MECS EForA study Report

Efficient AC cooker use and adoption validation for DC mesh networks.

Okra Solar

Date: 24th November 2021

This material has been funded by UK Aid from the UK Government and is implemented by the Foreign and Commonwealth Development Office; however, the views expressed do not necessarily reflect those of the UK Government.

Document Control:

Issue Status	Authors	Reviewed By	Loughborough University Approved By	Issue Date
Draft version	Emma Best and Otteh Edubio	Jane Spencer, Simon Batchelor		24 November 2021
Final version	Emma Best & Otteh Edubio	Simon Batchlor, Jane Spencer	Jane Spencer	December 2021

Contact Details:

https://okrasolar.com/

Executive summary

Project Aims

There are approximately three billion people who do not have access to clean cooking. This leaves households reliant on inefficient biomass stoves that expose individuals to harmful air particles, killing 4 million people annually and contributing to the eradication of local forests and global climate warming. Simultaneously there are approximately 800 million people who do not have access to electricity due to living in areas that are prohibitively expensive to electrify through traditional means using the national grid. These two problems have spun separate industries using a variety of independent solutions in an effort to achieve Sustainable Development Goals before the year 2030.

This study tests off-the-shelf Alternative Current (AC) e-cooking Appliances (rice cookers, airpots and blenders) which are very accessible to even the most remote of households on Okra Solar's DC solar mesh-grids. The mesh-grid is Okra's micro-grid variant solution for providing Tier 3 - Tier 5 off-grid energy on the multi-tier energy framework, (attribute dependent) to the most remote of communities cost-effectively. In addition, this study collects data on the adoption of the appliances and user behaviour of households under different energy tariff frameworks.

Findings

AC e-cooking appliances with power ratings that do not exceed the capacity of the Okra Solar mesh-grid system (1.2kWh) were compatible with the DC system.

Participants were keen to adopt clean cooking. 84.7% of participants noted they saved time due to having access to the e-appliances. 67.2% stated they now spent less money on fuel, due to solar energy access. Over 50% of households utilized their appliances over 1.5 times per day showing that users found real value in what was provided to them.

This study also depicted that overall use of energy was significantly higher due to the provision of the e-cooking appliances compared to simply providing households with access to electricity. Consumption of energy more than doubled when given access to e-cooking appliances. However, adoption of the appliances and the provided service after the study was completed was very dependent on the energy tariffs. Where energy costs were high, heads of households were dissuaded from adopting their appliances and the overall service even after acknowledging all the benefits.

Okra's Appliance Financing infrastructure, which enabled the costs of the appliances to be spread over individual days, meant that a household would pay 10c per day over a 340 day period. and the fact that it would get automatically deducted every time the system billed them for energy was very attractive to households and led to instant adoption of Appliances within the community of attractive energy tariffs.

Key Takeaways

The findings in this study provide a glimpse of how a holistic approach to tackling clean cooking and the lack of electrification problems could lead to a more realistic trajectory as 2030 nears. Combining e-cooking off-the-shelf Appliances with electrification projects reduces the dependency on custom-made appliances. This means no more high-learning curves and supply chain issues whilst driving up the demand for energy, bringing down the payback period of the electrification project. This effect is amplified when mesh infrastructure like Okra's platforms are utilized which brings down the cost of electrification and brings in additional features such as Okra's unique Appliance Financing system.

Contents page

1. Introduction

The need to cook food before consumption is a basic daily need for all humans. The ability to cook food "cleanly" has positive impacts on health, resources and lifestyle. There are approximately three billion people who do not have access to clean cooking.[1] Affected people are dependent on the burning of solid biomass (woods, sticks and dung) using open fires and inefficient traditional stoves to create the energy/heat needed to cook. The practice is highly inefficient in that a lot of fuel needs to be collected or paid for relative to what is consumed for cooking. In addition, the burning of biomass fuel releases toxic substances that cause 4 million annual deaths per annum.[2]

The general approach to increasing clean cooking adoption is around the provision of more efficient, custom stoves, known as improved cookstoves that have higher fuel efficiency. The idea is that doing so ensures that less biomass needs to be collected & more of that fuel is converted into energy for cooking and releasing less pollutants. Other strategies are driven by the provision of access to cleaner fuels e.g. fuels processed from waste into Pellets or briquettes, Liquid petroleum gas (LPG) and electricity. However, some tough barriers to adoption are:

1. Every market is different and it is difficult to provide a one-size-fits-all solution that meets all users demands
2. Distribution and supply chain issues associated with the provision of the fuel or providing adequate after-sales service.
3. High Initial cost of clean cookstoves
4. Lack of cohesive vision or approach to resolving this problem and instead segmented approaches that divert resources.

Cambodia

In Cambodia, where this study was conducted, 80% of the rural population do not have access to clean cooking. Most rural Cambodians spend 20.3 hours collecting wood per week and 1.5 hours a day, cooking with wood or charcoal. Reasons for cooking with these fuels include low cost, reliability, accessibility and preference. This behaviour has driven the loss of 33.6% of forest cover over the last 40 years.[3]

[1] Cleancooking Alliance - 2021 Clean Cooking Industry Snapshot
[2] WEO - 2017 Special Report; Energy Access Outlook, International Energy Agency, 2017
[3] Landscape Analysis Cambodia- MECs

LPG is a somewhat successful clean alternative in Cambodia. The majority of urban & peri-urban households and 18% of rural households use LPG & Gas stoves as their primary cooking fuel. The main appeal of LPG in Cambodia is convenience. However, the lack of regulation and resulting occurrence of dangerous fatal incidents have created a perception that LPG is not safe and this is hampering further adoption. In addition, the cost per kg of LPG on the last mile is prohibitive to full adoption.

