Opportunities and challenges for eCooking on mini-grids in Malawi: case study insight

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***Abstract*—Mini-grids are the least cost electrification option for over 30% of Malawi's population, and are expected to increase exponentially in deployment over the coming decade, however mini-grid developers face challenges in achieving sufficient income to ensure financial sustainability due to underutilised generation. Meanwhile, electric cooking is increasing in prominence globally and offers a low carbon and less harmful to health alternative to biomass, which is the predominate fuel source for cooking in Malawi. Powering electric cooking devices on mini-grids in Malawi has thus the potential to improve the profitability of mini-grids while offering increased environmental and social impacts. This paper explores the opportunity of eCooking on mini-grids in Malawi, drawing on key literature and case study data from piloting eCook devices on a hydro mini-grid in Mulanje through smart meter logging and social impact surveys. Technical analysis presents a statistical load profile and compares it to a modelled eCook profile from recent published literature, indicating lower eCook demand from the measured profile and the likelihood of fuel stacking. Case study findings are utilised to investigate the opportunities and challenges of eCooking on mini-grids in Malawi through technical and economic lenses, including the potential for carbon credits to positively impact mini-grid financial models. Recommendations are given to accelerate mini-grid eCooking in Malawi including demand side management, smart cooking subsidies, and further primary data analysis.**

Keywords—mini-grid, eCook, Malawi

I. INTRODUCTION: COOKING AND MINI-GRIDS IN MALAWI

Malawi has the third lowest per capita GDP (1) and fourth highest proportion of people living on less than $1.90 per day (2) in the world. 98% of the population rely on biomass fuels such as firewood and charcoal for cooking (3), while access to electricity is just 11%, reducing to less than 4% in most rural areas (4). Electricity is unreliable in grid connected areas due to blackouts from load shedding, exacerbated by recent critical infrastructure damages caused by tropical storms (5). The availability and use of other clean fuels such as liquid petroleum gas (LPG), ethanol and biogas is negligible (6). Deforestation and health impacts of cooking on wood and charcoal are recognised as national challenges and calls have been made to accelerate a transition towards modern cooking in Malawi to address the negative health and environmental impacts of biomass cooking.

Most energy policies in Malawi focus on improved cook stoves, with the National Energy Policy (7), National Charcoal Strategy (8) and Malawi Renewable Energy Strategy (9) mentioning modern cooking only briefly. The Malawi SDG7 cleaner cooking compact has targets for rural populations to phase out open fires through universal access to transitional, efficient wood stoves and urban populations to reduce the share of unsustainably produced charcoal and transition to alternative cooking fuels and/or sustainably produced charcoal by 2030. It has a further goal, that by 2050 there is a decreased share of non-renewable biomass through sustainable and regulated production and sourcing of a mix of cooking fuels including renewable biofuels (e.g. solid biomass, ethanol, biogas etc.), LPG, and electricity from renewable sources (10). While a strong focus is given to increasing access to electricity in these policies, electric cooking is rarely mentioned and LPG is considered the most viable alternative to biomass cooking in the medium term, with caveats acknowledging high costs, low demand and limited infrastructure to support a national scale-up of LPG cooking.

A Global Market Assessment for electric cooking was recently conducted by the Modern Energy Cooking Services (MECS) programme (11). The study set out to understand opportunities and challenges for a scale up of electric cooking in the Global South, drawing on the experience of a range of stakeholders to identify the key factors which influence the viability of a scale up of electric cooking, for three scenarios comprising national grid, mini-grid and off-grid (standalone) supported electric cooking. For mini-grids, Malawi ranked low priority, with a score of 119 out of 130. Key reasons for low scores included a low ability and willingness to pay and limited infrastructure (few existing mini-grids).

A more specific market assessment for modern cooking in Malawi (12) used household surveys and expert interviews to investigate cooking practices and understand the barriers and opportunities to the growth of the modern cooking sector in Malawi. Although the paper suggests the main opportunity for electric cooking is in urban areas and on mini-grids, findings highlight barriers to electric and LPG cooking around the weakness of existing infrastructure, lack of consumer willingness and ability to pay and resistance to the adoption of modern cooking devices. Household surveys demonstrated a diversity of cooking practices in Malawian households and that there is a latent demand for modern cooking in Malawi.

