability factors, and provides a measure of comparability.

15.1 Indicator Frameworks

Firstly, indicator frameworks have been developed for framing sustainable development efforts and are considered at a national level [13, 14, 15]. Efforts to re-envision them at the programme level [16] make them more relevant to projects, but nonetheless retain some of the national indicator framework and sustainable development legacy11. Nonetheless, the main pillars identified throughout are a reference point for evaluating project-level sustainability. They include the main themes: technical, economic, social, organizational, and environmental.

In [17] an assessment was carried out using indicators from [16] that assessed sustainability by ranking performance of seven organisations against the indicator set. The study included organisations in three countries: Tanzania, Kenya, and Zambia. The resulting analysis showed how the approach could be used to evaluate peer projects and demonstrated the potential for further use. The authors of [18] used these indicators in separate projects in Nepal, Peru, and Kenya with some modifications to the scoring method as well as introducing additional/revised indicators in areas of gaps. Both studies acknowledge methodological challenges associated interpreting the scores, but nonetheless achieve convincing results.

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11 For example through the use of indicators with a normative disposition: “Share of health centres and schools with electricity”, “Share of economically active children”, “Share of women in staff and management” and those which include global sustainable development indicators: “Share of renewable energy in production” and “Emissions of carbon dioxide”.

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Another source for comparison, [10] is aimed at uncovering causes of failure and success of stand-alone systems in Guatemala. Corsair uses the term success similarly to sustainability as used in this study, provides a myriad of examples of fragmentation of concept of sustainability, and concludes that the term is poorly defined. As a nuanced definition is built up, it bears similarity to the main themes of other sources including: “success”, “Economics and Utility”, “Institutions & Relationships”, to name a few key areas. As it becomes operationalized within the survey element comparable indicators are employed such as: “energy costs”, “income”, “functionality” for example. This research is another approach which deploys indicators in order to evaluate sustainability, though perhaps more nuanced and qualitative when compared to [16].

The several sources presented in this section show that research into evaluation frameworks for sustainability are active though perhaps not decisive in a definitive approach. There is comparable use of the concept of sustainability and similarity between themes and even some indicators. Finally, an approach to “operationalize” the indicators through the implemented study methods has resulted in convincing analysis of the sustainability of the included projects.

15.2 Sustainability ‘Toolkits’

Another resource for conceptualizing sustainability are ‘toolkits’ which can come under the name of guides, manuals, or other equivalent labels. Toolkits are typically framed from the perspective of designer, implementer, practitioner or manager rather than the evaluator. This distinction is helpful since knowledge to be used before implementation is necessarily normative and meant to be tailored to one’s particular situation.

A highly prominent toolkit from the World Bank [11] is a 21 page operational guidance note summarizing the World Bank experience in off-grid systems. Sustainability in this toolkit can be defined as the ongoing “operation of an off-grid electrification project over the long term”, a definition consistent with our own. The toolkit has useful guidance towards the development process, technology choice, financing options, and selection of business models. Its overall framework (see Figure 41 below) identifies necessary aspects for sustainability: practical technology choice, provision of training, community involvement, maximizing productive uses, etc. The elements that are included in [11] imply the project design address sustainability factors (i.e. technical, social, economic, organizational, and environmental) without necessarily prescribing the ‘right’ solution.

When compared to the indicator frameworks from section 2a, the toolkit has a relatively broader view of sustainability. By addressing aspects of project design, project implementation, institutional environment, regulatory environment, international support, the toolkit links together the whole lifecycle of an off-grid project.

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12 See [9], sections 2.2.1, 2.2.2 for this discussion.
While the World Bank guidance document is prominent, it is by no means the only source of guidance for sustainability of off-grid projects.