Electricity however is a space that has a lot of potential, especially in Cambodia. Cambodia is seen as a success story in electrification with over 95% of the country's population having access to at least one source of electricity. The government in Cambodia has set electrification as a national priority and aims to provide 100% of villages with grid-quality productive electricity.[4] This holds a lot of promise for the clean cooking space as well, assuming sufficient reliable energy can be provided for the most remote communities to leapfrog LPG straight into e-cooking.

Okra

Okra's mission is to bring reliable productive power to the 800Mn people currently living off-grid and Okra has been working to achieve this in Cambodia since 2018. The goal is to succeed at electrifying these communities through the use of Direct Current (DC) mesh-grids, also known as decentralized mini or microgrids. These mesh-grids provide 1.2kW of power to every node in the mesh/every household at as little as 50% of the cost of an equivalent traditional or centralised mini-grid. The cost reduction is due to the decentralised nature of the mesh-grid infrastructure. Even though it is an electricity network comparable to traditional grids or microgrids, the majority of power is consumed where it is generated. This means that transmission costs, the costs to deliver the power from the point of generation to the point of consumption, can be reduced by up to 90% and generation and storage can be better tailored to demand, reducing overall costs. In addition, Okra's mesh-grid can interconnect with mini-grids and the national grid, enabling sustainable infrastructure. This study is an opportunity to investigate the synergies between Okra's affordable electrification technology and clean cooking adoption.

[4] Cambodia beyond connections World Bank 2018

Figure 01: Okra Cambodia Manager presenting to community

How the Okra System works

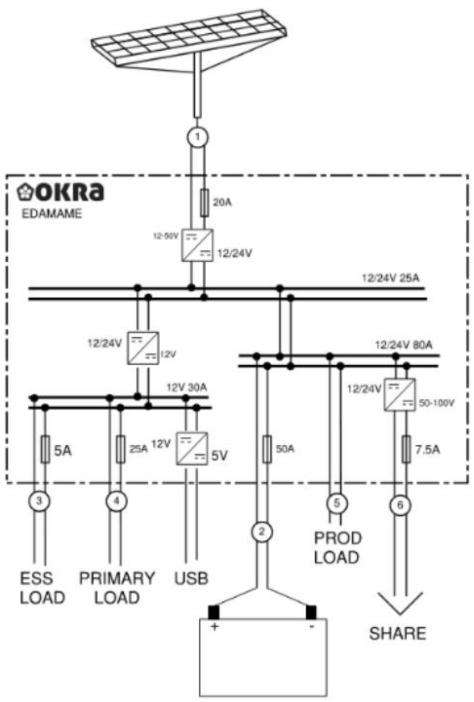
The Okra controller is a smart device that is installed in each home of an Okra network in addition to Battery & Photovoltaics.

It performs three main functions:

1. **Solar Charge Controller** - using a Maximum power point tracking algorithm (MPPT) to charge and maintain the health of connected batteries.
2. **Internet of Things (IoT) Remote monitoring system** - the Pod sends performance and billing data to the cloud continuously using cellular networks and that data is accessed through the Harvest Grid management platform.
3. **DC Sharing** - the pod makes decisions about when to send power to and receive from a network of other pods it is linked to.

Households in an Okra Network have access to 600 W / 1200 W of DC power by plugging into their Okra Pods through a 12V / 24V Load Port as shown in the basic wiring diagram in Figure 2. They are provided with more generation and storage capacity by the interlinking of pods which allows 300 W of power to be shared. Households electrified with Okra are provided power on an Energy-as-a-Service basis. This means they are not leasing to own but instead just pay for the Energy access. These systems are designed to be connected to form a network and this model ensures that developers who deploy these networks are incentivized to keep the network operating smoothly & sustainably.

Before this study, Okra Networks had only been set up with DC Load output, meaning Okra households could only use DC Appliances with the power provided. The use of DC Appliances with renewable energy sources like solar is considered energy efficient as there is no need for an Inverter. However, as national grids across the world are built to have an AC output, the Appliance supply chain globally is primarily built around AC Appliances. This becomes an issue when electrifying the most remote of communities, because the Global DC Appliance Supply chain is not as developed. Enabling the compatibility of the mesh-grid with AC e-cooking appliances may lead to enhancing the adoption of e-cooking in the most remote of communities.



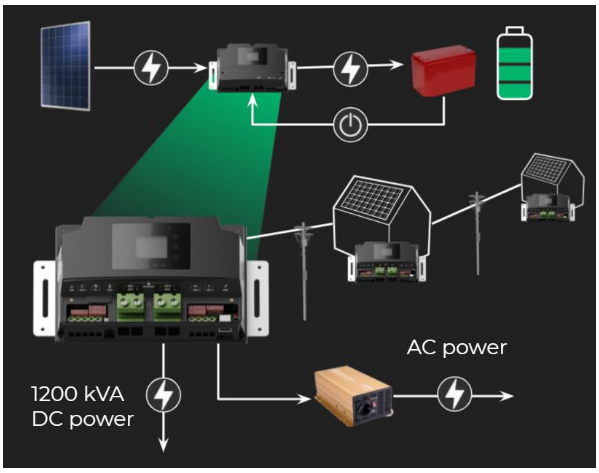


Figure 02: Simple line diagram of Okra pod (left), Schematic of Okra installation (right)

2. Approach

Selection of e-cooking Appliances

The approach to e-cooking selection was to offer households the opportunity to determine what they were interested in and then to determine from the list of their demands which appliances would actually work with the Okra mesh-grid. The choice was between:

- Rice cooker
- Electric Pressure Cooker (EPC)
- Induction Stoves
- Electric Stoves

ensuring households would be able to cover the spectrum of their cooking needs.

