Sustainability of Solar PV Energy Kiosks for Off-Grid Energy Access: Malawi Case Study

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Abstract — This paper presents learning relevant to off-grid energy access initiatives from a case study in Malawi. Deploying solar PV Kiosks in four rural communities, the Sustainable Off-Grid Electrification of Rural Villages (SOGERV) project set out to establish sustainable, community-based energy businesses. Focussing on access to renewable electricity and economic sustainability, the project deployed a set of services and products aiming to meet local needs identified in a detailed market survey of the area. The financial results of each business (sales revenues and operating expenses) are presented and discussed. The results demonstrate that, despite operating in remote areas with some of the lowest development statistics in Malawi, the revenues that can be obtained by these businesses have the potential to meet long-term operations and maintenance costs and generate a net surplus over a 10 year trading period. However, results are varied between businesses and many risks to long term economic sustianability remain. The learning provides a platform for further development of SDG7 focussed, community energy projects in Malawi and other similar contexts.

Keywords—Solar PV, Rural Electrification, Community Energy, Economic Sustainability, SDG7.

I. INTRODUCTION

In 2018, the Government of Malawi launched a new National Energy Policy [1] alongside the Malawi Renewable Energy Strategy [2]. Increased deployment of renewable energy generation and the use of decentralised energy systems are key strategies to support increased electricity access for the underserved rural populations. The national grid in Malawi serves 10% of the population with only 4.7% of the rural population being connected, despite accounting for 83% of the population [1] [3]. Although Malawi has one of the worst electrification rates worldwide, these statistics are reflective of a common challenge for many Sub-Sahara African (SSA) countries where, despite significant progress being made in recent years, only around 35% of the 910 million people in SSA has access to electricity, with the majority of this achieved via grid extension [4]. IEA modelling predicts that to achieve 'energy for all' by 2030, investment of $52 billion per year is required, more than double current plans, with 95% of the additional investment focussing on SSA and a major focus placed on solar PV and off-grid and mini-grid solutions [4].

Solar PV is not a new energy access solution to SSA and there is a long history of failed attempts (mostly led by aid agencies through the 80's and 90's) to establish this technology as a mainstream part of the generation portfolio of developing countries [5]. Many initiatives were deemed to have placed too much focus on technological development and badly underestimated the operations and maintenance requirements of even small PV systems in this context [6]. Despite a resurgence in interest and activity, and some notable success with more market orientated approaches, improving the sustainability of off-grid rural electrification projects remains a major challenge [7].

In Malawi, the off-grid renewables sector is particularly young and little learning on sustainable models for off-grid electrification in the Malawian context is available. Rural energy projects in Malawi typically include aspects of community ownership and operation, and target a public facility such as a primary school or health centre. However, despite the high impact, many of these projects have fallen short of sustainability expectations [8] [9].

The Sustainable Off-Grid Electrification of Rural Villages (SOGERV) Project was funded by the Scottish Government, running from 2015 – 2018. Working in four communities in Chikwawa District, the project's primary goal was contributing to progress against SDG7 and SE4ALL targets in Malawi. Although the design for the SOGERV project took a holistic approach to sustainability, economic sustainability was a key target. This paper provides analysis of the economic aspects of the SOGERV community energy businesses, lending insight to the viability of this type of energy access solution to meet the immediate needs of Malawi's rural poor.

II. METHODOLOGY

The project design was strongly influenced by evaluations of previous projects in Malawi [9] [10] and employed the common thematic classification of sustainability pillars: economic, technical, social, organisational and environmental [11]. A high level of community capacity building with clear roles and responsibilities for management and operations was prioritised along with a strong technical oversight in the demand assessment and system design stages. Placing a focus on economic sustainability, a detailed market assessment was undertaken to estimate the demand for a range of renewables-based energy products in each of the four communities [12]. The study implemented a custom survey at each location, deploying surveys to 314 households and 46 businesses. Populations were estimated in each location through analysis of GIS data (Table 1). Based on the determined ability and willingness to pay of the communities, the market assessment recommended a focus on sales of products and services to households and businesses for 'lower tier' energy access levels [13].