Another resource designed specifically for sustainability guidance in the establishment of community PV was produced by ESMAP [12]. The guidance points out that “[t]he key aim should be sustainability, which at the minimum is the reliable, cost-effective operation of a system over its design lifetime” (p5). It describes a phased approach which includes rapid pre-assessment, implementation planning, install, and long-term ongoing operation. The guidance provides very detailed suggestions throughout this process based on the author’s experience and is an excellent reference source. Nonetheless, its recommendations do not organize or explicitly address sustainability nor are there any specific indicators which could be used to evaluate sustainability over time.

15.3 Sustainability from Case Studies and other Field Experiences

Other sources come in many forms such as case studies, project reports, presented materials, or specific guides. They are too numerous to list comprehensively, but each has contribution to the understanding of what makes a project sustainable. For example, the case studies from the MREAP community energy evaluation in 2012 [7] identified many areas of concern for sustainability:

- The Solar Villages project was identified as not having a clearly established and effective ownership, operation, and maintenance arrangement. Furthermore, roughly a third of the batteries systems were non-operational, a key indicator of technical system failure. Additionally the ability of the project to secure an income to support its long term maintenance and operation was far insufficient.

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13 For reference see case study 6 within the annex of the evaluation
• The CRED project\textsuperscript{14} similarly identified insufficient financial resources in the initial study. Later field reports confirmed this but also identified additional issues such as with the functioning of the community energy committee, the defacto owners of the project, breaking down or in one case, acting on the behalf of a single individual.

• The Senga Bay project\textsuperscript{15} identified a lack of a financial model to support the system.

• The Milonde Youth Club Business Centre project\textsuperscript{16} identified a lack of transparency and accountability in the record keeping and only limited generation of revenues. Limited system availability was cited as a problem indicating inadequate system sizing during design. Finally, the technical support arrangement was not clear.

While many aspects of sustainability are addressed through these sources, there are challenges in their use as more generally. Rarely (if ever) do they comprehensively address all the potential scenarios and issues a project could face.

There is also a distinct issue of generality during re-use; any recommendations have to be re-interpreted to the particular circumstances of the new context. Monitoring and evaluation (M&E) is uncommon, especially with any standard indicators. This would allow a more robust comparison. Finally, many experiences go undocumented due to cost implications and obviously those which ‘fail’ are (understandably) not highly publicized.

15.4 Sustainability and PV Study Design

Figure 42 outlines a general framework for consideration of sustainability and connects up the relative role of the project design and implementation phases. This represents the conception of sustainability used in this study. Because the project is strictly constrained by the project design phase, sustainability itself will be linked the decisions made on the design earlier on. Finally, the whole project sits within a set of institutions (i.e. legal, governance, economics, etc.) that enable, detract, or constrain the project as the case may be.

Within the Solar PV Sustainability Study it is used as the framework for analysis and evaluation of sustainability factors in retrospect, that is, after the project has been installed and is operational. The approach to survey design was to capture a set of indicators from included projects that were related

\textsuperscript{14} See case study 1
\textsuperscript{15} See case study 8
\textsuperscript{16} See case study 11
to the various sustainability pillars that ultimately allows for comparison and further analysis. Each sustainability pillar (technical, economic, social, organizational, and environmental) has a distinct section in the survey with relevant questions. It was logistically impossible to capture and include indicators covering the “Institutional Factors and Overall Environment” within this survey.

Since there were no meaningful results from the environmental section of the survey, this has been omitted from the remainder of the report. In short, no significant environmental issues were reported by the projects. This is unsurprising given the fact that all projects utilized Solar PV which (installed) has minimal environmental concerns. Although issues around battery recycling and disposal are clearly relevant to environmental sustainability, the perspective of the respondents and the questionnaire approach was such that this issue was never broached.

In analyzing the results we review responses for each indicator individually and then undertake a ranking process, scoring projects against each of the indicators.

We take a similar approach as in [17] for ranking, but have used an alternative set of indicators which were more readily available and justified a similar ranking approach. It is important to note that this approach effectively establishes a scoring mechanism which is relative to other projects which are included. Some projects are not included due to lack of sufficient data. Thus, a project which is ranked relatively high among this data set may still be absolutely unsustainable; interpretation of the results is necessary.
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