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Sustainability of Solar PV Systems in Malawi

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Executive Summary

Background

Solar photovoltaic (PV) systems can offer a low carbon, low cost and economically competitive method of providing electricity in such remote areas unlikely to be grid connected in the near future. As such, they are being installed in significant numbers across sub-Saharan Africa. Malawi's off grid PV installed capacity has increased from 0.2 MW in 2007 to 5.7 MW in 2017 [1]. In 2012 there was an estimated 7,000 PV systems present in the country [2]. Despite the increase of installed capacity, many solar PV systems fall into disrepair, usually only achieving 10% of their lifetime expectancy, due to lack of maintenance, poor initial design, end-user misuse, or insufficient ownership and business model strategies. Research into factors that affect sustainability of off grid PV systems is needed to support identification of appropriate interventions and ensure project longevity with reduced lifetime costs of systems serving rural communities in sub-Saharan Africa.

Methodology

The study employs a novel scoring method which is used to support a sustainability evaluation of 65 off-grid community solar PV projects in Malawi. Projects are scored against the technical, economic, social, and organisational factors. An aggregated (total) sustainability factor is proposed here as a good early measure of project sustainability; however, there is insufficient evidence currently available to validate the accuracy this method as a predictor of long-term sustainability i.e. continued data collection and analysis of these sustainability factors, over several years, is required to obtain a sufficient evidence base to enable a deep understanding of the relative influence of the different sustainability factors for community energy projects in a variety of contexts.

Funded by the Scottish Government, The Malawi Renewable Energy Acceleration Programme (MREAP) ran from 2012 to 2015. A key part of MREAP was the Community Energy Development Programme (CEDP) that had a focus of increasing access to energy for low income communities in Malawi both directly and through interventions in the enabling environment. The programme's approach had a strong emphasis on community engagement, capacity building, and support; aspects deemed necessary for community energy projects to be sustainable.

Two phases of data gathering are included in this study. The first, in 2014, involved 43 projects not associated with MREAP, but analysed as part of MREAP to improve overall sector learning on sustainability of community energy projects [3]. The second phase, carried out in 2016, added a further 22 projects to this data set, including all of the MREAP projects which involved solar PV at schools and health centres (14 projects in total). The study adopted 3 different groupings, based on project implementer: *MREAP-CEDP* refers to projects established under the MREAP CEDP programme, *MREAP-WASHTED* refers to projects established under MREAP by the WASHTED Strategic Energy Project, and *OTHER* which refers to all other projects.

Results

The study results are summarised in Figure 1. The columns represent the key sustainability factors. The final column represents the total sustainability (the combined result). The rows represent the three project categories (top row is MREAP-CEDP, middle row is MREAP-WASHTED and the bottom row is OTHER). All projects that were surveyed as part of this work are represented as a black dot. The coloured lines represent the global average for that particular sustainability factor. The dashed blue lines represent the average for the sustainability factor for that project category only, for comparison with the global average.

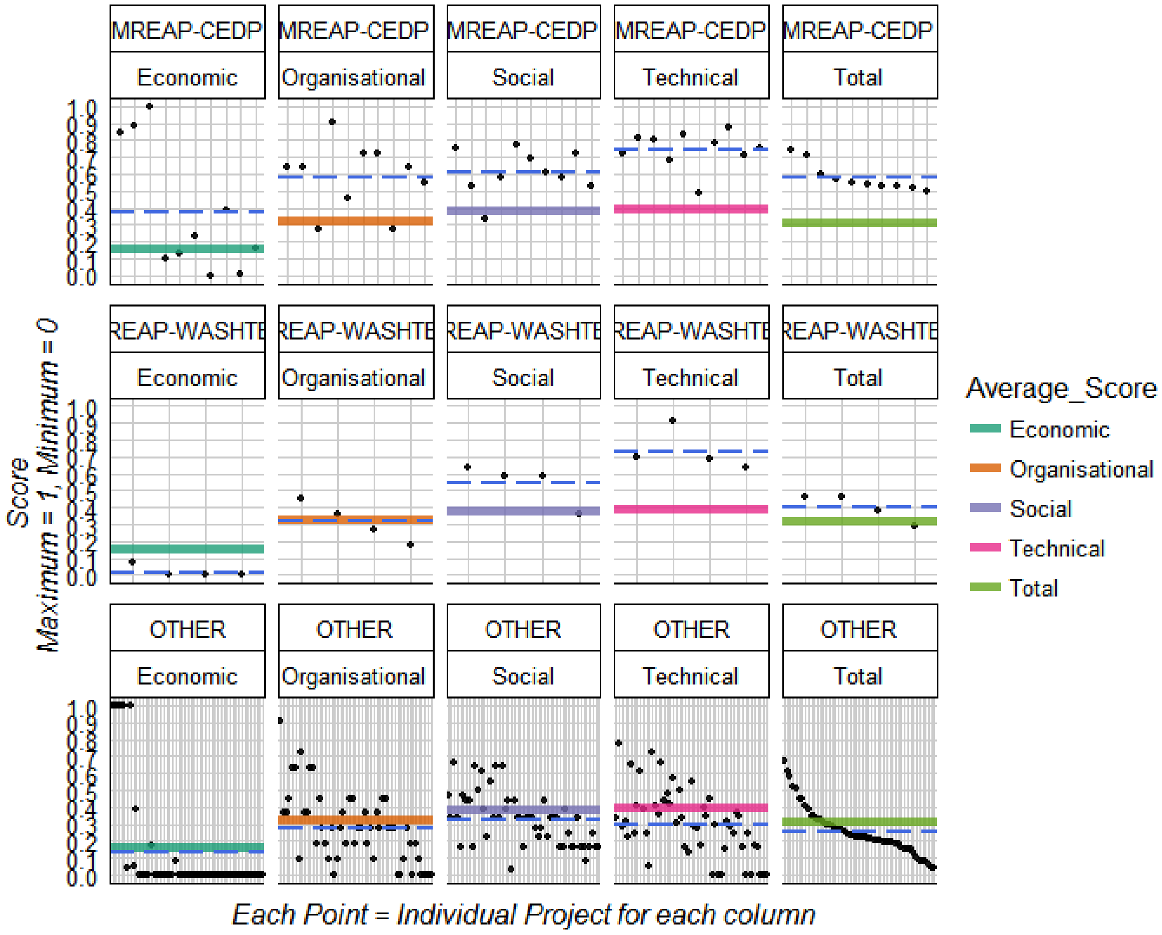

Figure 1: Summary of Sustainability Analysis

Key findings

- For the total sustainability factor, none of the MREAP-CEDP projects are scoring below the global average.
- MREAP-CEDP systems score significantly above average, with a total average score of 0.56.
- The MREAP-WASHTED projects are also above the global average with 0.40.
- Across the data set, the global economic average score stands out as the lowest of all scores.

Discussion

Further development of models for economic sustainability are required in the sector - many projects have failed to establish a sufficient financial model. MREAP-CEDP outperforms other project groups on this factor, but could still be improved compared to the other factors. Technical performance has been improved by MREAP systems when compared to OTHER systems - systems appear to be sized better for current consumption expectations and are more often meeting those expectations.

The OTHER projects consistently score low using the methodology employed in this analysis. Most significantly, this analysis highlights the large spread in responses for organisational, social and technical factors and a common economic score of 0. This suggests a low community engagement and low stakeholder management of the projects. The technical specification of OTHER projects is inconsistent and the economics are not secure.

The results of this study should be considered by practitioners and project developers in Malawi as well as policy decision makers concerned with the sustainability at the project level.

Contents

1 Introduction

1.1 Energy Access and Off Grid Solar PV as a Solution

Access to energy is an enabler for development. Conversely, a lack of energy is a barrier to economic empowerment and poverty eradication. Access to energy has been globally recognised as a high impact development priority through the UN Secretary General's "Sustainable Energy for All" initiative [4] and a subsequent Sustainable Development Goal 7, with a target of universal access to energy [5]. Nearly 1.2 billion people lack access to electricity globally and the region of Sub Saharan Africa has the highest population percentage lacking electricity, where only 290 million out of 915 million people have access to electricity. To further compound the problem, the total number without access is also rising [6].

Solar photovoltaic (PV) systems can offer a low carbon, low cost and economically competitive method of providing electricity in such remote areas unlikely to be grid connected in the near future. The cost of PV has been declining steadily in recent years [7]; the technology requires little maintenance compared to competitor technologies (such as small wind or hydro power); its modular nature allows systems to be up scaled easily. The availability of components is also improving, even in rural trading centres.