Figure 03: Appliance confirmation site visit (Left), Mrs Keo saying how much she would charge for her smoothie on a test setup.

Mrs Keo (seen above) noted "We want appliances, like people in the city. But I cannot afford the electricity, my battery is no good to power the rice cooker or blender"

Controlled Testing

The initial survey led to a reshuffling of appliances based on the communities. All the appliances were off-the-shelf, meaning they were designed to be used with the national grid, i.e. 220 V- 230 V AC. It was hypothesized that by setting lower voltages the product may still function adequately but consume less power overall.

The test voltages selected were: 110 V AC, 160V AC and 230 V [Performance Specification]

Label No.	Test Equipment
1	24V 150Ah LiFePO4 Battery
2	Variac Transformer
3	Inverter (MSW/PSW)
4	Okra Pod
5	Test Appliance

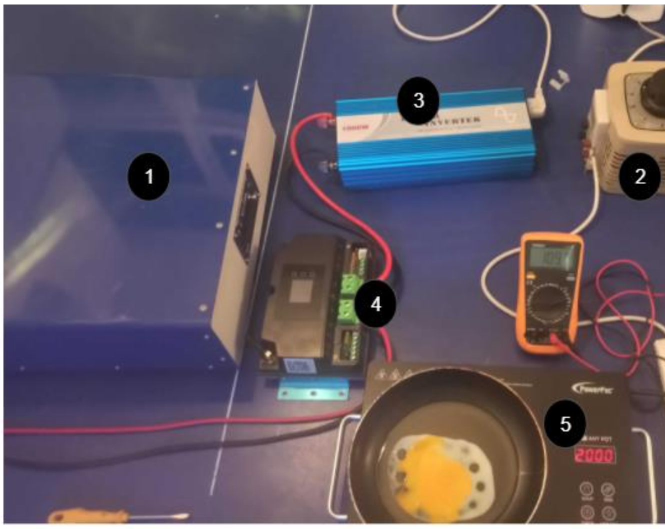


Figure 04 : Controlled Test Rig Setup

The testing setup was as shown in Figure 04. The Okra Pod draws power from the battery and outputs through its load port to the inverter to which an appliance is connected. The pod would communicate all data to the Okra Harvest platform.

Five inverter types were tested as part of the study:

- 12 V DC to 110 V AC Inverter (Modified Sine Wave) - Imported
- 24 V DC to 220 V AC Inverter (Modified Sine Wave) - Imported
- 24V DC to 220 V AC Inverter (Modified Sine Wave) - Locally Sourced
- 24V DC to 220 V AC Inverter (Pure Sine Wave) - Imported
- 24V DC to 220 V AC Inverter (Pure Sine Wave) - Locally sourced

The Inverters regulated the amount of voltage each appliance would receive. It would prove difficult to source a 12V/24V DC to 160 V AC locally and so for testing purposes a Variac Transformer was used instead. The Variac would be connected at the AC Output end of the 230 V Inverter and then would step down the voltage to 160 V. A multimeter was used to ensure precise Voltage measurements.

The main variables in each test were:

- Appliance [6] - *Rice Cooker, Airpot, Blender, Kettle, Electric Stove, Induction Stove*
- Voltage [3] - *110V, 160V, 230V*
- Inverter type [2] - *MSW, PSW*

The measured outputs in each test were:
- Maximum Power drawn
- Energy consumed for one use
- Duration of one use

The ultimate goal was to select the most cost-effective and practical combination of variables that would minimise the power consumption and therefore the amount it would cost remote households to use the appliance, whilst maintaining an acceptable user experience as deemed by the tester.

Field Testing

> *Mrs Sreypov noted, "I am very scared to use electricity and worry about electricity shock. So I do not use my power. But my daughter is coming back from the city and she will teach me how to use it."*
>
> *Comment received upon inquiring when a lady was not using her power*

Field testing was also required to test the appliances that passed the controlled testing in real application. The questions the field test was meant to address were:

- Was the Okra system, and AC appliances able to meet the needs of the users?
- How often were people using their energy system per day?
- Community's willingness to adopt e-cooking appliances.
- Impact of the households due to adopting e-cooking appliances.

At the start of the field-testing households were provided several group training sessions on how to use their appliance of choice as shown in Figure 05. A simple Appliance Manual was produced to enhance understanding and more specifically to encourage the utilization of rice cookers to cook other Khmer meals than just for cooking rice. This document is captured in Appendix VIII in English and Khmer.

Figure 05: Images from the different Training events performed in each community

In addition, guidance was provided on the concept of Energy Allowance and how Okra's appliance financing would work. Households were instructed that their billing would occur at midnight every day during which their appliance payment would occur. In the case of a rice cooker this would mean that every midnight 10c would be deducted from any amount they have topped - up on top of the billing for their energy consumption which would depend on the tariff. The appliance billing would continue for the entire financing period which was 340 days in the case of the rice cooker.

