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Estimating Mini-grid Demand in Malawi: Initial Findings from a Mini-grid Scale-up Assessment

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***Abstract*— Mini-grids and other Distributed Energy Resource (DER) systems are expected to play a major role in achieving sustainable electricity supply for the 580 million people currently lacking access in sub-Saharan Africa. Data for mini-grid planning is essential for sustainable business models and efficient technical designs; however, primary data in the African mini-grid sector is sparse, especially in Malawi. This paper presents initial case-study findings from ongoing work by Community Energy Malawi to initiate a roll-out of mini-grids in Malawi. Different data sources for estimating mini-grid customer consumption are presented and compared, highlighting the importance of quality datasets for planning and the need for greater efforts on data gathering and sharing in Malawi. With such data, informed decisions on tariffs and business planning can be made to improve financial sustainability for mini-grids.**

Keywords—Mini-grids, DER, SDG7, Rural Electrification,

I. INTRODUCTION

The United Nations Sustainable Development Goals (SDGs) include specific targets for energy access and deployment of renewable energy (SDG7), with the aim of ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 [1]. Tracking frameworks indicate that significant progress has been made in the last decade and the number of people without electricity access reduced from 1.2 billion in 2010 to 733 million by 2020 [2]. However, progress has slowed in recent years; estimates based on the current rate of progress indicate the 2030 target will be missed and 670 million people will remain without access [2]. There is also an access gap between regions. In sub-Saharan Africa (SSA) around 580 million people currently lack access to electricity and previous progress is being reversed as the number without access increased in recent years [3].

Mini-grids are decentralised energy systems that utilise Distributed Energy Resources (DER) [4]. By 2019, 47 million people in 134 countries were connected to mini-grids [5] and mini-grids are currently being positioned as a key solution for meeting the 2030 SDG7 targets in SSA [3] [6]. However, the mini-grid market in SSA is still nascent and there are significant barriers to mini-grids achieving their potential impact on energy access [7]. Establishing sustainable business models, even with grant-based capital funding, requires sufficient revenue is collected from customers in some of the poorest and most vulnerable communities where consumption is likely to begin at low levels [8] [9].

Implementing cost-reflective tariffs is a foundation of achieving sustainability; however, this may often not be permitted by local regulatory frameworks [10]. Even so, tariffs cannot be set based on developer costs alone. A sustainable business model requires an Average Revenue per User (ARPU) that ensures cost recovery but exists within a realistic range of customer Ability and Willingness to Pay (AWTP). However, forecasting these metrics when developing mini-grid projects for un-electrified communities is challenging and datasets are limited [8] [11]. Nevertheless, data from the African mini-grid sector is starting to emerge. A recent report provides information on costs, average consumption per user (ACPU) and ARPU from companies comprising an estimated 85% of the private sector developers operating in Africa with commissioned sites [12]. A key finding shows increases in reported ARPU overall, but particularly for mini-grids installed prior to 2019, with consumption increasing the longer customers are connected. Whilst useful, the aggregated nature of the data means it is not easily applied to specific project development needs. There is considerable diversity in ARPU due to local socio-economic demographics and the presence of high consumption anchor loads. Accurately predicting consumption and revenue remains a key challenge for mini-grid developers [13] and building local datasets is critical to supporting growth in the sector.

This paper presents initial case-study findings from ongoing work to plan a roll-out of mini-grids in Malawi. At the pre-feasibility stage, AWTP data has been gathered and analysed at 41 potential sites and compared with ACPU and ARPU data from an existing 80kW mini-grid. Section II describes the case-study and data sources, Section III presents the results from the analysis, Section IV discusses the implications for next steps and Section V provides conclusions.

II. CASE STUDY: COMMUNITY ENERGY MALAWI

Community Energy Malawi (CEM) is a Malawi Energy Regulatory Authority (MERA) licensed mini-grid developer, operator and renewable energy technologies supplier/installer. It is registered as an NGO with a subsidiary social enterprise, CEM Trading Ltd. The Sitolo Solar Mini-grid is an important pilot project in Malawi's nascent mini-grid sector, funded by UNDP, Global Environment Facility and Government of Malawi (GoM), with post-implementation support from Community Energy Scotland and the Scottish Government. CEM operates the mini-grid with the consent of the local community and GoM Ministry of Energy. Building on the experiences of operating the mini-grid since December 2019, CEM are pursuing a strategy of mini-grid scale-up to achieve their vision of energy access for all rural Malawian communities. They are currently undertaking feasibility assessment work across 41 villages in Central and Northern Malawi where MoUs have been signed with the communities. None of the villages are served by the national grid or mini-grids. The feasibility work is based on analysis of community surveys and learning gathered from the Sitolo mini-grid. Community energy access surveys were completed between September and November 2022. Enumerators asked a group of key informants from each village a set of questions designed to establish how energy was used by different demographic segments and the costs involved. Electricity top-ups at Sitolo are purchased as tokens from the CEM site agent and these payment records provide aggregated information on quantities of kWh consumed. This data has been analysed for the 2022 calendar year.