A growing evidence base suggests that in many settings alternatives to traditional biomass-based cooking such as eCooking are already cost-effective alternatives, with successful pilots being demonstrated in Tanzania, Kenya and Zambia (13). For many countries in the Global South with a

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strong enabling environment (including having access to affordable, reliable electricity and the presence of a strong, active modern cooking sector) a transition to electric cooking is already taking place (11). For Malawi to access the social and environmental benefits of electric cooking, these barriers must be overcome, and a suite of innovative business models and technologies need to be trialled, one of which is electric cooking via mini-grids.

Malawi's National Energy Policy has set the target to electrify 80% rural population and reach universal modern energy access by 2030 and is exploring both on-grid and off-grid solutions (7). Mini-grids are recognised as a key part of a portfolio of interventions to improve electrification rates, particularly in areas that will not be reached by the national grid in the near future, with a target of 50 mini-grid systems to be in place by 2025 (14). The context for and expected contribution from renewable energy mini-grids is reflected in several key policy and planning documents. The overall legal framework in the country adequately allows for the planning, development, operation, maintenance and utilisation of mini-grids in Malawi, although further enhancements are possible and institutions have not yet fully embraced the policies, as observed by licencing delays in the mini-grid sector (15). The addition of a Mini-grid Regulatory Framework, published in 2020 after extensive consultation, created a firm foundation for mini-grid development as well as private sector participation in developing this sector (16).

Mini-grids present a significant opportunity to both enhance energy access and promote private sector participation in energy delivery in Malawi. A recent market assessment suggested that solar mini-grids are the most cost-effective electrification option for 37% of the population (17). However, there is a lack of valid evidence in terms of impact and sustainability regarding mini-grids in Malawi. The country has seen a number of mini-grid pilot installations, including very small projects, containerised systems, community led projects and hydro mini-grid projects, with several case studies documenting challenge and lessons learnt that have contributed to the emerging sector. Past failures have been ascribed to lack of funding for sustained operations and system maintenance, quality of equipment or installations, limited community ownership and lack of local capacity for mini-grid technical and businesses aspects (15).

II. CASE STUDY ANALYSIS: MEGA

A. *Background to MEGA and eCooking pilot study*

The Mulanje Electricity Generation Agency (MEGA) built and operates the first mini-grid in Malawi, powered by 3 hydro-electric run of the river power stations with a total generation capacity of 220kVA and no energy storage (18). The mini-grid supplies over 1500 customers, with a reliable electricity supply at an affordable tariff of only 0.08 USD/kWh for non-commercial customers. Customers are mostly domestic including small holder tea farmers, artisans, and tea estate workers using electricity to meet their lighting and domestic needs, with some customers beginning to use the power for cooking. While in 2015 only 0.8% used electricity to meet their cooking needs (19), this figure rose to 4.5% in 2019 (20) without any outside interventions.

Between March 2021 and February 2022, atmosfair (21) conducted a pilot study on electric cooking in the MEGA mini-grid in Malawi, in order to understand cooking demand to inform their plans for leveraging carbon finance to support clean cooking in Malawi. 20 households participated in the pilot, each receiving an electric cooking set (a 1.5kW hotplate, pots and a heat retention device) along with two smart meters. While one smart meter measured total household power consumption, the other one measured only the consumption of the hotplate. The households were also interviewed on their cooking habits before and after receiving the electric cooking set.

B. *Technical findings*

The cooking data collected indicates high use of the hotplates in the beginning of the pilot project, as shown in Figure 1. This may be associated with excitement about the new device, which is sometimes called the honeymoon phase in clean cooking programmes. Hotplate usage then gradually declined over the course of the pilot project, but slightly picked up again in the beginning of 2022. The electricity consumption of other devices also fluctuated over the course of the pilot project and the cooking portion of consumption ranged between 50% in March 2021 and 22% in December 2021.

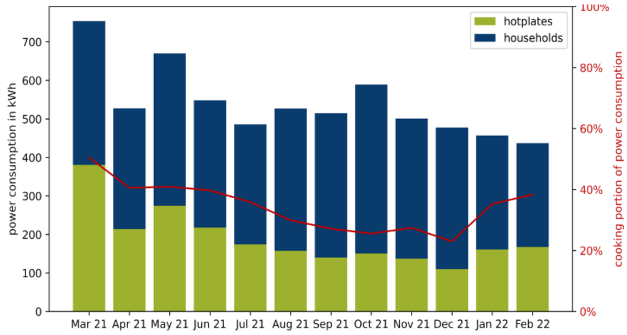

Fig. 1. Total household power consumption (blue) and hotplate power consumption (green) over time

The fluctuations of household consumption over the course of the pilot period may be explained with factors impacting both the supply and the demand side. Since the power generation capacity depends on the water levels of the river, supply shortages may occur at the end of dry season (August - September) causing blackouts and load-shedding. On the demand side, rural households in Malawi often experience a seasonality in income with harvest season around April or May typically marking the peak of household income and the months before that being known as the lean season. Singular events, such as for example a failure of the billing system for prepaid power units, which occurred in the MEGA mini-gird in April 2021, also affect power consumption profiles. For a detailed explanation of the observed power consumption, more data on household income levels and historic power generation data is needed.