1.2 Sustainability of Solar PV

Despite the increase of installed capacity, many solar PV systems fall into disrepair, usually only achieving 10% of their lifetime expectancy, due to lack of maintenance, poor initial design, end-user misuse, or insufficient ownership and business model strategies. Research into factors that affect sustainability of off grid PV systems is needed to support identification of appropriate interventions and ensure project longevity, reduced lifetime costs of systems serving rural communities in sub-Saharan Africa.

Sustainability of such solar PV systems is not a trivial matter. Research in this area has developed and implemented general frameworks for understanding the sustainable development aspects of rural electrification programs. These include the technical, economic, social, institutional, and environmental pillars of sustainability [3, 8-11] (Figure 2).

The pillars of sustainability provide a high-level framework; however, within this, a working definition of sustainability for the specific technology of solar PV systems is useful. For this study, sustainability has been defined 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 lifespan or evolve into another beneficial form".

For this study, a survey was designed and implemented to extract a set of variables for each sustainability pillar, with the exception of environmental sustainability. The variables were then combined to create a sustainability factor for each pillar. Environmental sustainability factors are not considered for PV systems because, in the current context of Malawi, the effect on the environment is assumed to be positive and therefore not included as a sustainability risk. The sustainability survey variables and factors are explained further in the following sections.

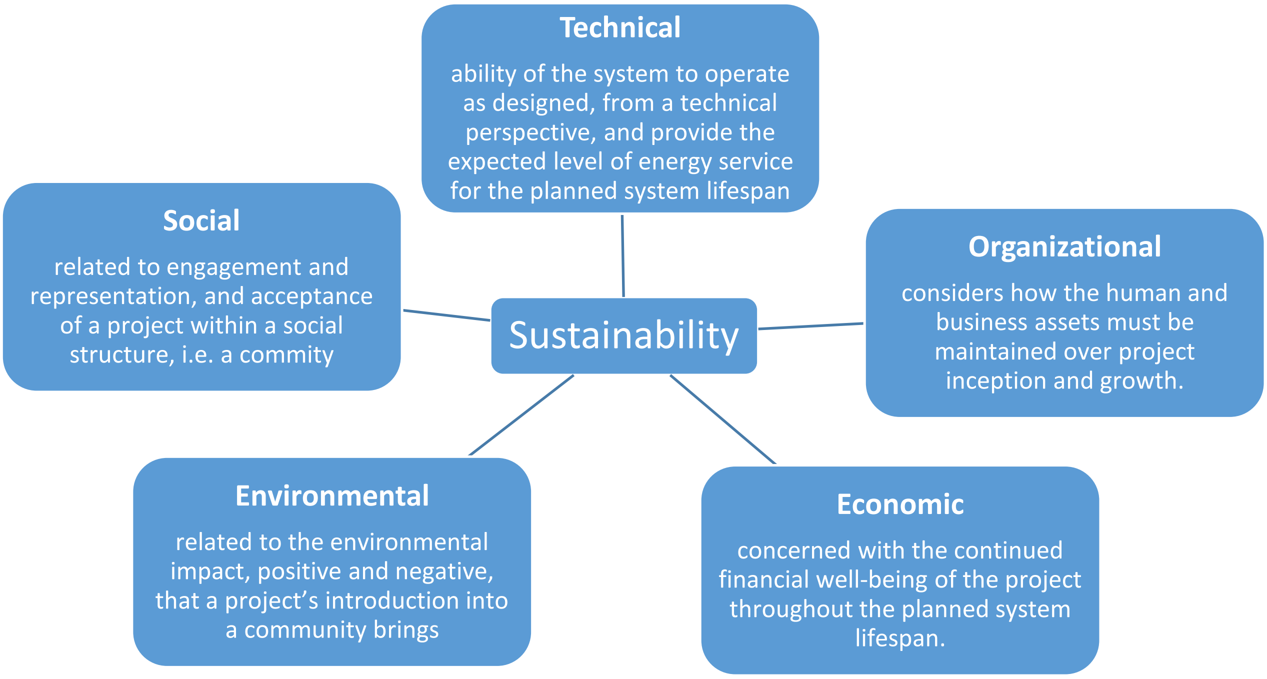

Figure 2: Conceptualising Sustainability

1.3 Solar PV in Malawi

Malawi is one of the poorest countries in the world, with an economy highly dependent on agriculture (83% of the population is located in rural areas and approximately 75% of the population is living a subsistence farming lifestyle [12]). According to the World Bank Sustainable Energy for All (SE4ALL) database (2016) access to the national electricity grid in Malawi is currently just 9.8%, with rural electrification at only 5.3% [13]. This equates to over 15 million people in Malawi living without access to the main electricity grid, and those with access currently experiencing blackouts on a regular basis. Despite Government of Malawi efforts to extend and modernise the grid it is clear that new generation and grid extensions will not reach the entire population of Malawi in the short term. Mini-grids, though a promising option in the future, are in pilot stages currently.

Malawi's off grid PV installed capacity has increased from 0.2 MW in 2007 to 5.7 MW in 2017 [1]. In 2012 there was an estimated 7,000 PV systems present in the country, though many are known by practitioners not to be fully functional [2]. Recent market assessment for off grid technologies found that PV systems have a significant role to play in the electrification of off-grid communities in Malawi, that PV is scalable across the entire country and its modularity and simplicity are ideally matched to the needs of off-grid communities, where technical capacity and individual household demand is low [14]. With market conditions favouring of off-grid project development, it is therefore crucial that these projects are developed to ensure sustainability.

1.4 MREAP and Community Energy Malawi

Funded by the Scottish Government, The Malawi Renewable Energy Acceleration Programme (MREAP) ran from 2012 to 2015 with a focus of increasing access to energy for low income communities in Malawi both directly and through interventions in the enabling environment [15]. The coordinated multi objective development programme's approach had a strong emphasis on community engagement, capacity building, and support, deemed necessary for community energy projects to be sustainable.

A key intervention to ensure renewable projects were supported following the completion of MREAP was the creation of the social enterprise Community Energy Malawi (CEM). CEM have continued to provide institutional and technical support the MREAP systems through training of technicians on maintenance of the solar PV systems, plus organisational and financial training.

1.5 Evaluating Solar PV Sustainability in Malawi

In 2016, with many of the systems reaching the 3rd year of their lifetime, it was an opportune time to compare the sustainability of MREAP projects against other projects installed in Malawi. This study therefore, proposes a novel scoring method which is used to support a sustainability evaluation of 65 off-grid community electrical projects in Malawi. Projects are scored against the technical, economic, social, and organisational factors.

The study adopted 3 different groupings, based on project implementer: *MREAP-CEDP* refers to projects established under the MREAP CEDP programme (later becoming CEM projects), *MREAP-WASHTED* refers to projects established under MREAP by the WASHTED Strategic Energy Project, and *OTHER* which refers to all other projects.

The results of this study are relevant to project developers in Malawi as well as practitioners concerned with the sustainability at the project level. The proposed scoring framework is novel in that it is aimed squarely at off-grid projects and indicators relevant to their sustainability (as opposed to a wider “sustainable development” framework [16]).

The data set is described in Section 2. Analysis of individual sustainability factors is in Sections 3 – 6. Analysis of the overall sustainability factor is described in Section 7.

2 Data Set Description

2.1 Questionnaire design and data handling

Two phases of data gathering are included in this study. The first, in 2014, involved 43 projects not associated with MREAP, but analysed as part of MREAP to improve overall sector learning on sustainability of community energy projects [3]. The second phase, carried out in 2016, added a further 22 projects to this data set, including all of the MREAP projects which involved solar PV at schools and health centres.

Data gathering was carried out by a facilitated questionnaire with project managers and their support staff on site. Records, such as log books and financial reporting, were used when available; however, this was rare. The facilitated questionnaire captured current finances, technical conditions and equipment, organisational structure, and social support networks for each project. Enumerators were trained by the research staff at University of Strathclyde and, during phase 1, the survey was field tested. Minor changes for clarity adjusted the survey between phase 1 and phase 2, though the content was identical.

A major difference in the survey methodology between phase 1 and 2 was the update to use of KoboCollect, a digital data collection platform which utilises smart phones for recording questionnaire data and uploads it to a digital server. The data presented in this paper represent the data available from both data-sets.

2.2 Overview of Projects

An overview of project statistics is shown in Table 1. 65 individual projects were included in this study. A project has been defined as a set of energy assets in which a distinct management team is responsible. Within an energy project, multiple systems may have been installed, e.g. a school with a system for classroom lighting and further systems providing lighting and power to teacher's homes. Within a system, lighting and power may have been supplied to several rooms. In order to accurately capture technical equipment and energy consumption data, it was necessary to survey at the system and room level. In total 246 systems were found, consisting of 642 separate rooms. Economic, social and organisational data, which was available at relatively greater granularity, was surveyed for the project as a whole.