III. Initial Findings

A. *Ability and Willingness to Pay*

1) *Current Spend on Energy*

The representatives of each of the 41 mini-grid candidate communities were asked to estimate the average (across the whole village) household monthly spend on: total energy, lighting, and cooking. The results are summarized in Table 1 below. In general, lighting comprises around 30% of energy spend (mainly on dry-cell batteries for torches). Spend on energy for cooking was estimated at either zero or somewhere in the range $7-$20, based on the extent of charcoal use over firewood.

Table 1: Estimated Average Household Energy Spend

	Total Energy	Lighting	Cooking
Mean	$13.16	$4.50	$8.28
Mode	$19.02	$4.39	$0

There is a wide spread in the estimates for total energy spend. The majority sit within the $9-$21 per month range and few communities estimated more than $21 per month. A sizeable number estimated less than $6 per month.

2) *Estimated Spend on Electricity*

The representatives of each community were also asked to estimate the average willingness to pay (WTP) for three possible future mini-grid options: a household connection constrained to power for lighting and entertainment appliances, an unconstrained household connection and an unconstrained business connection. The results for a constrained household connection are shown in Fig. 1.

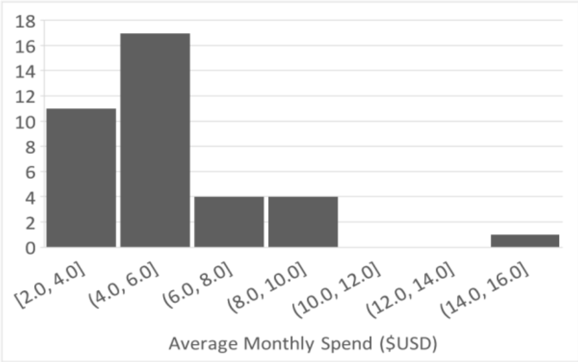

Figure 1: Histogram of Estimates of WTP for a Constrained Household from 41 off-grid Communities

Estimates for an unconstrained household connection are shown in Fig. 2. The majority of estimates are less than $30 per month and the average estimate was $11.35.

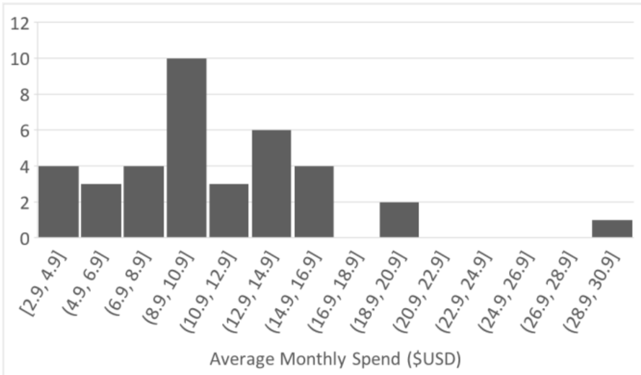

Figure 2: Histogram of Estimates of WTP for an Unconstrained Household from 41 off-grid Communities

Fig. 3 charts the estimates for business mini-grid connections. There is a greater range across these estimates ($4.9 - $48.9), with the average being $21.19. The mode is $19.5 with the most common response being in the range $13.9 - $19.9.

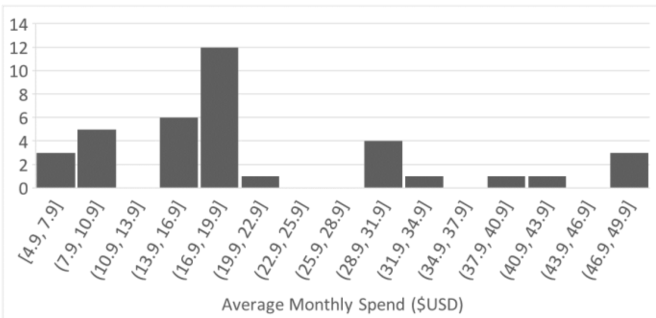

Figure 3: Histogram of Estimates of WTP for an Unconstrained Business from 41 off-grid Communities

B. *Mini-grid Electricity Consumption*

Customers connected to Sitolo mini-grid are classed as domestic, business, or social institutions. Analysis of the metering data revealed that total consumption from all customers in 2022 was 70,003 kWh. 12% of this came from 4 large business customers. 82.5% of consumption was from domestic customers, 17.3% from business customers and 0.2% from social institutions (Table 2). Domestic consumption is plotted in Fig.4, with the average being 83kWh per annum or 7.9kWh per month.