A key observation from the collected hotplate power consumption data was that the majority of households consume less than 1kWh per day for cooking (see 2). This indicates that the households are practicing fuel stacking, as they are unlikely to meet their cooking energy demand with the observed hotplate usage. This corresponds to a world bank report which found that when using a mixture of conventional and energy-efficient appliances, cooking power consumption for an average household is 0.9–2.1 kWh (22). The hotplate being a conventional cooking device, the households in the pilot would be expected to be closer to the higher end of that range, if they were exclusively cooking with electricity.

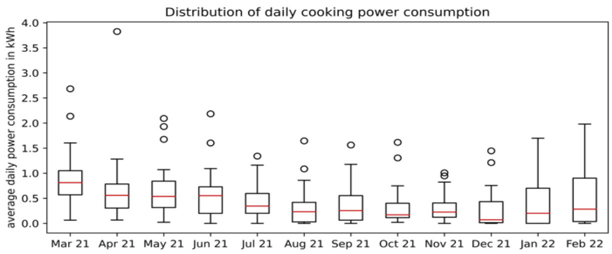

Fig. 2. Distribution of daily cooking power consumption

The study revealed large differences in hotplate usage between households, with the two largest consumers making up more than a quarter of total consumption. Both total household consumption and hotplate consumption were highest on Sundays and lowest on Mondays. Data on overall grid power consumption from MEGA shows that the beginning of the pilot project coincided with the highest electricity sales recorded.

A subset of the smart meter data from the initial 5 months was used to produce a statistical profile for a household with hotplate, as shown in Figure 3. An average daily load profile for the whole household and for the hotplate was calculated from the measured data, and an estimate of the baseline household consumption derived by subtracting the hotplate profile from the total. This provides an indication of the effect of eCook, bringing the largest peak earlier into the evening and creating two additional peaks during the day. The peak load value is doubled. Similar analysis of a larger deployment of eCookers with at least a full year of data would provide greater insight and move towards a profile that the MEGA grid operator could confidently utilise for higher eCook penetrations planning and adoption.

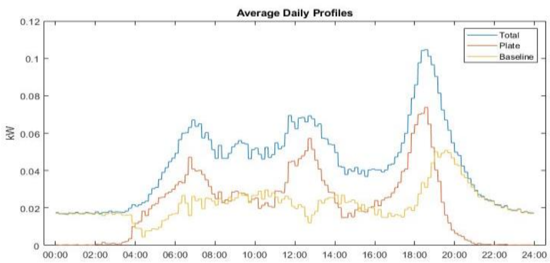

Fig. 3. Average Daily Profiles

eCook network impacts have been studied using a case study hybrid solar minigrid that connects 108 customers and simulated load data from the MECS project (23). As can be seen in Figure 4, the MECS profile follows the same peak pattern but is substantially larger. The MECS data used in (23) indicates that most houses with eCook are expected to be cooking 100% with electricity at the same time frame (where breakfast and lunch are cooked using a hotplate, while dinner is cooked on either or both a 1 kW hotplate and a 1 kW EPC).

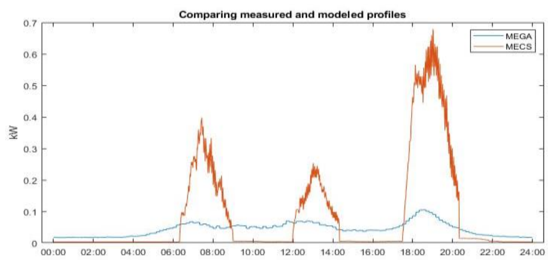

Fig. 4. Comparison of MEGA and MECS load profiles

Regarding electrical network constraints, the MECS study [22] found eCook penetrations above 20% created generation capacity constraints unless substantial diesel generation was added, and that the network would need to be designed to national grid loads, which is often not the practice of mini-grid developers who tend to expect for lower demand customers. However, as might be expected from the scale difference between profiles, running the analysis using the modelled data from the MEGA smart meters confirms few implications on technical performance, even for the worst-case scenario (100% eCook penetration where all 108 HHs are using a hotplate in addition to fuel stacking). This difference between simulated and measured data highlights the importance of contextually appropriate load models, reflecting local consumption patterns for mini-gird planning.