Table 1: Estimated Size of Communities

Location	No. Households
Kandeu	473
Mandrade	604
Thendo	841
Gola	1334

Solar kiosks were identified as a suitable method for serving such a market where either solar home systems or full mini-grids are not deemed viable [14] [15] [16] and a 'social' business model involving multi-stakeholder partnerships was indicated for improved social sustainability.

Each SOGERV business implemented a solar kiosk (alternatively called a 'Charging Station' by the project). The high-level technical specifications are described in Figure 1.

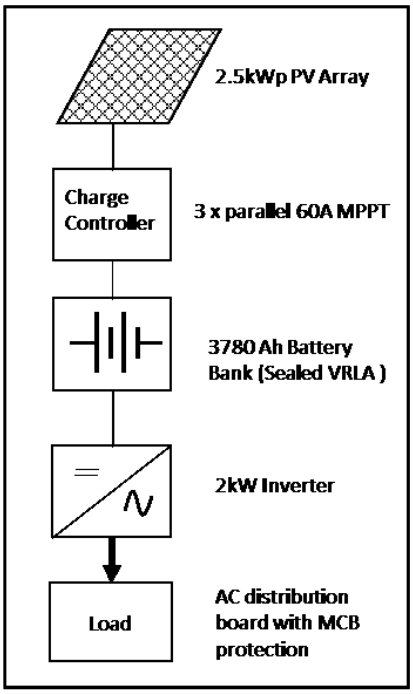

Figure 1: Single Line Diagram of Kiosk Configuration

The main services offered by each business were: portable solar product (PSP) sales and rentals, mobile phone charging and portable battery charging. Each business was supplied with a seed stock of a range of PSP that provide basic lighting and small power supply services (Table 2). In this paper, only the aggregate sales of PSP are considered. More comprehensive details are available in a complementary paper focussing specifically on PSP sales from the SOGERV project [17]

The businesses also offered PV solar home systems (SHS) and 'wired connections' for a monthly fee to local businesses employing productive use of energy (PUE) [18] [19]. The SHS offerings were rated at 120Wp or 240Wp, comprised of PV panel, charge controller, battery and inverter, and were hard wired into a customer's premises. Wired connections consisted of a metered distribution spur extending from a circuit breaker at the kiosk distribution board to a nearby (<10m) customer premises.

Table 2: Overview of PSP Range

PSP Product and Description	Cash Price MWK
1 - Small Solar Lantern	8,000
2 - Small Solar Lantern with Mobile Charger	21,000
3 - Portable battery kit (PBK) with 2 lights and mobile phone charger	96,000
4 - DC Solar Home System (SHS) with 4 lights, mobile phone charging, radio, and task light	134,000

Three business operation models were trialled. For the villages of Mandrade and Kandeu, a business operator was recruited with the assistance of the local community. The business operators were positioned as 'franchisees' entitled to 15% commission with any surplus returned to the project for reinvestment (modelling a possible non-profit approach to deploying a fleet of community energy services). The commission value was agreed in discussion with the operators, with monthly earnings expected to be comparable to local community health and education workers. In the village of Gola, a local entrepreneur was recruited as the business operator with the assistance of the local community. The business operator is accountable to the community but is a 'sole trader' and is entitled to retain all profits. In Thendo, a community energy committee was formed to operate the business, with all profits in the long term available for community benefit.

Each business operator was trained in the SOGERV monitoring evaluation and learning (MEL) protocols and given templates to record all income and expenses arising on a daily basis. At monthly intervals these were audited by the SOGERV team and uploaded to a central database.

The database of income and expenditure is analysed here and an assessment made of the performance of each business over a set trading period during 2017/18. Detailed financial information including itemized income streams and expense categories are analysed. A financial forecast is then projected for 10 years of operation to build a simple financial model for the long term business operations. All financial data is presented in local currency, Malawian Kwacha (MWK). At the time of writing the MWK:USD exchange rate was 730:1.