Table 1: Statistical Overview of Projects included in Study

Metric	**MREAP-CEDP**	**MREAP-WASHTED**	**OTHER**	**TOTAL**
Number of Projects	10	4	51	65
Number of Systems	87	21	138	246
Number of Rooms	275	28	339	642
Metric	**MREAP-CEDP**	**MREAP-WASHTED**	**OTHER**	**Average**
Mean design PV system size (Wp) per system	197	357	288	259
Mean design number of panels per system	2.24	4.10	2.9	2.79
Mean battery capacity (Ahat 12V) per system	241	475	225	257
Mean no. of batteries per system	2.51	4.63	2.41	2.65
Mean total daily load (kWh) per system	0.43	0.31	0.49	0.45
Mean daily lighting load (kWh) per system	0.12	0.07	0.11	0.11
Median Year of Installation	2014	2014	2010	

The age of the systems is an important consideration as older systems are more likely to have experienced issues in comparison to more recent installation. From Table 1 and Figure 3, it is clear that the OTHER set of systems spans a significant age range compared to the relatively new MREAP installations.

Further basic statistical information on the technical capacity of the systems surveyed is shown in Table 1 for reference and comparison during the study.

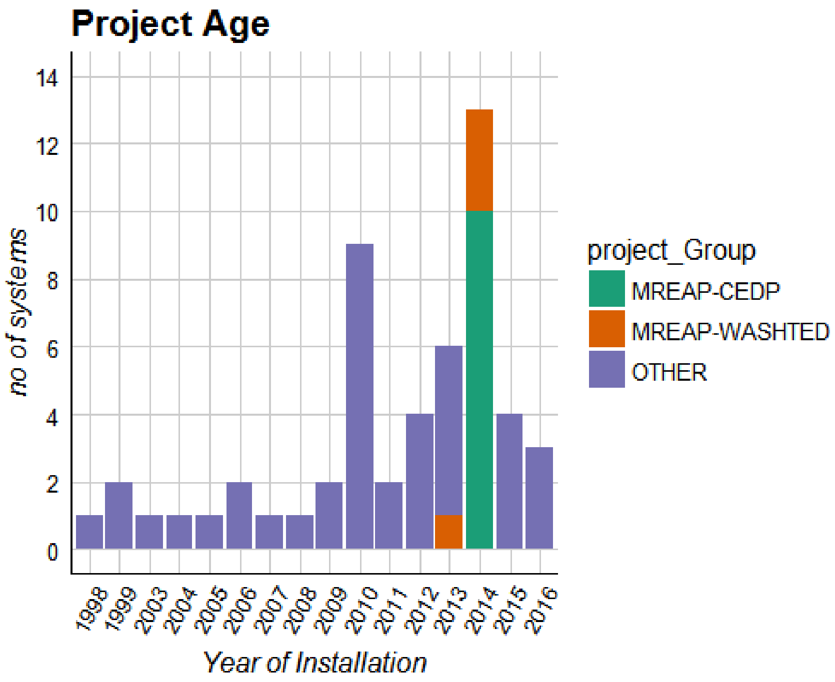

Figure 3: ***Project Year of Installation by Project Group***

2.3 General Scoring Methodology

The choice of scoring metrics, weight and reduction immensely affects the conclusions which can be drawn. Due to lack of literature supporting specific valuations of sustainability metrics, the selection of metrics is theoretical and involves some subjectivity. This research therefore starts to build an empirical base for more objective approaches. The choice of included metrics for this study, are proposed as generally relevant indicators to the sustainability factor and in the context of off-grid community energy projects in Malawi.

Sustainability factors are computed by an average of sustainability metrics. Each metric has equal weighting and is normalised to a scale ranging from 0 (lowest) to 1 (highest). Ranking is conducted at the project level for all factors except technical sustainability, which is analysed on a per system basis.

Since robust longitudinal studies that quantify the degree to which each sustainability factor metric and sub-metric actually influences the long term sustainability of a project have not been published, assigning an arbitrary weighting is not justified. It is unclear whether other approaches, such as metric identification and weighting by stakeholder consensus, have thus far been validated.

3 Technical sustainability factor

3.1 Technical variable definitions and methodology

Technical sustainability refers to the quality of technical system design as well as the ongoing functionality of the sub-components. For this factor, each individual system in a project was analysed. Because some projects contain more than one system, it is useful to see which systems are performing technically and which are not.

A set of technical questions were used to investigate the health of system components, system use and system design. The variables utilised in the analysis presented here are: quality of PV panels installed, quality of batteries installed, battery health at time of survey, and three ratios related to usage and design.

The first ratio is *Actual Usage* against *Expected Usage*. This provides a gauge of how well the system is meeting user expectations.

The second ratio is *Installed PV Panel Array Size* against *Optimal PV Panel Array Size*. Optimal size is calculated by applying a known design standard to the expected usage revealed from the survey. This variable provides a gauge of the installed systems ability to meet user expectations effectively. A system may be incorrectly sized due to either poor design methods and/or incorrect estimation of usage and associated load profiles.

The third ratio is *Installed Battery Bank Size* against *Optimal Battery Bank Size*.

These technical variables are averaged to create an overall Technical Sustainability Score. Further details of variable methodology can be found in table A of the Appendix.

3.1.1 Technical analysis

Figure 4 compares the actual sizing of panels and batteries against the optimal sizing of panels and batteries in MREAP-CEDP, MREAP-WASHTED and OTHER systems. The red line on each graph indicates the optimal sizing of the system, which is normalised to 100 in all cases for comparison. The columns indicate three different system sizing methods from the literature (Practitioner, IEEE_Optimistic and IEEE_Pessimistic) [17] [18] [19]. The Practitioner method represents a commonly used method in the practitioner community, the IEEE methods are implementations of an IEEE standard.

The top row of Figure 4 shows MREAP-CEDP systems, the second row is MREAP-WASHTED systems and the third row is OTHER systems. A score of 100 refers to an optimally sized battery/panel compared to the usage, with <100 being considered under-sized and >100 scores indicate the components are oversized.