Data Collection

The Okra pods are collecting data and transmitting it to the cloud. All this data is stored on a cloud database and is then distilled and presented on our Harvest Platform. A team would review the data three times a week to make sure that people were using the equipment and if they weren't it was not due to insufficient training and also to make sure that the Okra system was providing adequate power for participants to be able to use their systems. A weekly catch-up to discuss replacements of any broken equipment and to resolve any issues with the system that may be hindering the study was undertaken.

Figure 06: Mrs. Moeurn going through the Baseline Survey

Survey Data

In addition, surveys were performed. A baseline survey was conducted to capture information of all participants along dimensions that could potentially be affected by the provision of the appliances to potentially capture a change. At the end of the field testing, an endline/satisfaction survey was conducted to access the data. The baseline and endline survey templates can be found in Appendix II & IV.

The dimensions for the survey were:

- Income
- Who does the cooking
- Time of cooking
- Frequency of cooking
- Means and Fuel
- Cost of Fuel
- Location of Cooking
- Duration of Cooking
- Wood collection
- Sources for electricity
- Cost of power

Site selection / Energy Tariffs

The site selection for the study was driven by a need to gauge the impact of tariffs on adoption of the selected e-cooking appliances.

To test this aspect communities on both ends of the cost-to-energy spectrum of electrification projects were selected. Private vs. publicly funded electrification projects have different priorities in output. Government-funded projects are typically politically driven to minimise the cost of power typically at the expense of product reliability and sustainability. Privately funded projects aim to maximise the cost of power to reduce their payback period and make profits sooner. We ended up selecting the following three communities to test those variables. All communities were extremely remote with no grid access.

Figure 07: **Steung Chrov Village** in Kampong Preah Korki Commune, Boribo District Kampong Chhnang Province [Publicly funded]

Village one was a greenfield site that was soon to be electrified by the Ministry of Mines and Energy (MME) as a pilot using the Okra Technology. The MME had stipulated that the cost for energy be comparable to the grid in the cities, even though this community was on an Island.

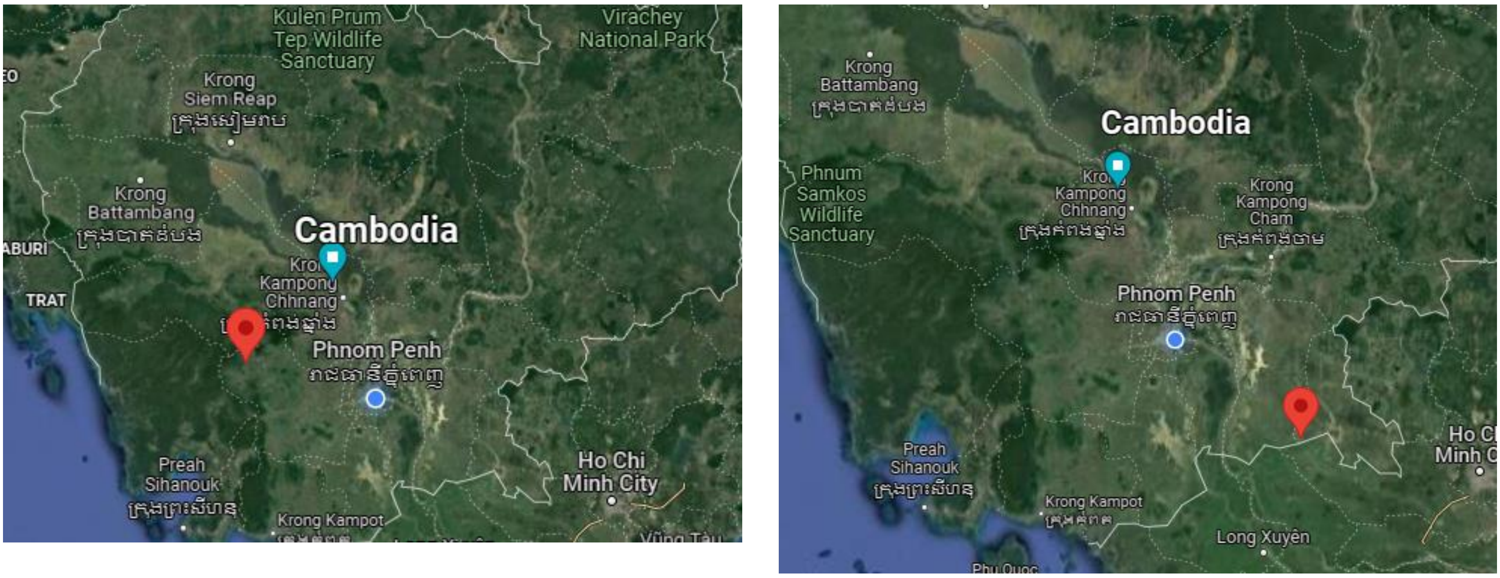


Figure 08: (Left) Village two: **Kbal Damrei Village** in Tropiang Chor Commune, Oral District, Kampong Speu Province [Private Network] (Right) Village three: **Svay Rieng** in Svay Chrum District, Svay Rieng Province [Private Network]

Village two and three were already using Okra's DC Networks, owned and operated by a local company. For the private entity to cover the cost of generation and storage required to electrify this community, households were charged higher rates.