III. Results

A. Summary of Business Activity

The basic metrics of trading period, total income and total expenditure are set out for each business in Table 3. Figure 2 provides a summary of the total revenues for each business, categorized by the main product groups. The category 'other' covers additional sales and services, e.g. supplying small electrical components. It is immediately notable that the majority of revenues realized has been through PSP sales. However, Mandrade, the best performing business, has also recorded high revenues related to portable batteries.

Table 3: Summary of Basic Business Metrics

Business Metric	Mandrade	Kandeu	Gola	Thendo
Months in Business	19	18	11	11
Total Income (MWK)	9,013,212	2,577,358	2,815,395	2,935,648
Total Expenditure (MWK)	6,508,536	1,466,063	648,250	1,401,070
Surplus (MWK)	2,504,676	753,225	2,160,445	1,534,578

Figure 3 provides a summary of the total expenditures for each business, categorized by: restocking, staff costs, transport, operations and maintenance and 'other'. The kiosk O&M category includes all costs associated with operating, including land access, community payments and physical facility maintenance.

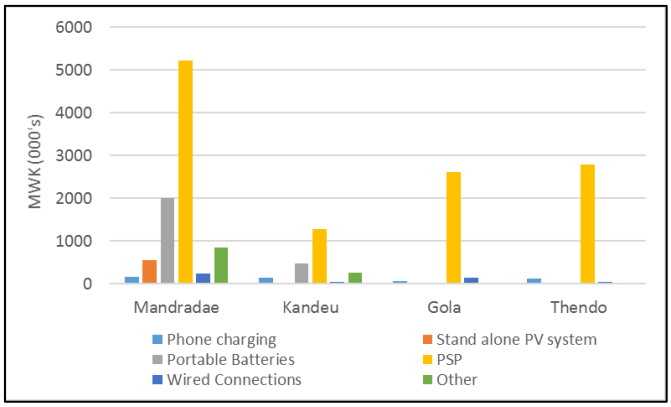

Figure 2: Summary of total revenue collected

As would be expected with the extent of sales from Mandrade, restocking is a dominant expense for that business. There does not appear to be a common pattern in the proportion of expense incurred by each business per category.

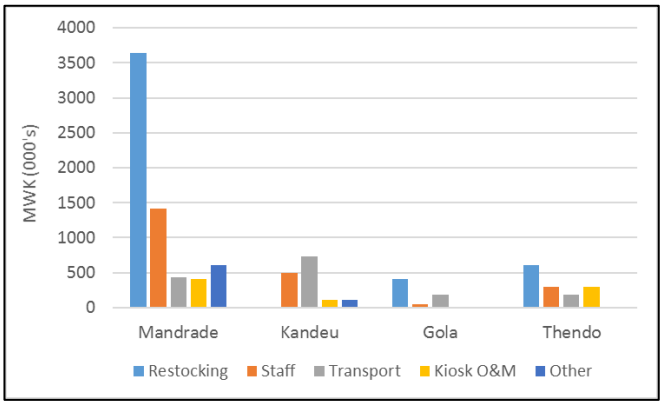

Figure 3: Summary of expenditures for main categories

In the following sections, the income and expenditure for the whole trading period of business commencement through to September 2018 is discussed in more detail.

B. Income and Expenditure

Table 4 and Table 5 show the detailed income and expenditure data for all four businesses.

Table 4: Business Income Streams (in MWK)

Income Stream	Mandrade	Kandeu	Gola	Thendo
Phone charging	163,632	147,468	63,750	122,198
Stand-alone PV system	553,000	25000		
Portable Battery sales	1,218,000	178,000		
Portable Battery rentals	783,950	303,600		
Portable Battery charging	51,300	43,070		
PSP sales	5,219,630	1,280,950	2,615,645	2,778,450
Wired Connections	237,000	350,000	136,000	35,000
Other electrical component sales	786,700	249,270		
TOTAL	9,013,212	2,577,358	2,815,395	2,935,648

Table 5: Business Expenditure Categories (in MWK)