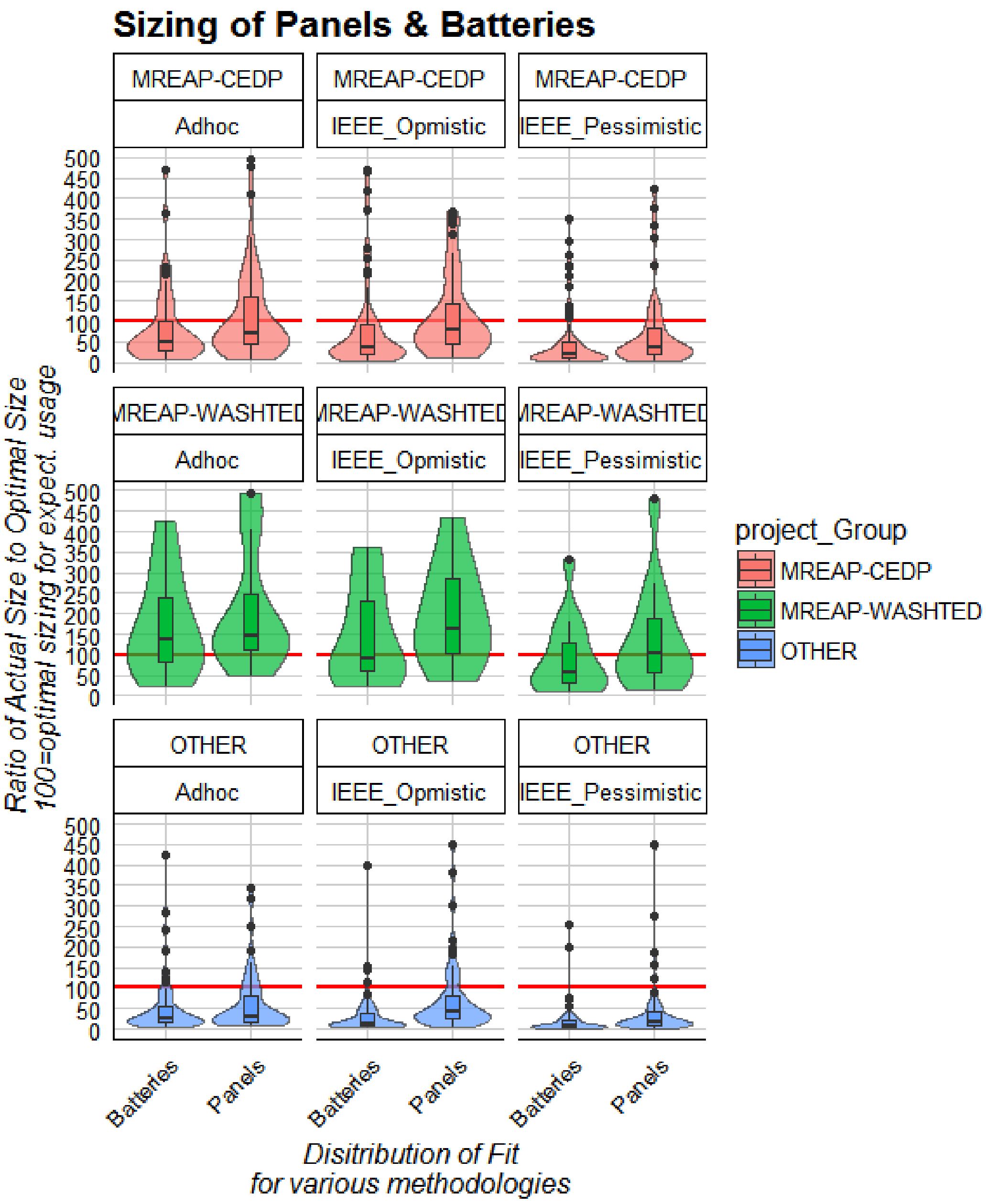

Figure 4: Ratios of optimal sizing of panels and batteries versus actual sizing

The violin chart utilised in Figure 4 shows the kernel density distribution of the selected variable along a vertical centre line. Bulges indicate relatively more observations were found, while thin "strings" indicate relatively fewer observations. Plotted on top of the violin chart is a box and whisker plot which shows median (dark black line), and 25% and 75% percentile (within box). The whiskers are 1.5 times the inter-quartile range (range between 25% and 75% percentile). Solid dots indicate outliers outside the whisker range.

For all projects, these graphs of system sizing show a significant variation between how the community is using the systems and how the system was designed, the tendency being to be undersize. These results highlight the difficulties in correctly sizing an energy system at installation. This is not surprising as even though design guides take into consideration load growth, the installation of the energy system itself significantly changes the living patterns and associated energy use of the local population.

In general, the MREAP-CEDP panel arrays are undersized, but to a much lesser degree than OTHER systems. MREAP-WASHTED projects have tended to oversize panel arrays. The same pattern exists for battery banks, although batteries tend to be more undersized than panels. System under-sizing may be due to a combination of: incorrect estimates of system usage, inaccurate methods for system sizing, and unanticipated load growth over time. Relatively fewer systems meet IEEE standards, which are generally require larger systems providing a higher level of reliability/availability.

This study highlights the wider question and difficulties of ‘correctly’ sizing a PV installation at the design stage, raising the complex question of how engineers correctly size PV energy installations in rural off-grid locations, knowing that the introduction of electricity access will significantly affect the social and economic activities and profile of the local area.

Figure 5 shows the actual to expected usage of daily lighting specifically (this reasonably reflects all loads on the system). The average actual usage is less than the average expected usage for all 3 categories of project. This result may be due to poor system design, or system inadequacy (not performing due to failure). Conversely, the result could also be caused by user expectations increasing after positive experience of energy access.

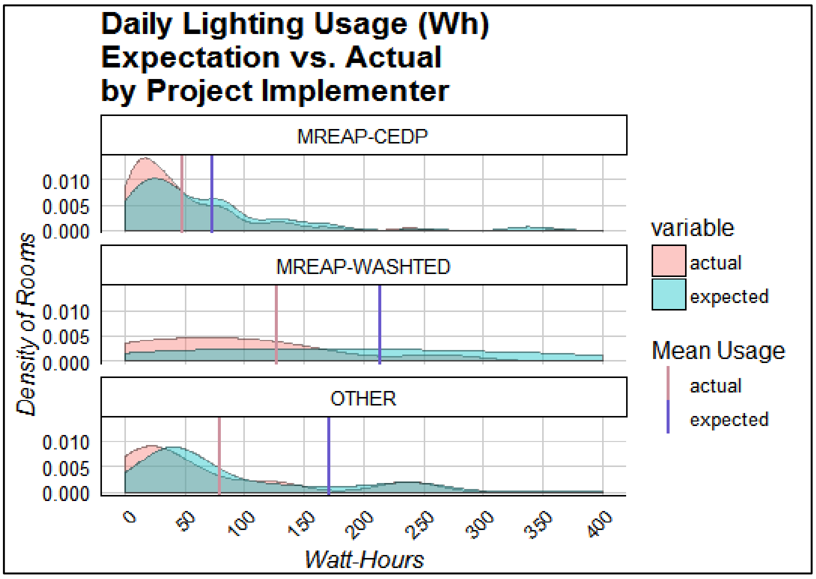

Figure 5: Expected and actual Watt-Hours for the 3 categories of project

The charts show that design for OTHER systems has, in most cases, underestimated expected usage and/or made poor design assumptions. MREAP-CEDP system design has, in some cases, encountered the same issue; however, these systems are better designed on average. MREAP-CEDP achieves the least difference between average actual and expected usage, indicating that the design incorporated thorough community consultation and needs assessment. Although MREAP-WASHTED systems have average actual usage significantly less than average expected usage, those systems appear to be correctly or oversized much more often. A design approach that avoids optimistic assumptions would yield this result.

These results highlight the need for further research into the optimal way to size a project before installation. There may need to be more recognition of the change in local behaviour, population aspirations and population priorities (in terms of lighting vs. other appliances); with this change instigated by an energy system. Energy systems should be designed for future activities rather than current activities and further research into how to estimate future activities based on current activities will be useful for improving sustainability of energy installations. There will be significant change to local economics and social profile with the introduction of electricity and a system is expected to begin over-sized in an ideal case. As a system ages, and the local and social economy normalises with electricity access the system will naturally move towards being undersized. Project life-time projection and scenario modelling can be used as part of future work to investigate lifetime profiles and to backwards-engineer from the best case scenarios to determine system size when designing the system for the future. This forms part of future research activities and interests at Strathclyde University.

4 Economic sustainability factor

4.1.1 Economic variable definition and methodology

The economic analysis of the systems is dependent on two input variables: income as reported in the survey, and a model of expected operating and maintenance costs based on known or estimated system install costs. Although the systems are primarily schools and health posts, rather than a commercial operation, income may be achieved through a number of routes: a maintenance revenue budget provided by local government, a maintenance revenue budget provided by community fundraising, and income generation activities associated with the project.

The yearly expected operating and maintenance costs were estimated as 10% of initial capital costs.

The ratio of the income and expenditure variables provides the economic sustainability factor.

4.1.2 Economic analysis

Figure 6 provides a breakdown of the mean monthly income from a range of income generating activities. MREAP-CEDP project significantly outperform all other projects in this respect.

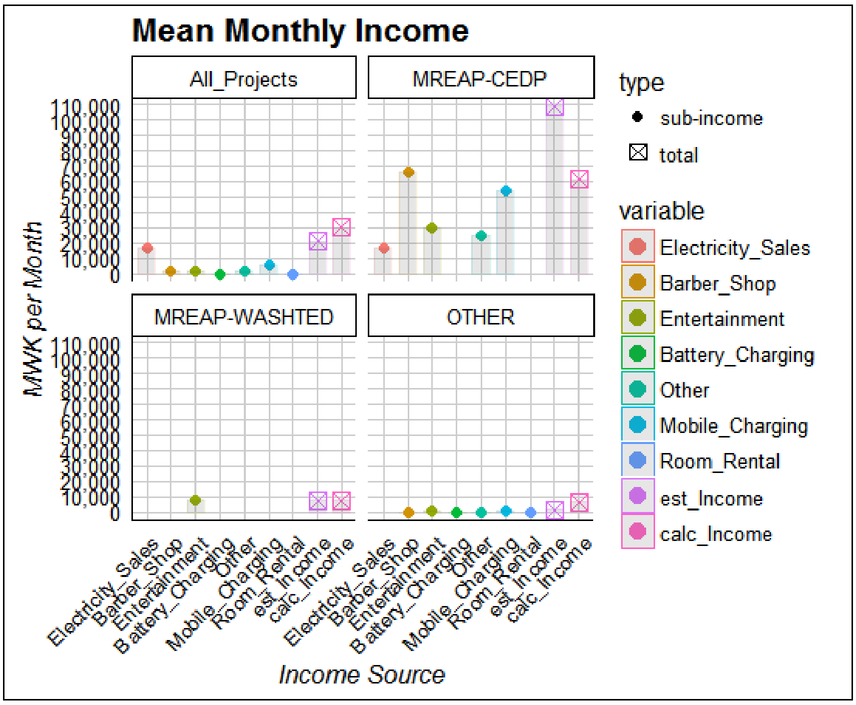

Figure 6: Mean Monthly Income

Figure 7 shows the yearly income, expenses breakdown and NET income (after minus expenses) for all projects, MREAP-CEDP projects, MREAP-WASHTED projects and OTHER projects. The All_Projects graph shows how generally projects break even as the expenses meet the yearly income. In each graph, the first bar is the yearly income, the following 4 bars are the breakdown of expenses and the final bar is the NET income (i.e. yearly income – expenses). If the final bar is positive, then income from the system covers the maintenance and operational costs for the energy system. The MREAP-CEDP systems are the only projects showing a positive income after expenses.