Breakdown of cost per energy for selected villages.		
	Private ($/kWh) Kbal Damrei and Samroung	Public ($/kWh) Steung Chrov
Average cost per kWh	>0.75	0.15

Table 1: Differences in tariff cost between Private and Public Energy Networks

Distribution

Distribution was a cause for concern because it would be inconvenient to have to make offers to the community that would not be accepted and then having to negotiate on a case-by-case basis which would lead to confusion and breaching the community's trust in the study. For this reason, 2 offerings shown in Table 2 were prepared that would enable data collection on households' willingness to purchase the e-cooking appliance whilst providing an alternative option to ensure data on the e-cooking appliance functionality and use could still be collected. These were presented during a Launch event with raffles and getting local community leaders and key community nodes involved for maximum effect.

	Phase 1	Phase 2
Cost	Purchase Cost + 30%	Free
Installation Cost	$7.5	No
Limit to appliances	No	2
Okra system + Inverter	Free	Free
Financing	Yes (12 months)	N/A
Ownership of Product	Yes	No (return at the end of testing period)
Extra	No Cap (pay for everything you use)	Capped at $5 per month

Table 2: Distribution Strategy for the Study in two phases

3. Presentation of Results

Figure 09: Images from the installation process (left), Installed pod within a customer house (right), Map view of installation on Harvest Desktop (bottom)

Overall, the project ran for over 6 months during which 140 Households were installed in Stueng Chrow of which 45 households would join the study. The total cost per connection of each household was approximately $800, this price covers the cost of the photovoltaics, batteries, inverter and Balance of System components (such as poles for the shareline, cables and miscellaneous consumables). This number does not include the appliances. The communities in Kbal Damrei & Svay Rieng were upgraded in January 2021 to enable them to use the appliances.

Figure 10: Fully installed household in Stueng Chrov

Out of the 75 households participating in the study, 75 households partook in the baseline survey and 74 in the endline survey. To conduct the survey, adult members of the household were surveyed, 64% of survey participants were female. From the baseline survey to the endline survey we were able to maintain the same participants for 66 of the interviews.

Reason for partaking

Participants were asked about their reason for buying the appliances. Analysis of the dominant reasons for accepting the appliances will help increase understanding on how the community members perceive the appliances and what aspects of the appliance they find most beneficial. This question was asked with multiple choice answers and the ability to add additional answers, Figure 12 highlights the results of the findings. The dominant answers are that it improves my standard of life, is easy to use and time-saving. Interestingly only one respondent answered it would save them money, even in the communities where the appliances were offered to them for free, highlighting that community members have not been informed on the long-term cost-saving benefits of electrical appliances. Moreover, only one household mentioned they selected the appliance due to its positive impact on health - highlighting either a lack of importance placed on the benefits of clean cooking to health or a lack of knowledge accessible to the community on the dangers of high-pollutant fuels such as kerosene.

As shown in Figure 12, some answers given include VIP guests, No Idea and Get Special promotion. The free trial of appliances to SC and KD appliances were offered to village chiefs and other authority figures within the community to maintain good relations between Okra Solar and shareholders within the community.