Expenditure Category	Mandrade	Kandeu	Gola	Thendo
Portable battery stock	1,135,643			
Electrical components for resale	631,150			
PSP restock	1,875,200		409,600	611,200
Employee salaries	60,000	167,500	50,000	300,000
Transport fees	440,100	736,890	181,950	189,300
Physical facility maintenance	405,742	115,830		300,570
All other operating expenses	608,720	112,950	6700	
Commission	1,351,982	332,893		
TOTAL	6,508,537	1,466,063	648,250	1,401,070

1) Mandrade

Tables 3, 4 and 5 provide the overall income and expenditure metrics for Mandrade and Figure 4 shows the income and expenditure per month. The business has built up slightly in

excess of MWK 2.5 million cash in hand and has brought in over three times the income of each of the other four businesses. There are some months with very low income levels, but this does not initially appear to be a seasonal issue. Expenditure is quite erratic with particularly large expenses in January and April due to PSP and portable battery stock purchases.

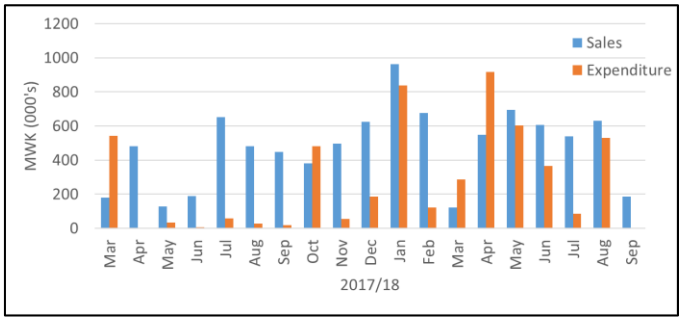

Figure 4: Mandrade Income and Expenditure Totals per Month

PSP sales dominate and are reported to be mostly 'rent to buy', paid up in instalments. 'Other' operating expenses includes a MWK 340,000 spend on a motorbike by the business operator. Rather than earn a salary, the business operator takes a 'commission' on sales, which fully constitutes their take home earnings and represents their incentive to participate. They also employ additional staff, shown in the table as 'employee salaries'. Physical maintenance includes community payments to cover land rights and permission to operate. Transport costs are dominated by motorbike rental and fuel.

2) Kandeu

Tables 3, 4 and 5 provide the overall income and expenditure metrics for Kandeu and Figure 5 shows the income and expenditure per month. The business has built up MWK 753,225 cash in hand. The business suffered a 5-month period of non-operation due to issues with the commitment and professionalism of the business operator. Eventually, this led a change in business operator. Expenditure records for the first 10 months had no monthly breakdown and were submitted as one figure for the total period. This has been represented as a pro-rata value in the figure. PSP sales dominate, and portable batteries and wired connections also provide a sizable proportion of total revenues. Overall, revenues are significantly less than Mandrade, yet transport costs and employee salaries are substantially higher.

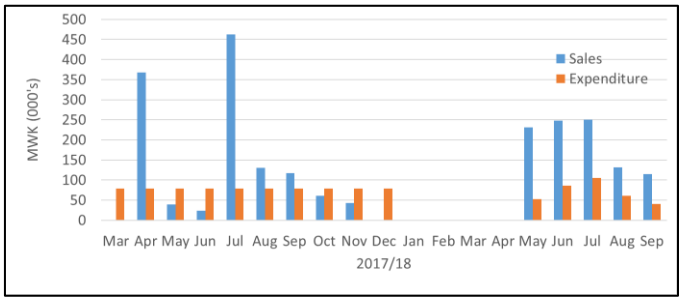

Figure 5: Kandeu Income and Expenditure per Month

3) Gola

Tables 3, 4 and 5 provide the overall income and expenditure metrics for Gola and Figure 6 shows the income and expenditure per month. The business has built up nearly MWK 2.16 million cash in hand maintaining regular sales through the period of trading.