As the smart meters used in the pilot collect data with a time resolution of 5 min, more detailed information on demand spikes and usage frequency could have resulted from the pilot project. It was found, however, that users typically disconnected the hotplates and hard-wired smart meters from power whenever they were not cooking. As a result of this, smart meters had to reconnect to the server every time they were plugged in, which in many cases lead to a loss in timestamp information. This illustrates the challenges of gathering high quality data on ecooking and the need for further pilot projects.

C. Social impact findings

The average household in the pilot has 4.9 members, out of which 2.9 are adults and 2.0 are children. 84% of households indicated that the hotplate has changed who cooks in their household, with responses stating that cooking is now done by the husband or children. All households say that electric cooking has impacted their life positively, with positive impacts noted in safety, health, cleanliness, cost savings, ease and speed of cooking, and that it's a modern method of cooking.

The proportion of households cooking mostly indoors has increased after the households received hotplates, from 63% to 79%, while the hotplate has become the main cooking device in 89% of households. Additionally, the time of cooking as reported by the survey responses has shifted slightly earlier for breakfast and dinner, but remained the same for lunch. According to the survey, 45% of participants use the hotplate for heating water for bathing (daily or more than once per day) with one participant using both a kettle and the hotplate. 20% indicated they had a fault with the fuse, which was rectified.

III. Implications for wider mini-grid eCook deployment in Malawi

This section draws on the data and experience gained in the MEGA pilot, along with relevant literature and experiences of existing solar mini-grids in Malawi to assess the wider viability of eCooking on mini-grids in Malawi, in technical and economic themes.

A. Technical feasibility

The sizing and technical specification of components for mini-grids in Malawi is challenging due to uncertain demand and lack of load profile data from pilots. Under or over-sizing a mini-grid has implications on cost and technical sustainability, and moving towards clean cooking using mini-grid electricity potentially offers technical risks for mini-grids in terms of voltage drop, voltage unbalances, increased distribution losses and capacity shortages.

According to a recent paper investigating technical feasibility of eCook on solar diesel hybrid mini-grids (23), voltage drop and voltage imbalance issues can be reasonably and affordably addressed by using cables of a larger cross-sectional area. However, an issue exists prohibiting higher penetrations of eCook based on generation capacity requirements. The study calculated that a mini-grid comprising 30 kWp PV, a 9kW diesel generator, 41.4 kWh lithium ion batteries, 8 kW battery converter and 10 kW PV-inverter can accommodate around 20% of customers using eCook, but demand cannot be met as eCook penetration increases. For 100% eCook penetration, there is an energy shortage of 42%. Technical solutions proposed to reduce peak demand include battery supported eCook, with an innovative charging management concept to maximize daytime PV utilisation and offset peak demand.

The MEGA data suggests lower demand from eCooking than this study, but is likely due to fuel stacking. This implies that eCooking may be technically feasible in the short term, but as fuel stacking decreases and eCook loads increase, generation capacity of solar mini-grids will need to increase at additional cost to the mini-grid developer. For Malawi, where solar mini-grids offer one of the most scalable solutions to off-grid electrification, these technical challenges and proposed solutions will need to be integral to sustainable eCook planning.

B. *Economic viability*

Current mini-grid models struggle to cover operational costs, while unutilised energy, specifically daytime power for solar mini-grids, remains unused. Mini-grid developers are looking for ways to increase demand to improve system financial sustainability, with current strategies focussing on productive uses of energy in agricultural value chains to utilise daytime electricity. eCooking may present a solution to utilising surplus power, however it faces two major barriers. Firstly, at least for solar mini-grids, the availability of surplus energy is during the daytime, while peak cooking loads occur in the evening. This can be mitigated through the use of battery eCook devices, described above. Conversely, for hydro-power mini-grids off-peak night time use is an opportunity to level the demand curve.

Secondly, although time savings are offered through eCooking solutions, unlike agricultural productive uses of energy, eCooking customers are not making any additional income from the use of electricity, and therefore it comes at additional cost. Comparison of these costs with current spending on cooking fuel is necessary to assess consumer affordability. According to (23), for a 100% eCook penetration with a system size of 165 kWp PV, 110 kW diesel generator and 193.2 kWh battery, eCooking electricity costs would be approximately USD 24–30/month per consumer. Atmosfair's calculations for monthly eCooking electricity costs are summarised in Table 1, which suggest lower monthly costs of around 6 USD for a 6 person household, although the low tariff offered on MEGA is unlikely to be achieved on a solar mini-grid.