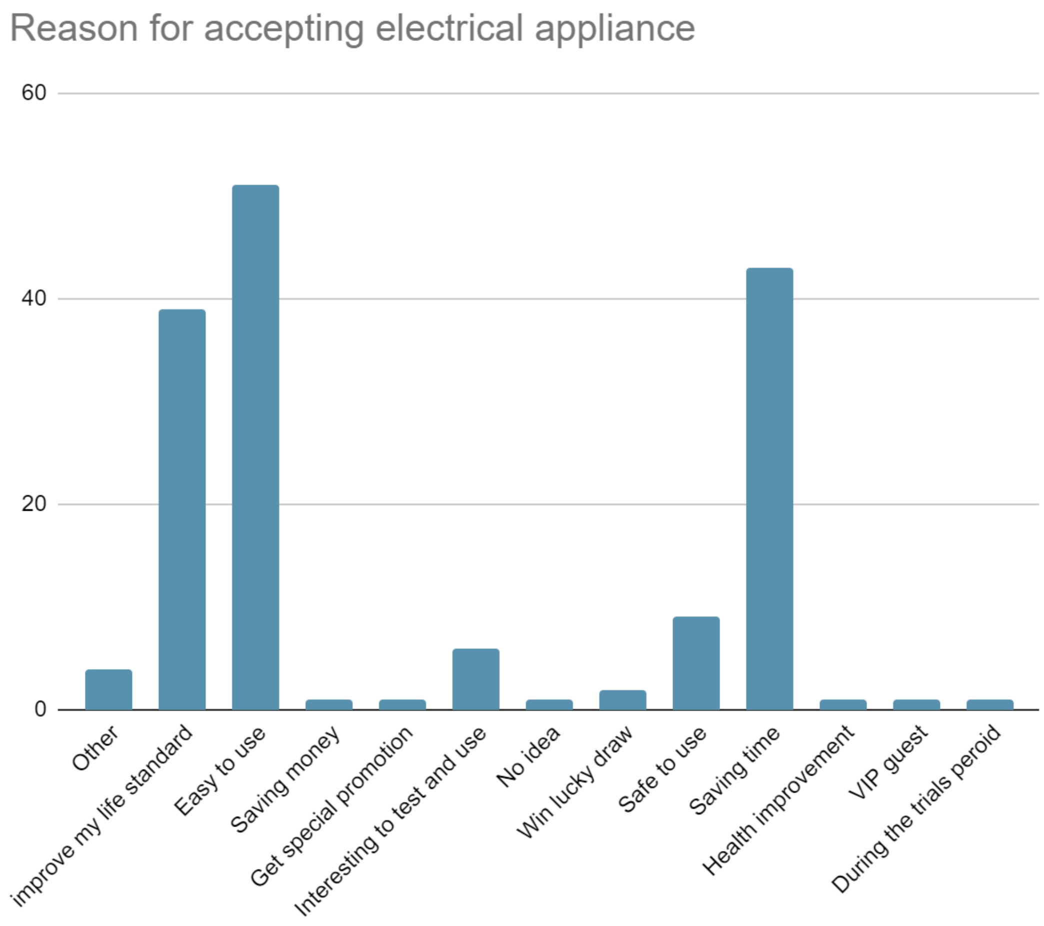


Figure 12: Reason for accepting electrical appliances

Demographics

Household sizes were varied with the average size being four. Figure 13 highlights how large households in the community can be, with 17 people being the largest household in the study. An average of two adults per household were working and receiving an income. With only one household in the study having 7+earners, this highlights the high level of dependents within households and the importance of steady income for the breadwinners. Only 28% of households had grandparents living in the homes. Out of the 75 households studied, 58 had children between the ages of 1 and 15-years old living in the home. Figure 14 showcases the breakdown of children within households, two children were the most dominant number of children to have, closely followed by zero children

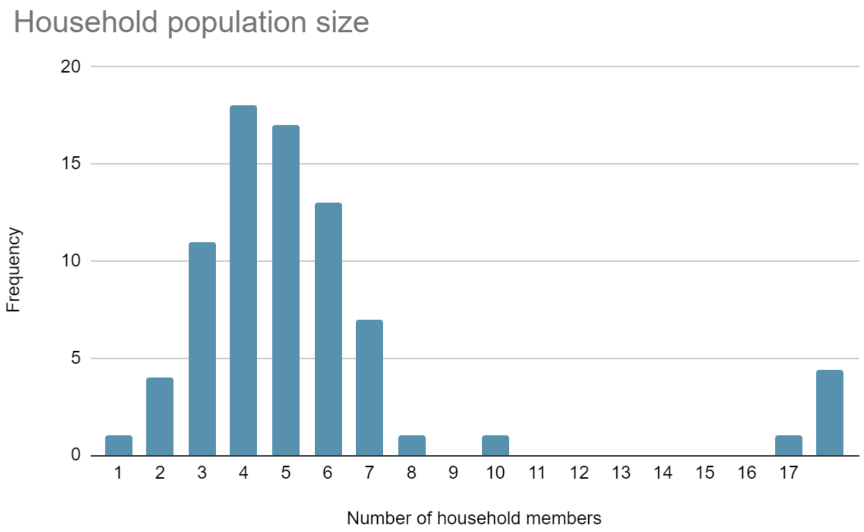


Figure 13: Household population size

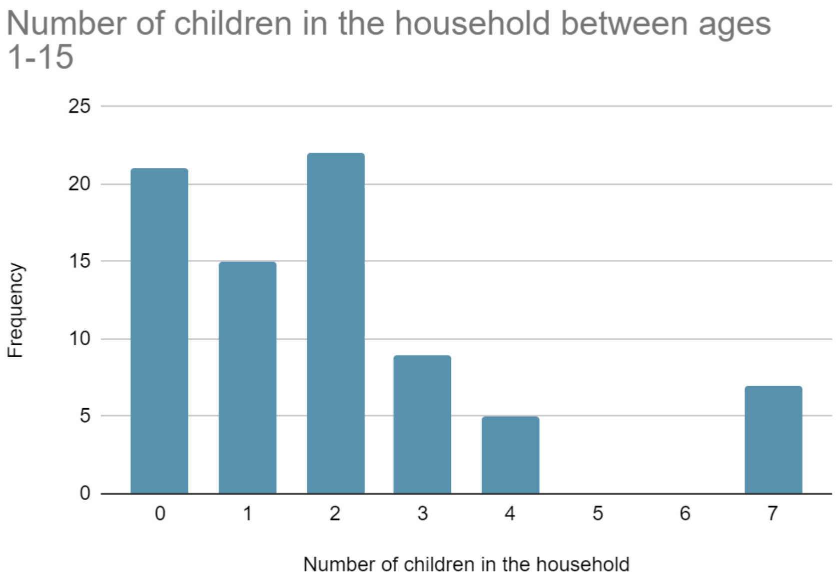


Figure 14: Number of children in the household between ages 1-15

The predominant income generating activities across the three communities was farming, with over 80% of households having this as their primary source of income. Other jobs included running a small shop, factory work and selling wood. Out of the 74 households interviewed in the endline survey, 14.3% of the study population partook in multiple revenue generating activities to increase cash flow. Figure 15 breaks down sources of secondary income, as shown a dominant source of secondary income comes from working in factories. Interestingly 10.5% of participants made a secondary income by cutting and selling wood. Wood in rural areas is collected in unsustainable and unregulated ways diminishing local habitats. A selling point of solar energy and clean cooking appliances is it removes the need for local deforestation, by replacing wood stoves with clean appliances. This finding highlight that removing the need for wood stoves could create an income deficit for some of the community.