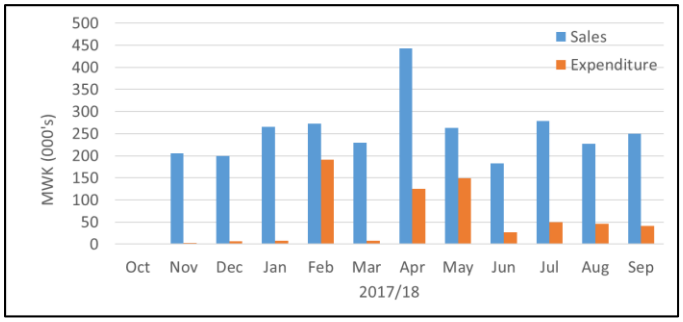

Figure 6: Gola Income and Expenditure per Month

Income streams are less varied than Mandrade and Kandeu. PSP sales dominate, and wired connections and mobile phone charging tops up total revenues. Again, overall, revenues are significantly less than Mandrade; however, expenditures are much lower than Kandeu. It is noticeable that no costs are recorded for physical facility maintenance (including community payments). It is reported by the operator that community contributions have been waived due to free provision of lighting systems to the local school.

4) Thendo

Tables 3, 4 and 5 provide the overall income and expenditure metrics for Thendo and Figure 7 shows the income and expenditure per month. The business has built up just over MWK 1.5 million cash in hand maintaining regular sales through the period of trading.

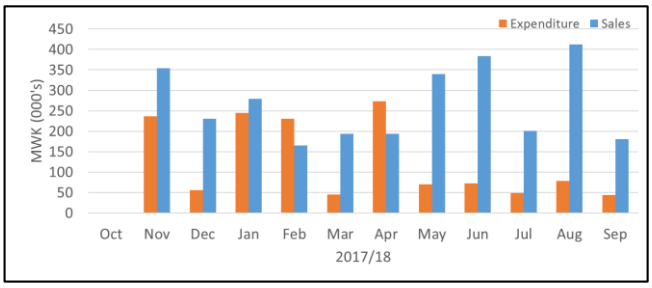

Figure 7: Thendo Income and Expenditure per Month

Similar to Gola, income streams are less varied than Mandrade and Kandeu. PSP sales dominate, and mobile phone charging tops up total revenues. There is a small wired connection income as these were installed in the later months of the trading period. Again, overall, revenues are significantly less than Mandrade and expenditures much lower than Kandeu. It is noticeable that no costs are recorded for commission or physical facility maintenance (including community payments). This is due to the model of full community ownership. Employee salaries are substantial as the community energy committee (comprising 10 people) take payment for their efforts.

C. Basic Financial Projection

The data presented in the section above is used here to make a simple 10-year financial forecast for each business (summarised in Tables 6 and 7). A 10-year time span has been chosen as this energy access solution is viewed as an interim solution for communities unserved by mini-grids or national grid in the short to medium term. The question motivating this project was whether an energy kiosk of this type (with grant funded start-up costs) could generate sufficient revenue to cover its operational costs and maintain the interest of the business operator(s) through providing sufficient financial return for their efforts. It is assumed that after 10 years, alternative, higher tier, energy access would be available and affordable to the communities and the kiosk business would be wound up.

Table 6: Mandrade Annual Sales Projection (in MWK)

Annual Sales	Mandrade	Kandeu	Gola	Thendo
PSP	4,175,704	1,707,933	2,853,431	3,031,036
Wired Connections	480,000	360,000	480,000	480,000
PV SHS rental	312,000			
Rent/Sale portable batteries	1,601,560	481,600	1,100,000	
Phone Charging	130,906	147,468	69,545	133,307
Battery Charging	51,300	43,070	51300	
Component Sales	422,000			
TOTAL	7,173,470	2,740,071	4,554,276	3,644,343

The basic approach is to calculate an average monthly income/expense for each category and then project this to an annual figure.