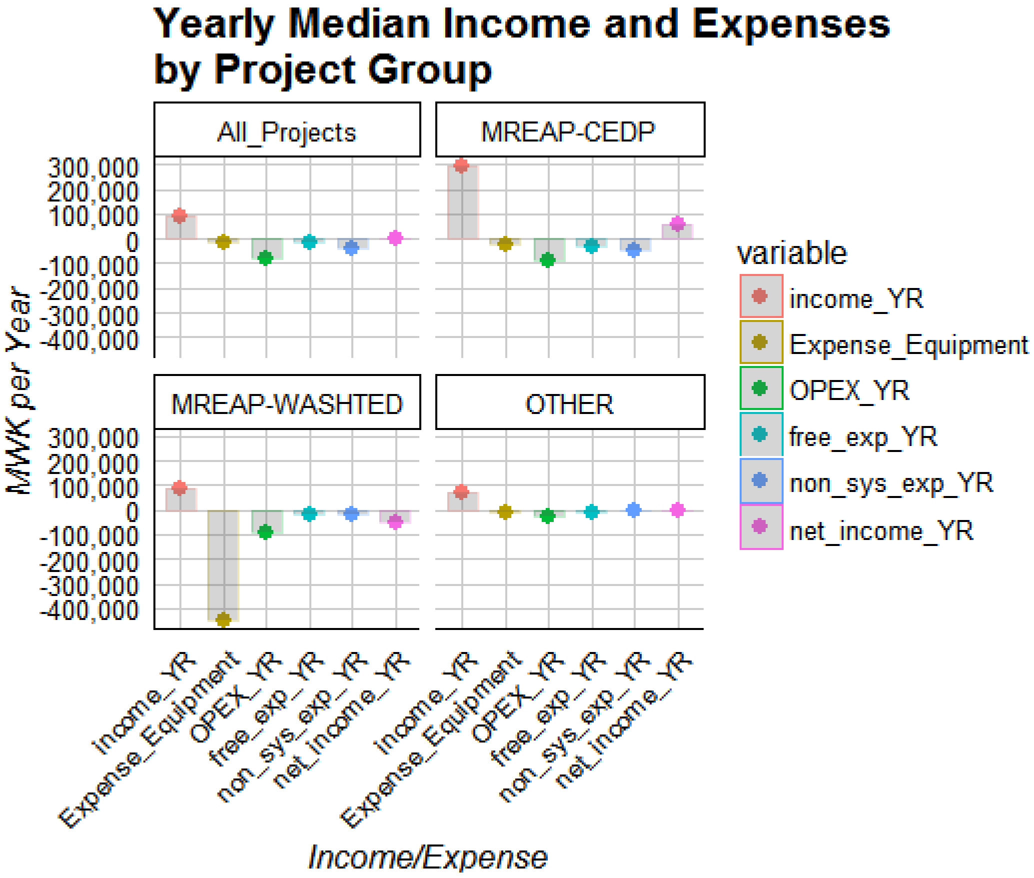

Figure 7: Income compared to expenditure (MWK per year).

The economic stability for the PV system is an important sustainability factor. An equally weighted combination of the reported income and the model of expected operation and maintenance costs is a logical initial indicator of the economic stability of a PV project. The minimum considerations and requirements of income exceeding expenses seems to be a low consideration in most PV installations, despite the high impact economic stability has for sustainability. This study highlights the gap in economic planning at the design and installation stage, indicated in Figure 7.

5 Social sustainability factor

5.1.1 Social variable definition and methodology

A set of questions were implemented through the survey to assess: the degree of community participation in the design, implementation and operation of the project, the range and level of stakeholder involvement, and the degree of district government involvement in the project.

These scores were combined with equal averaging to obtain an overall social sustainability score.

5.1.2 Social analysis

Engaging the local community is understood to be an important step towards sustainable projects in Malawi and for rural off-grid communities in general. As a result of this, stakeholder involvement was a significant aspect of the MREAP methodology to improve community ownership of the projects and therefore sustainability.

Figure 8 shows the % of projects with different types of stakeholders present within the three categories of MREAP-CEDP, MREAP-WASHTED and OTHER. The MREAP projects have purposefully involved stakeholders in as many areas of project development and management as possible. This represents a significant improvement compared to OTHER projects and, considering the literature review findings, stakeholder involvement in this way is expected to improve sustainability of the MREAP installations.

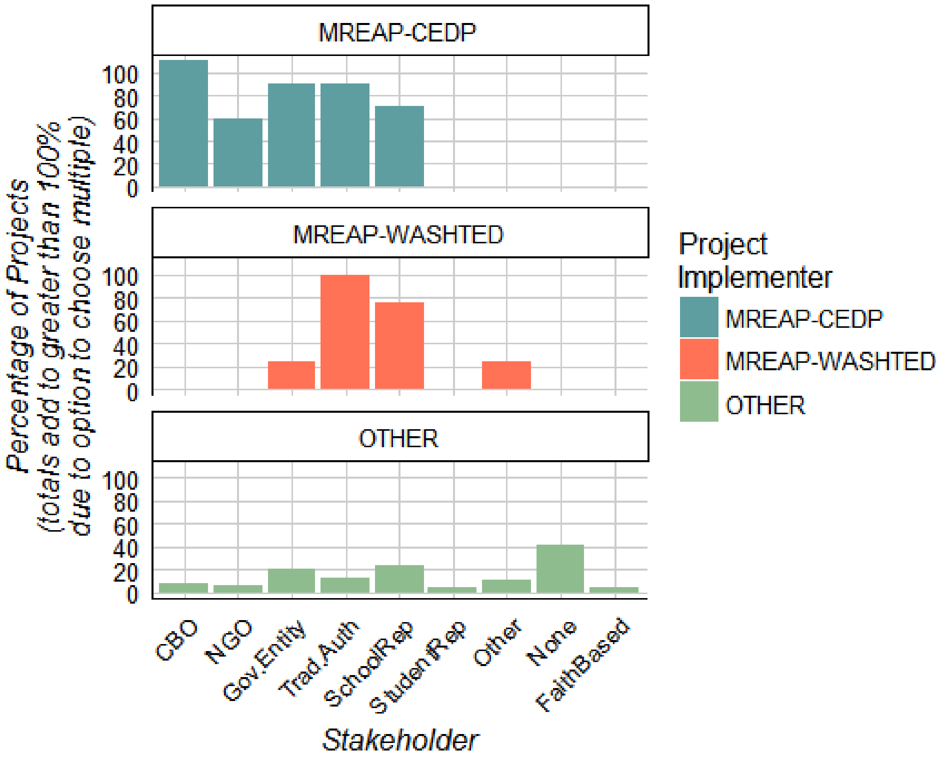

Figure 8: Percentage of projects with different types of stakeholders present.

Sustainability is linked to community consultation and contribution as this fosters a sense of community ownership at the concept stage. Figure 9 shows how MREAP installation methodology includes local community consultation and local community needs assessment.

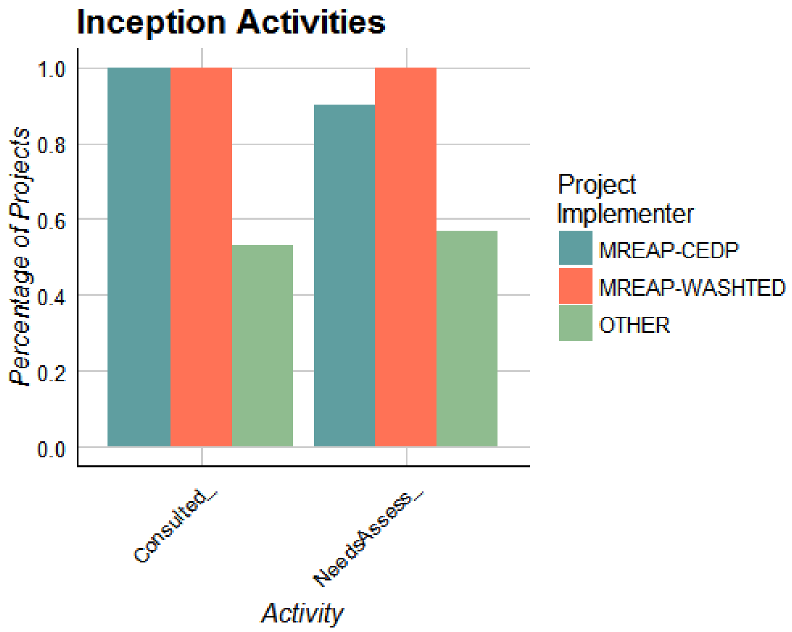

Figure 9: Numbers of Projects Including Inception Activities

As well as having multiple stakeholders, sustainability is linked to the frequency of the stakeholder meetings to make decisions about the energy system. Figure 10 is a bar chart of the meeting frequency of the stakeholders. MREAP project stakeholder are encouraged to meet more often. Most surprisingly, OTHER project stakeholders usually never meet to discuss the project together. This is a negatively indicator for project sustainability.