TABLE I. ELECTICITY COST OF ECOOKING ON MEGA

# people in HH	Av. Power consumption (kWh)	Monthly cost (USD)
2	29.5	2.02
4	59.0	4.05
6	88.6	6.07
8	118.1	8.09

Firewood is the dominant fuel in rural Malawi with many households gathering it for free. If Malawi were to protect public forests as mandated, a cost reflective biomass market would develop making eCooking more competitive, but firewood gathering customers are currently unlikely to achieve savings through eCook use. In peri-urban areas, which may reflect mini-grid aspirational demographics, households use a combination of charcoal and electricity, spending 2.46 – 7.38 USD per capita per month (12). **Error! Reference source not found.**2 shows current spend on cooking fuels at an existing mini-grid in Malawi (Mthembanji, Dedza) (24), indicating an Ability to Pay of around 3.69 USD per month. The cost for a 4 person household to use eCook on this mini-grid, based on the power consumption in Table 1 at Mthembanji tariffs would be 60 USD, an order of magnitude higher than the current cooking fuel spend, suggesting eCook may be affordable for hydro but not for solar mini-grids in Malawi. Additional to electricity cost is the cooking appliances cost, which is significant for a low-income household currently using a three stone fire for free. This may be overcome with appliance financing.

TABLE II. MONTHLY SPEND ON COOKING FUELS, MTHEMBANJI

Monthly spend (USD)	Firewood	Charcoal	LPG
Mean	3.79	3.51	3.69
Max	12.29	7.38	3.69
Median	3.69	3.07	3.69
n	51	17	1

a. conversion rate of 1 MWK = 0.0012 USD

C. *Financing eCook: carbon finance*

Opportunities exist to generate carbon credits through deploying eCook devices, resulting in reduced firewood and charcoal consumption and associated reduction in carbon emissions. However, appropriate methodologies allowing for the carbon certification of eCook activities are still under development. At the time of writing no other experience of mobilising carbon finance for eCooking are known to the authors other than the efforts of atmosfair with MEGA in Malawi. With additional income through carbon credits, to support appliance costs as well as subsidising electricity costs for the consumer, business models for eCooking on mini-grids will become more financially viable and attractive for mini-grid developers to scale. Further research is needed to justify how much carbon revenue is required to make eCook on mini-grids viable.

IV. CONCLUSIONS AND RECOMMENDATIONS FOR THE SECTOR

In order to combat deforestation, reduce the climate impact and address the health impacts of biomass-based cooking, Malawi needs innovative strategies that can work at scale. Mini-grids are offering a cost competitive, low carbon route to rural electrification, and enabling mini-grids to offer eCooking services would play a significant part to address these issues. This study has identified the current research and existing knowledgebase in the area of eCooking in Malawi and presented key data and findings from an eCook pilot on a hydro mini-grid in Malawi. Current challenges stymying eCook deployment have been identified as:

- Technical: current solar mini-grids don't have enough generation capacity to support 100% eCooking. Networks could experience voltage fluctuations and system power losses, particularly in mini-grids that are designed with small cross-section-area cables which are enough only to support the base-load demand. Future mini-grids will need to be adequately sized to cater for cooking loads.
- Economic: the additional costs of eCooking devices, as well as the electricity costs for cooking are currently unaffordable for customers. This shortfall needs to be covered through other methods such as smart subsidies.
- Carbon Finance offers a potential solution to the financial challenges of implementing eCooking on minigrids, however suitable methodologies for carbon certification of eCook activities are not yet fully developed and there is no simple route for project developers to access carbon finance.

The following recommendations are proposed to address these challenges:

- Conducting pilot projects: primary data is key for informing sustainable eCook scale-up through accurate technical design and business models. Robust data collection methods need to be tested to ensure high quality data outputs.
- Trialling cooking subsides: well-designed financial support to mini-grid developers would allow reduced tariffs, increasing eCook deployment and strengthening mini-grid business models.
- Research: several research frontiers have been identified, with key areas in technical design and business modelling highlighted for study to increase the knowledgebase on eCook in Malawi.
- Demand side management: the use of battery eCook devices offer potential to maximise the utilization of electricity in mini-grids with surplus daily power generation in order to accommodate increased eCook demand, without the need for a significant upgrade in systems or network reinforcement

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