Table 7: Mandrade Annual Expenditure Projection (in MWK)

Expenditure	Mandrade	Kandeu	Gola	Thendo
Portable battery stock	908,514		785,714	
Electrical components for resale	397,500			
PSP restock	2,982,646	1,219,952	2,038,165	2,165,026
Employee salaries	120,000	120,000	120,000	327,273
transport fees	440,100	631,620	198,491	206,509
Physical facility maintenance	228,000	115,830	100,000	130,000
All other operating expenses	54,400		30,000	
Commission	1,076,020	411,011		
TOTAL	6,207,180	2,498,413	3,272,370	2,828,808

For PSP sales it is noted that the business started with a seed stock and the incomes reflect a payment by instalment model. Therefore, it is not possible to directly match income to expenditure and calculate exact profits from the available data. The cost of PSP stock is calculated using the knowledge that the business operators mark up the wholesale buy price by 40%. Although some portable battery stock is rented rather than sold, it is assumed that the expenditure recorded against portable battery restock is required each year to maintain the battery related income. For the wired connections, the number deployed and monthly rental income have both varied during the period. However, as demand has been reported as high and all businesses have been expanding their capacity to provide this service, a positive assumption is made that each business will maintain 4 wired connections at MWK 10,000 per month each. SHS system rental has only been established at Mandrade where it is assumed that 2 systems are maintained at MWK 13,000 per month each. A further assumption is that the average monthly PSP sales volumes for each business can be maintained year on year.

In Table 8 the capital replacement costs of the major technical components of the kiosk are projected over 10 years. These costs are based on the installation costs at the time of deployment. It is assumed that each of the main power electronic components will fail once during the 10 years, but the timing has been chosen arbitrarily. It has been assumed the batteries will also need to be replaced once during this time-span, at around the 5-year point. Further capital costs would be required (particularly for battery renewal) to enable continued operation beyond 10 years; however, that scenario is not being tested in this analysis.

Table 8: Charging Station Capital Replacement Cost Projection (in MWK)

Year	Battery Replacement	Inverter Replacement	Charge Control Replacement	Other Fault
3				300,000
4		700,000		
5	5,000,000			
7			1,000,000	
9				300,000

1) Mandrade Basic Finanical Model

In Mandrade, it is assumed that the business operator has one employee paid MWK10,000 per month, transport costs remain substantial despite motorbike purchase, and commission for the business operator is 15%.

The Mandrade projections from Tables 6, 7 and 8 are combined for a basic 10-year cash flow projection in Figure 8. Based on these figures, after 10 years, the business has MWK 3.9m surplus and the business operator has earnt just over MWK 11m.

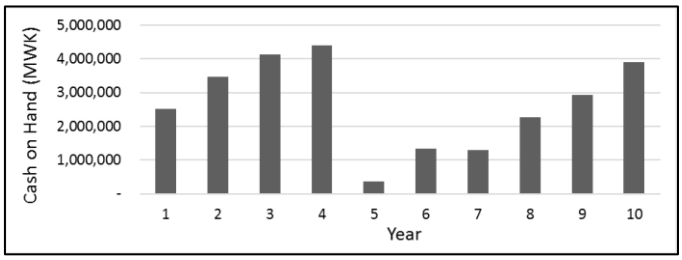

Figure 8: Mandrade 10 Year Financial Projection

2) Kandeu Basic Finanical Model

In Kandeu, it is assumed that the business operator also has one employee paid MWK 10,000 per month, transport costs remain substantial and commission for the business operator is 15%.

The Kandeu projections from Tables 6, 7 and 8 are combined for a basic 10 year cash flow projection in Figure 9. Based on these figures, after 10 years, the business has MWK 4.3m deficit and the business operator has earnt just over MWK 4m. Compared with Mandrade, Kandeu has an extremely bleak outlook. The business urgently needs to increase sales and reduce costs.

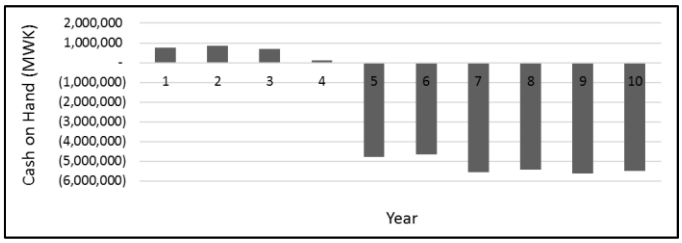

Figure 9: Kandeu 10 Year Financial Projection

3) Gola Basic Finanical Model

In Gola, a major assumption has been made on the inclusion of a portable battery business stream. This has been included as it is known that the business had established this service by November 2018. Whilst the proposed income is not based on sales data from Gola, the Mandrade data gives some confidence that the proposed sales could be achieved.