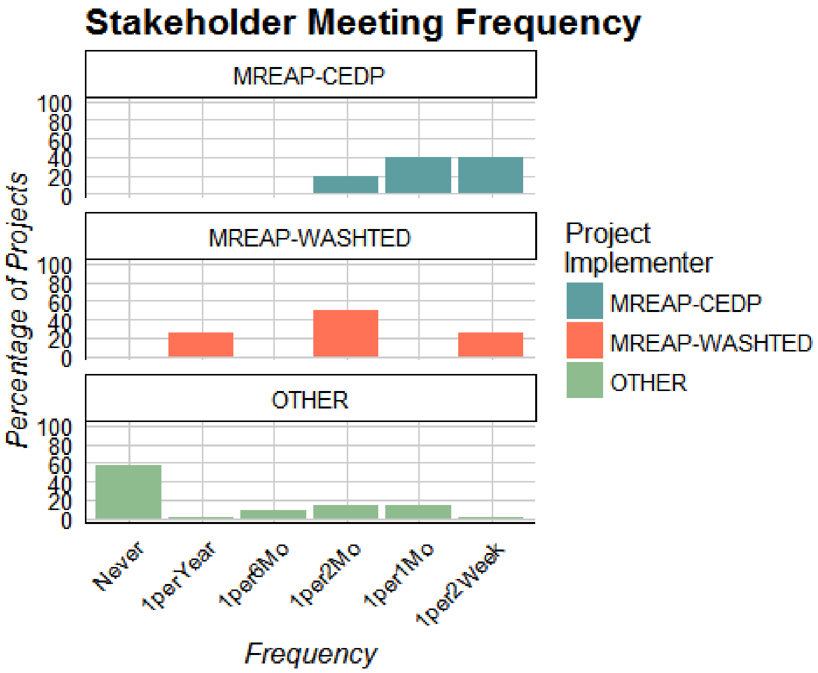

Figure 10: Meeting Frequency of Stakeholders

Figure 11 is the percentage of district involvement in projects. 90% of MREAP-CEDP projects have district involvement. There is currently no framework or formal support mechanism for energy projects and governmental support is given in an ad-hoc way. This is surprising, given that energy access is an enabling infrastructure, and the government of Malawi recognise the need for a national policy and framework to offer support for rural electrification (alongside grid extension). The government is dedicated to initiating District Energy Officers in every district in Malawi and the current system of gaining support through the district council is expected to improve. Although the MREAP projects include district governance as a stakeholder, the projects have suffered from inconsistent district council support and sudden changes to their contributions. As the government of Malawi create a more formal framework for rural energy projects, the support from government is expected to be clear and consistent and have a positive impact on the sustainability of energy system installations.

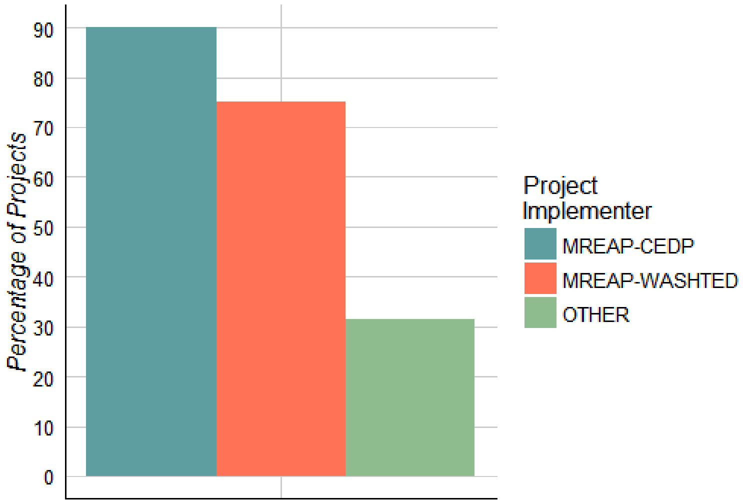

Figure 11: Percentage of projects with district government involvement

Although the types of decisions a stakeholder makes is not included in the scoring, projects with more stakeholders were given a greater sub-score. However, clearly the decision process and roles of these stakeholders are important for managing a project. Each project was asked the stakeholder and type of decision made, broken down into major areas as shown in Figure 12. Obviously, not all stakeholders are considered equal. Community based organisations (CBOS) stand out as instrumental in all forms of decision making whereas other common stakeholders, such as traditional authority, served a limited and specific role.

Though CBOs provided the most comprehensive decision making, it is unclear which combination is most effective at managing projects. If one assumes that a capacity to make all the decisions is needed for a sustainable project, then a combination of entities seems necessary. The mechanics of decision making is out of the scope of this project, but this data suggests further research is needed into their decision making process in greater detail than is typically identified.

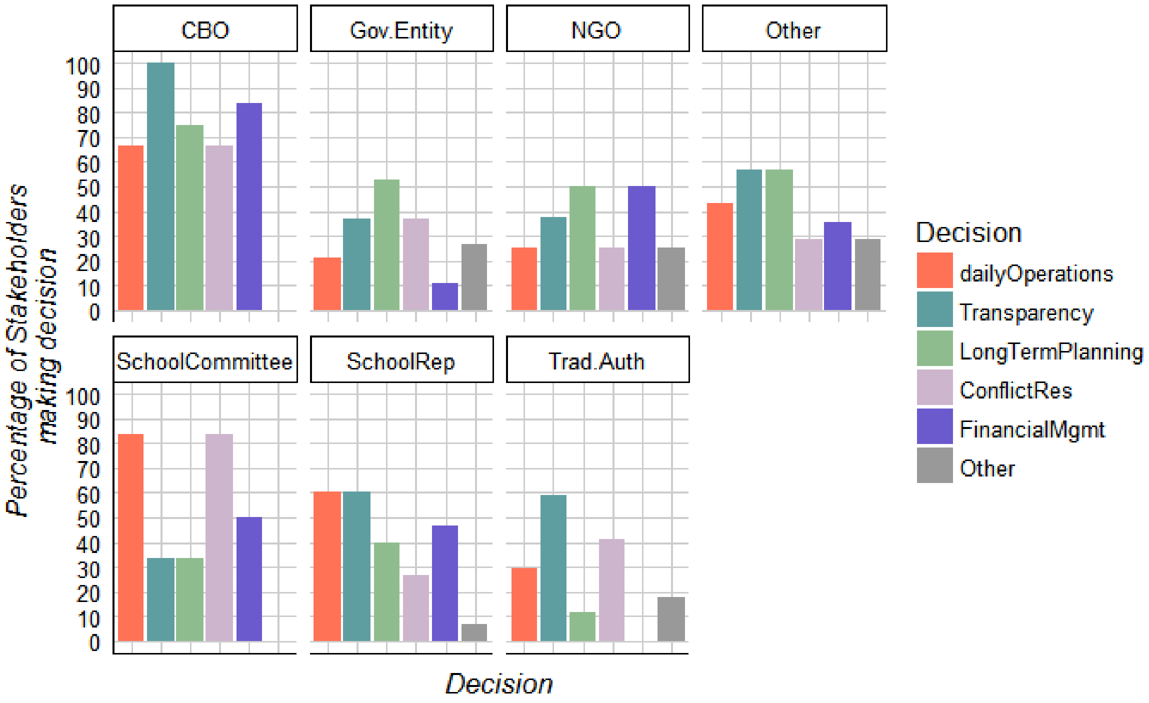

Figure 12: Percentage of the stakeholders that are making the decisions about the installations

6 Organisational sustainability factor

6.1.1 Organisational variable definition and methodology

The organisational scoring variables are obtained from questions regarding 3 different roles needed to sustain the installation. For the technical, financial and managerial roles of the project, the survey asks:

- Is there someone fulfilling this role?
- Did they receive initial training to carry out the role?
- Do they receive ongoing training to carry out the role?