Table 2: Summary of Mini-grid Consumption and Average Spend

	Domestic	**Business**	**Social**
2022 Total Consumption (kWh)	57741	12087	175
Average Monthly Spend ($ USD)	1.35	6.27	0.28

Although domestic consumption outweighs business consumption by nearly 5:1, the business consumption is concentrated with a small number of customers.

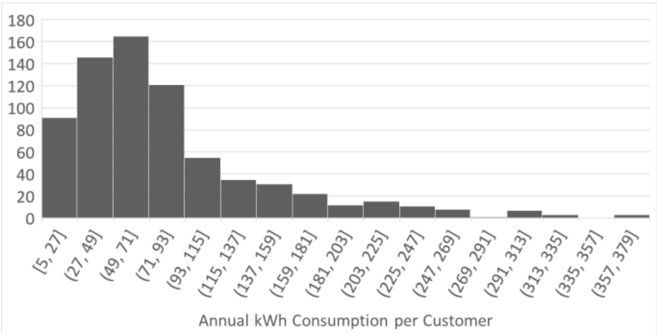

Figure 4: Histogram of Annual kWh per Customer for Sitolo Mini-grid

IV. DISCUSSION

When planning mini-grid developments, forecasting revenue is an essential stage of initial feasibility assessments and subsequent detailed financial modelling. In Malawi, the recently developed mini-grid regulatory framework allows for cost-reflective tariffs [14]. However, tariffs must be positioned carefully with respect to the AWTP of the communities to be served. For planning mini-grids in Malawi, developers have limited access to data on feasible tariff ranges; they can either survey the community, make an estimate based on regional industry averages, or utilise sparse data from the few mini-grids operating in Malawi. Table 3 summarises the data available to the CEM case study. The survey data indicates that estimates of existing household energy spend in the communities (ability to pay) are sufficient to support the estimated willingness to pay for mini-grid connections. However, the survey estimates are considerably higher than the evidence of actual spend at Sitolo mini-grid (e.g. a factor of 10 higher for unlimited domestic). The ARPU for all customers at Sitolo is also considerably less than the regional industry average ($1.57 vs $4.44). Both of these findings indicate that the Sitolo mini-grid tariffs (set prior to the establishment of the mini-grid regulatory framework) are at the low end of a feasible AWTP range.

Table 3: Comparison of Mini-grid Revenue Planning Sources

Data Source	**Monthly Spend ($)**
Survey estimate: existing household energy spend (no electricity connection)	13.16
Survey estimate: limited domestic	5.37
Survey estimate: unlimited domestic	11.36
Survey estimate: business	21.19
Sitolo Mini-grid: ARPU unlimited domestic	1.35
Sitolo Mini-grid: ARPU business	6.27
Sitolo Mini-grid: ARPU all customers	1.57
Regional Industry Average ARPU [12]	4.44

Further comparison against regional industry data provides additional insight to the data sources. The regional ARPU of $4.44 per month [12] corresponds to a monthly ACPU of around 6kWh and hence an average tariff of 0.70$/kWh. Applying this tariff uniformly across all customers at Sitolo would return an ARPU of $5.56. The survey estimates are not outside the range of mini-grid monthly ARPU reported by the industry [12]; however, they are on the higher end of the spectrum.

V. CONCLUSIONS

Data for mini-grid planning is essential for sustainable business models and efficient technical designs; however, primary data in the African mini-grid sector is sparse, especially in Malawi. Although community surveys provide useful insights to AWTP and demand for mini-grid services, it is likely that estimates on expected spend are over optimistic. Data on consumption from existing mini-grids in Malawi provide a different perspective, but where a low tariff (e.g. set to match national grid pricing) is in place, it is not clear if consumption would remain the same should a higher, cost-reflective tariff be applied. Regional industry data provides a perspective that can be used to offset these uncertainties; however, Malawi needs more mini-grid pilot projects and data sharing to grow a more localised data set that can support planning and contribute to the growing regional data. With such data, informed decisions on tariffs and business planning can be made to improve financial sustainability for mini-grids, accelerating their deployment and progress towards SDG7.

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