The Gola projections from Tables 6, 7 and 8 are combined for a basic 10-year cash flow projection in Figure 10. Based on these figures, after 10 years, the business has nearly MWK6.4m surplus that represents profit for the business operator.

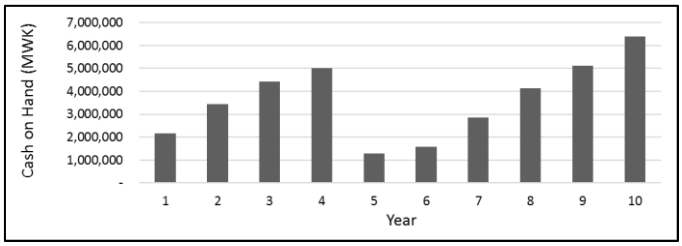

Figure 10: Gola 10 Year Financial Projection

4) Thendo Basic Finanical Model

The Thendo projections from Tables 6, 7 and 8 are combined for a basic 10-year cash flow projection in Figure 11. Based on these figures, after 10 years, the business has nearly MWK 500,000 surplus.

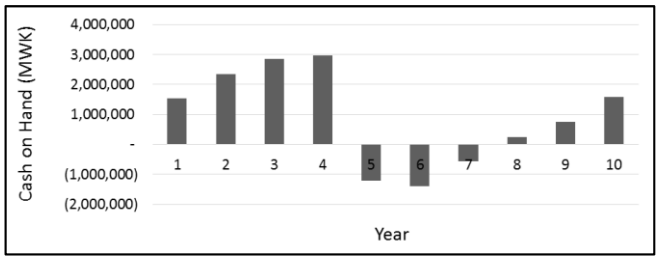

Figure 11: Thendo 10 Year Financial Projection

IV. Discussion

The financial data from the SOGERV project provides a mixed picture on the viability of the implemented solar kiosk businesses as a scalable model for meeting rural electricity needs in Malawi. As a donor subsidised project with multiple aspects of development involved in the provision energy access to these communities, a comprehensive economic analysis to evaluate the kiosk businesses in terms of return on investment has not been attempted here. The financial data collected from the four businesses has been analysed with the objective of providing insight on the potential revenues and likely costs of operating such energy access businesses in Malawi.

The franchise businesses of Mandrade and Kandeu provided both the best and worst examples. Kandeu has clearly suffered major setbacks and failed to establish a strong business. The superficial assumption here is that this has been due to the staff capacity and/or motivation. Although the 15% commission available has been reported by the Mandrade operator as agreeable (averaging >$100 a month which compares well to other locally available, comparatively well paid, jobs in health or education) it is possible this was not sufficient motivation for the Kandeu operator. However, other aspects of social, organisational and economic sustainability are likely to be involved, requiring a deeper investigation than our current data set enables.

The Gola business has shown potential to generate reasonably good revenues; however, the potential profit for the operator is less than the commission earnings forecast for the Mandrade operator and it is questionable whether this represents a sufficient incentive. Thendo shows less potential to create a significant surplus over 10 years; however, with the energy committee operators receiving a wage and also motivated by enabling a valuable energy service for their community, a surplus is perhaps not a requirement in this model. Although benefiting from no community payment requirements and low remuneration for the operating committee, Thendo's sales are low in comparison to the comparative trading periods of Mandrade and Gola. This may be due to lack of profit motivation from the committee. Thendo also will require the

availability of low-cost finance over 3 years to manage the battery refresh period.

Both Thendo and Gola businesses have brought in substantially less income than Mandrade and have less variety in income streams. Again, the project experience indicates that this is a result of a particularly dynamic and capable business operator in Mandrade but without further follow-up analysis, no strong conclusions can be drawn at this stage. Mandrade has shown potential to generate a surplus over 10 years in addition to providing commission to the operator. There is no indication of potential to generate sufficient surplus to recover start-up costs, so a social-return-on-investment, grant-funded, model would need to underpin any roll-out of Mandrade style kiosks.