The final question is whether there is a maintenance arrangement currently in place (i.e. a contract with a company). The organisational variables are combined by averaging with equal weighting to obtain an overall organisational sustainability score.

6.1.2 Organisational analysis

The MREAP projects rely on initial and ongoing training for financial, technical and managerial roles to improve sustainability through organisation. Despite detailed project knowledge confirming that this training has been delivered in all of the MREAP-CEDP projects, results do not reflect this, instead showing between 30% and 80%. This anomaly is to be investigated with respect to survey design and implementation. MREAP-WASHTED projects provide training prior to installation only and no ongoing training is available. OTHER projects also provide some initial and ongoing training, although the % is generally less at 5% to 40% of projects.

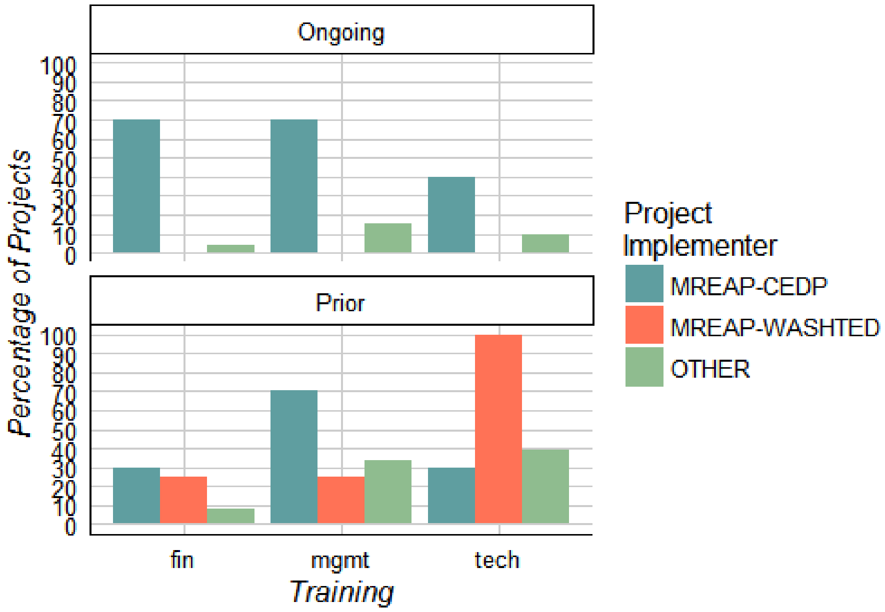

Figure 13: Level of ongoing (top graph) and prior training (bottom graph) in terms of percentage of projects within the three project categories.

Figure 14 shows the roles present at the time of survey for each project category. The most obvious is the lack of any organisational role at all OTHER installations. This highlights the important issue of community ownership and knowledge sharing between community members. The community could implement an apprentice scheme to spread knowledge beyond the initial training and involve more people, to retain knowledge and mitigate against the risk of the organisational roles not being filled.

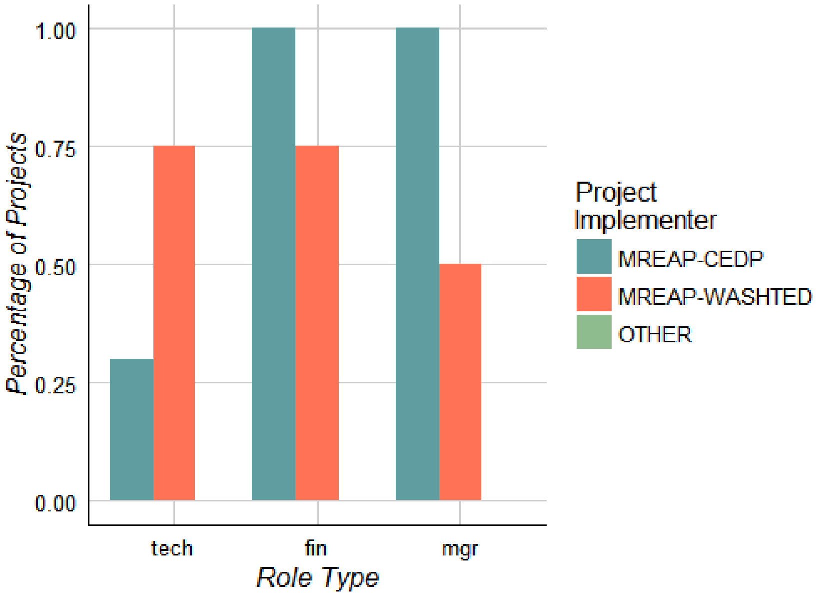

Figure 14: Percent of projects with technical, financial and managerial roles present

7 Aggregated Sustainability Factor

The final aggregated sustainability factor combines survey results of technical factors, economic factors, social factors and organisational factors. The aggregated sustainability factor is proposed here as a good early measure of project sustainability; however, there is insufficient evidence currently available to test this method as a predictor of sustainability. i.e. continued data collection and analysis of this project set, and others, over several years, is required to obtain a sufficient evidence base for sustainability measures of community energy projects.

Figure 15 shows the final results of the sustainability survey and modelling, using the methodology described in this report. The columns of Figure 15 represent the economic sustainability, organisational sustainability, social sustainability, technical sustainability. The final column represents the total sustainability (the combined result). The rows of Figure 15 represent the three project categories (top row is MREAP-CEDP, middle row is MREAP-WASHTED and the bottom row is OTHER). All projects that were surveyed as part of this work are represented as a black dot. The coloured lines in Figure 15 represent the global average for that particular sustainability factor. The dashed blue lines represent the average for the sustainability factor for that project category only, for comparison with the global average.

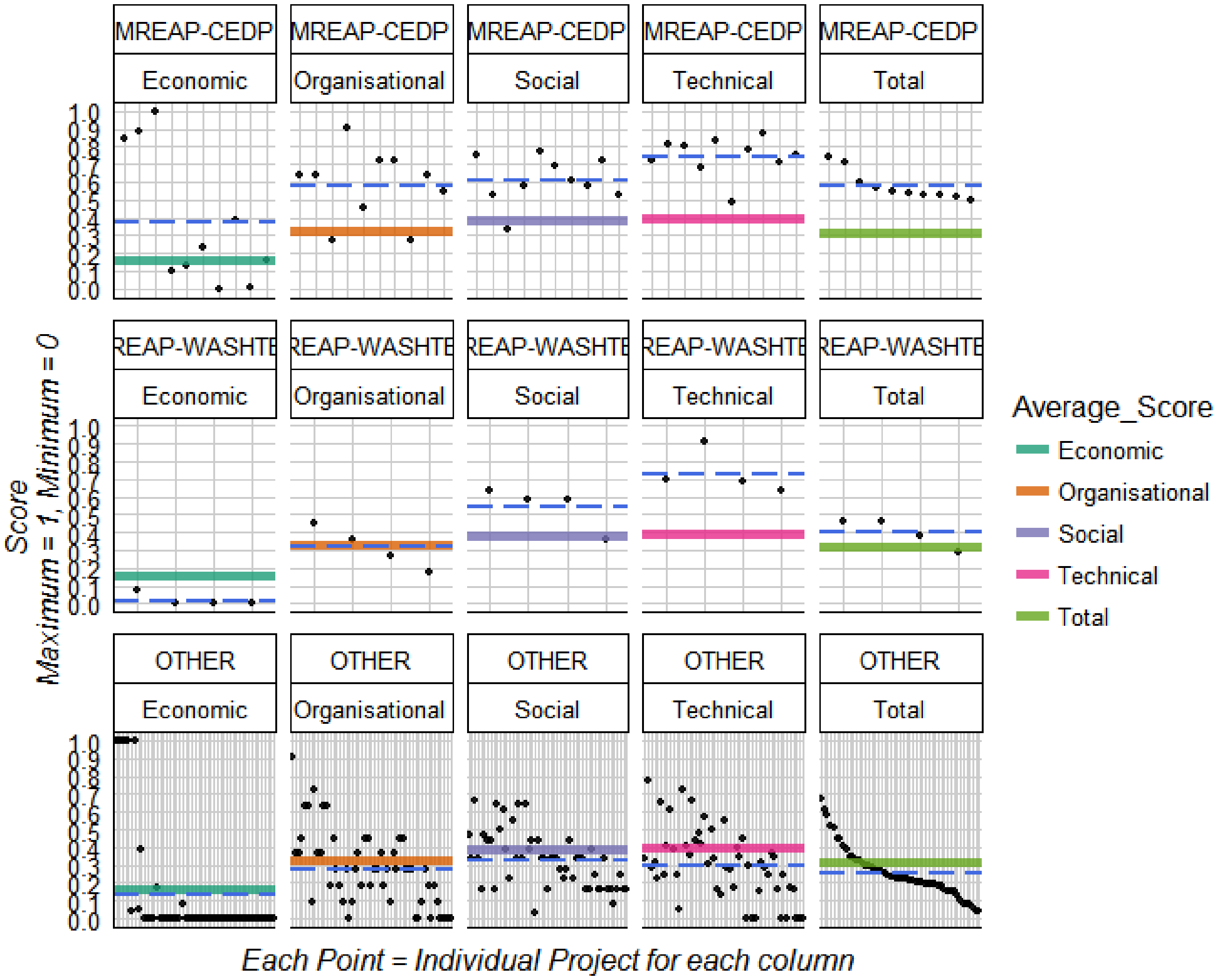

Figure 15: Aggregated Sustainability Scores by Project

Table 2 provides a summary of the mean scores for the individual and aggregated factors.