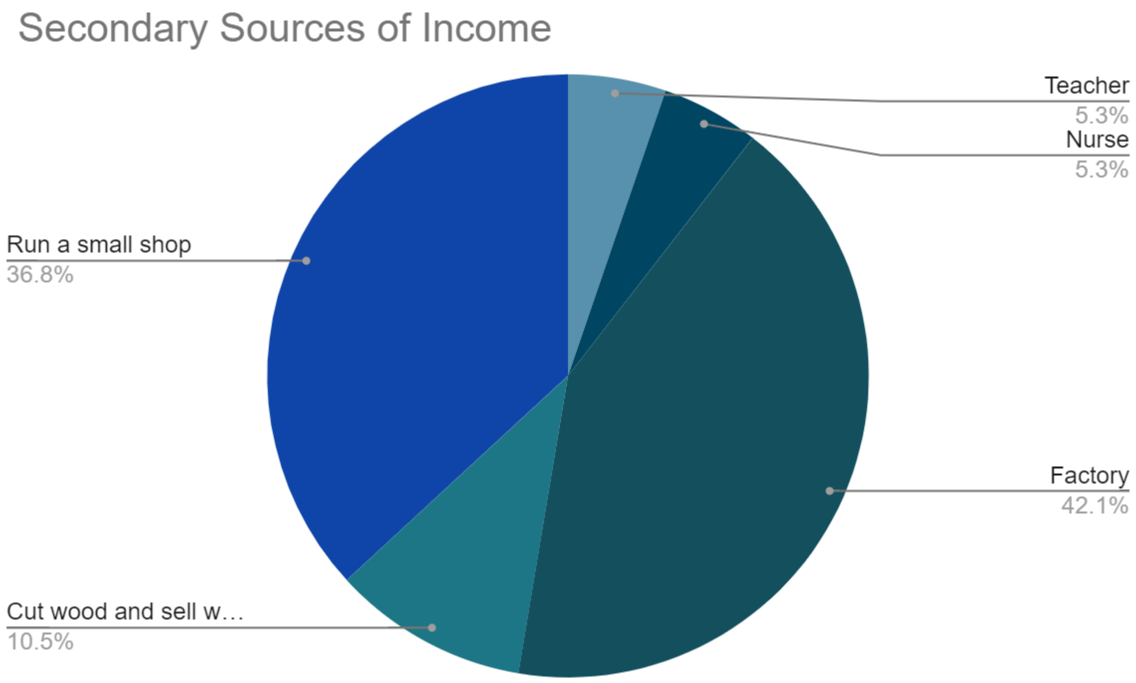


Figure 15: Distribution on the breakdown of incomes

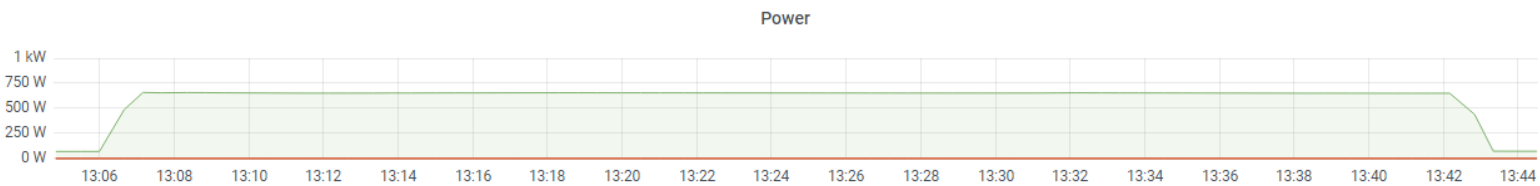
Appliances & Controlled testing

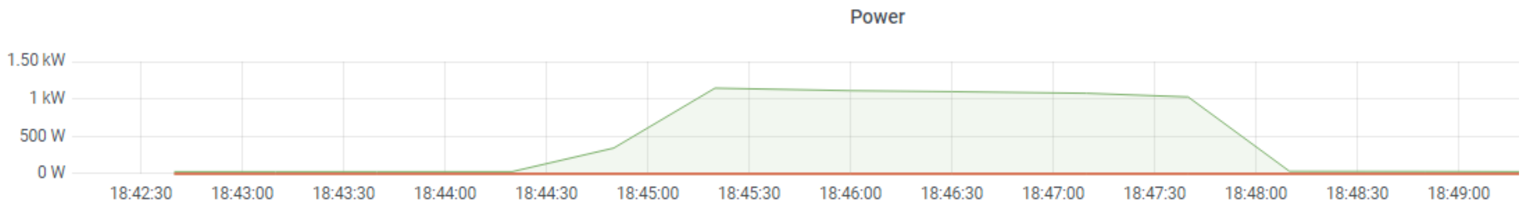
During the initial appliance survey, anecdotal data was collected that households overwhelmingly knew and understood Rice Cookers. They had in some way, whether it was through relatives or neighbours, had interactions with it. A reasonable amount had some experience with electric stoves. The consensus was that these were seen in restaurants during excursions to the city. However, the distinction between induction stove & electric stove was difficult to make. On the other Electric Pressure Cookers were not known at all. Even the Translators struggled to translate the word as they had no experience with it. The community was queried about appliances they would be interested in. This led to households suggesting they would be interested in kettles and blenders. Kettles for making teas and medicine and Blenders for grinding spices and potentially setting up smoothie businesses. This led to the addition of these appliances to the controlled testing.

The data table below depicts the observations that led to the final decisions around which appliances to offer the community.