Incomes from portable battery sales and rentals were substantial in Mandrade but seem to have been difficult to establish in the other locations. Given that these batteries are unprotected and will most likely be suffering deep discharge and poor environmental conditions, life expectancy and viability of this solution in the long term is a concern.

It is clear that PSP sales dominate in all businesses; however, a major assumption of the financial projections is that these sales can be maintained year on year, which may be unrealistic. The potential market depends on a limited number of relatively nearby customers. With the quality of PSPs improving, replacement after equipment failure generates only small long-term revenues. Retailing these products also requires a significant sales input by the operator. Given these factors, and that portable battery charging has the challenges outlined above, there is a question on whether the physical infrastructure investment required to deploy kiosks is justified.

The only other established income stream that requires the physical infrastructure is wired connections. However, under the current operating model, these do not provide sufficient revenue to cover long term maintenance costs on their own. This raises a question on whether the fee of MWK 10,000 per month is undervaluing the service. Also, could more wired connections be supported? Furthermore, should the business operator get commission for wired connection incomes where no ongoing sales effort is required?

Although these questions would need to be more thoroughly investigated in further work, the learning does point towards a simplified solution that optimises utilisation of the kiosk infrastructure. For example, taking the Mandrade example and replacing stand-alone PV SHS systems and portable battery charging with wired connections that are billed based on consumption. Assuming that over 10 years a similar surplus could be expected, there would appear to be potential for a sustainable roll-out of such a solution. The feasibility of such a roll-out would need to consider the asset-management model required to support a large number of kiosk businesses with operators working under commission. With the need for grant or social-return-on-investment funding, a social enterprise asset-management organisation would be a possible option [20]. A feasibility assessment of any scale up would also need to consider if the product offering and infrastructure design are optimal. For instance, given the extent of the demand for basic lighting and power services (currently being met mainly by PSP sales), would a solar PV microgrid be a more appropriate infrastructure deployment to meet this household demand plus serve a small number of local businesses. Alternatively, a PSP distribution business could be established without the physical kiosk and in 'hot-spots' of PUE activity a solar PV 'hub' could be deployed to meet local business demand.

V. Conclusions and Further Work

The financial records of four electricity access businesses operating solar PV kiosks in rural Malawian communities have been analysed. One of the businesses (Mandrade) has performed particularly well in comparison to the others, demonstrating that substantial revenues (in this context) can be obtained from such businesses. Revenues of this level create the potential for 10-year operations and maintenance costs to be met, commission paid to a business operator, and a net surplus to be created over the 10-year trading period. To the knowledge of the authors, this represents the first documented example of potential economic sustainability for off-grid electricity access solutions of similar focus and scale in Malawi. However, as shown by the data for the other three businesses analysed here, achieving the required revenue is challenging and, for all four businesses, subsidized start-up capital is required. In addition, a sustainable business model in excess of 10 years would need to account for further equipment replacement (particularly batteries) that would quickly erode any available cash reserves. Only one business demonstrated the potential to generate sufficient surplus for a battery replacement in year 10 (Gola) and doing so would eliminate the majority of the earning potential for the business operator under that model.

Overall, the analysis presented here does not provide strong evidence for like-for-like replication of this solution in Malawi. The data is derived from a small pilot project in one of the poorest districts of Malawi and there are significant variations in costs and revenues between the businesses. Follow up quantitative and qualitative research in each community is required to fully explore the reasons for these differences in performance. A more detailed economic analysis evaluating investment in similar businesses in other more affluent areas in Malawi would then be required to establish the opportunity for this solution to make a significant contribution to Malawi's SDG7 targets.

Nevertheless, operating in a challenging market, three of the four businesses demonstrated potential to continue operating for a ten year period, delivering improved access to modern, sustainable energy in their respective communities. Given the previous sustainability record of off-grid solar PV solutions in Malawi, this represents a positive development and the learning provides a platform for further refinement of technical solutions and sustainable business models for off-grid electricity access projects in Malawi.

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