Table 2: Sustainability Factor Mean Scores

Metric	MREAP-CEDP	MREAP-WASHTED	OTHER	Factor Mean
Economic	0.37	0.02	0.13	0.16
Organisational	0.58	0.31	0.28	0.33
Social	0.61	0.54	0.32	0.39
Technical	0.75	0.73	0.30	0.40
Project-Group Mean	0.56	0.40	0.26	
Overall Mean				0.32

The results show that, for all sustainability factors, the MREAP-CEDP systems score significantly above average, with a total average score of 0.56. None of the MREAP-CEDP projects are scoring below the global average. The MREAP-WASHTED projects are also above the global average with 0.40. The MREAP-WASHTED projects are significantly affected by a very low economic factor score. This is due to a very low yearly income and a relatively high yearly OPEX.

Across the data set, the global economic average score stands out as the lowest of all scores. Further improvement in the sector is required as many projects have failed to establish a sufficient financial model. MREAP-CEDP outperforms other project groups on this factor, but on the whole has low scores compared to the other factors. Technical performance has been improved by MREAP systems when compared to OTHER systems, as systems appear to be sized better for current consumption expectations and are more often meeting those expectations.

The OTHER projects consistently score low using the methodology employed in this analysis. Most significantly, this analysis highlights the large spread in responses for organisational, social and technical factors and a common economic score of 0. This suggests a low community engagement and low stakeholder management of the projects. The technical specification of OTHER projects is inconsistent and the economics are not secure.

8 Appendix – Tables of Sustainability Metrics

Table A: Technical Sustainability Factor

Technical variables	***Variable range and type***	***N/A number as a % of responses (out of 139)***	***Value assignment methodology***
Panel Quality	*Discrete values 0 and 1*	*3%*	*Determined through prior experience and internet search for the panel manufacturer and make. If the panel manufacturer and make is known or easily found on the internet - the panel is assumed good and given a score of 1. If the panel manufacturer and make is not known or not easily found on the internet - the panel is assumed a sustainability risk and given a score of 0.*
Battery Quality	*Discrete values 0 and 1*	*12%*	*Determined through prior experience and internet search for the battery manufacturer and make. If the battery manufacturer and make is known or easily found on the internet - the battery is assumed good and given a score of 1. If the battery manufacturer and make is not known or not easily found on the internet - the battery is assumed a sustainability risk and given a score of 0.*
Battery Health	*Discrete values 0, .5 and 1*	*15%*	*Usually there is a traffic light health indicator on the battery, though this depends on the type of battery. The indicator red/orange/green light directly is allocated 0/0.5/1 scoring. N/A means there is no indication of the health of the battery.*
Ratio of Actual Usage to expected usage	*Continuous values between 0 and 1*	*58%*	*The ratio of actual usage versus expected usage (in Watt-hours/day) for each system. For each system, all appliances are accounted for and their expected as well as actual usage estimated by the user.* *If the system is not used at all, it receives a score of 0. A maximum of 1 occurs if actual usage meets or exceeds expected usage. In all other cases, this variable is equal to the ratio described. A ratio higher than 1 would usually indicate growth. However, with the low usage, this ratio can reach very high numbers. As such, a cap of 1 is used. This variable is the actual usage of the system as a ratio of expected usage of the system.*
Ratio of the designed panel sizing to an optimal panel sizing.	*Continuous values between 0 and 1*	*58%*	*By using the values for expected usage, and using a chosen standard for system sizing, the optimal system size can be compared to that actually installed. A score of 1 in this component refers to a perfectly optimally sized panel array, with less than one being considered under-sized. Nominally, scores over 1 indicate systems that are oversized. However, there is a limit of 1 as, with low usage, the ratio can reach very high numbers.*
Ratio of designed battery sizing to an optimal battery sizing.	*Continuous values between 0 and 1*	*58%*	*Calculated similar to the panel design, this is the ratioTechnical battery description of designed battery sizing to an optimal battery sizing.*
Overall Technical Sustainability Score			*The above variables are combined through averaging with equal weighting given to each variable.*

Table B: Economic Sustainability Factor

Economic variables	Variable range and type	N/A number as a % of responses (out of 139)	Value assignment methodology
Ratio of Income to Expenditure	Continuous value 0 to 1	0%	A simple economic model was calculated for each system. System capital costs were estimated using known component sizing (panels and batteries) for each system. Project capital costs include aggregate system costs. Other components (labour, install, inverter, charge controller, other costs) are estimated as a ratio of estimated system costs. Panel costs were calculated as \$1.555/Wp, battery costs \$0.168/12VAh. This was determined by linear regression from roughly 20 quotes of each taken in 2015. Additional capital costs (as proportion of panel and battery costs) are 24.2% (balance of system). Operating costs were estimated as 10% of initial capital costs. A replacement for panels (every 20 years), batteries (every 5 years), and other capital equipment (every 10 years) was assumed. Yearly operating and maintenance costs were levelised and compared to reported income. The ratio of reported income to required income to cover calculated costs is used. If this ratio is >1, it is capped at 1.

Table C: Social Sustainability Factor

Social variables	Variable range and type	N/A number as a % of responses (out of 139)	Value assignment methodology
Needs Assessment	Discrete values 0 and 1	0%	Did a needs assessment take place? If so 1, if not 0.
District Involvement	Discrete values 0 and 1	0%	Is there district governance involvement? If so 1, if not 0.
Meeting Frequency	Discrete positive values	0%	How often does the community meet? 6 steps, representing more or less frequent meeting was recorded. 0 = never, 1=every year, 2= every 6 months, 3= every two months, 4= every 2 weeks, 5 = once every week. This was rescaled to range from 0-1.
Theft	Discrete values 0 and 1	0%	Has theft occurred in the history of the project?
Stakeholders	Discrete positive values	0%	How many stakeholders are there? For all projects that maximum number is 6. It is assumed in general, for off-grid projects more stakeholders have a positive effect on the social sustainability, representing higher level of local engagement and wider impact. A score of 1 is given to projects with 3 stakeholders or more. Projects with 2 stakeholders receive .66, 1 stakeholder .33, and no stakeholders 0.
Community Contribution	Discrete positive values	0%	Three types of community contribution were possible, money, materials, or labour. Hence if a community contributed all three, a score of 3 was given. If they did not contribute anything, a score of 0. This was scaled to range from 0-1.
Overall Social Sustainability Score			The above variables are combined through averaging with equal weighting given to each variable.

Table D: Organisational Sustainability Factor

Organisational variables	Variable range and type	N/A number as a % of responses (out of 139)	Value assignment methodology
Technical role	Discrete values 0 and 1	0%	Is there an organisation/individual responsible in the community for technical organisation of the project? If so 1, if not 0.
Finance role	Discrete values 0 and 1	0%	Is there an organisation/individual responsible in the community for financial organisation of the project? If so 1, if not 0.
Managerial role	Discrete values 0 and 1	0%	Is there an organisation/individual responsible in the community for managerial organisation of the project? If so 1, if not 0.
Technical training	Discrete values 0 and 1	0%	Was technical training provided prior to installation? If so 1, if not 0.
Financial training	Discrete values 0 and 1	0%	Was financial training provided prior to installation? If so 1, if not 0.
Managerial training	Discrete values 0 and 1	0%	Was managerial training provided prior to installation? If so 1, if not 0.
Technical training ongoing	Discrete values 0 and 1	0%	Is ongoing technical training provided? If so 1, if not 0.
Financial training ongoing	Discrete values 0 and 1	0%	Is ongoing financial training provided? If so 1, if not 0.
Managerial training ongoing	Discrete values 0 and 1	0%	Is ongoing managerial training provided? If so 1, if not 0.
Maintenance arrangement	Discrete values 0 and 1	0%	Is there a maintenance arrangement in place currently? If so 1, if not 0.

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