<table>
<tr><td rowspan="2">Rice cooker
</td><td colspan="2">Max. Power drawn</td><td>Energy consumed</td></tr>
<tr><td>110 V
160 V
220 V</td><td>180 W
382 W
650 W</td><td>-
420 Wh
390 Wh</td></tr>
<tr><td colspan="4">Intended use:
Cooking rice and other Khmer dishes</td></tr>
<tr><td colspan="4">Best configurations:
● Imported PSW
● Imported MSW Inverter
● 160 V and 230 V

The amount of energy consumed at 160 V was not significantly higher than what was consumed at 230 V, however, the maximum power pulled was over 40% lower. This is significant. In an Okra system the maximum power available for 12 V configuration would be 600 W. Therefore using 160 V output this appliance could be used in the 12 V configuration enabling wider access.</td></tr>
<tr><td colspan="4">Worst configurations:
● 110 V
● Locally sourced MSW inverter

At 110 V the Rice cooker never actually switched off as it was supposed to once it had completed cooking / reached the desired temperature. The rice cooker simply kept cooking until it was manually switched off. The locally sourced MSW inverter started heating up very fast and the shut-off would get tripped even though it had a 1200 W power rating.</td></tr>
<tr><td colspan="4">Power Profile for Reference (220V):

</td></tr>
</table>

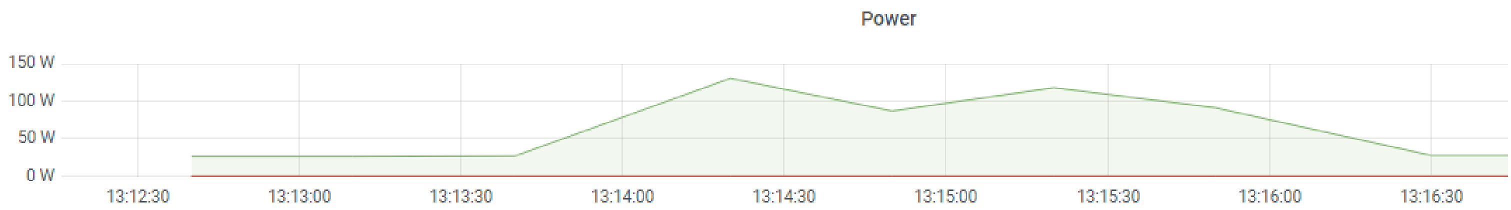
<table>
<tr><td rowspan="2">Induction Stove
</td><td colspan="2">Max. Power drawn</td><td>Energy consumed</td></tr>
<tr><td>110 V
160 V
220 V</td><td>442 W
1.14 kW
-</td><td>40 Wh
70 Wh
-</td></tr>
<tr><td colspan="4">Intended use:
Quick-cooking to replace cooking with gas stoves. E.g. fry an egg or frying in general</td></tr>
<tr><td colspan="4">Best configuration:
PSW
160 V
The induction cooker requires quite a lot of energy to function but is quite energy efficient. Especially when compared to the electric stove. Using between 30 % and 50 % less energy dependent on the voltage.</td></tr>
<tr><td colspan="4">Worst configuration:
MSW
110 V
The induction cooker took around 6 - 8 minutes to fry an egg which while acceptable is significantly slower than using a gas stove. The MSW inverter also would not work with the induction cooker.</td></tr>
<tr><td colspan="4">Power Profile for Reference(160V):
</td></tr>
</table>

Blender	Max. Power drawn		Energy consumed
	110 V 220 V	130 W 450 W	< 10 Wh < 10 Wh

Intended use:
For blending spices to be used in cooking. There was interest in using this for making smoothies and sweet drinks for sale.

Blenders worked in every configuration. The energy consumed and power drawn were dependent on the resistance caused by the load, i.e. harder to blend content required more energy than easier to blend content.

Power Profile for Reference (220V):



Electric Stove	Max. Power drawn		Energy consumed
	110 V 160 V 220 V	626 W 1240 W -	80 Wh 110 Wh -

Intended use:
Quick cooking to replace cooking with gas stoves. E.g. fry an egg or frying in general.

Best configuration:

- 160 V

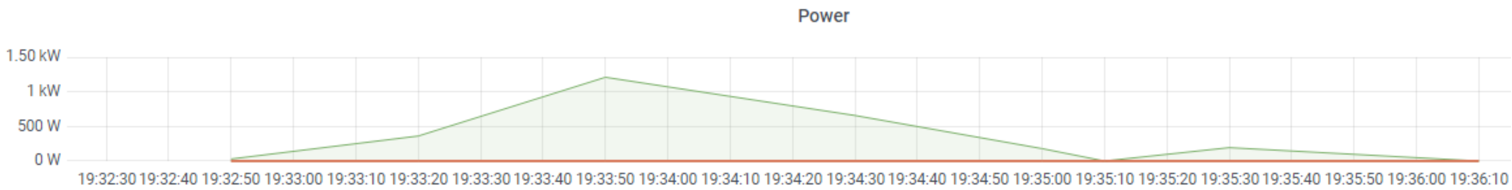
The 160 V configuration was the most useful variant of cooking with the electric stove in an Okra network.

Worst configuration:

- 110 V

The electric stove worked with the modified sine wave inverter. However, it draws a lot of power and consumes a lot of energy for how short it was used. This led to several instances of the Okra pod shutting - off due to the power output rating being exceeded. It also took longer than the Induction stove to complete a cook.

Power Profile for Reference (160V):



Kettle	Max. Power drawn		Energy consumed
	110 V 160 V 220 V	484 W 993 W -	590 Wh 278 Wh -

Intended use:
For boiling water.

Best configuration:

- 160 V

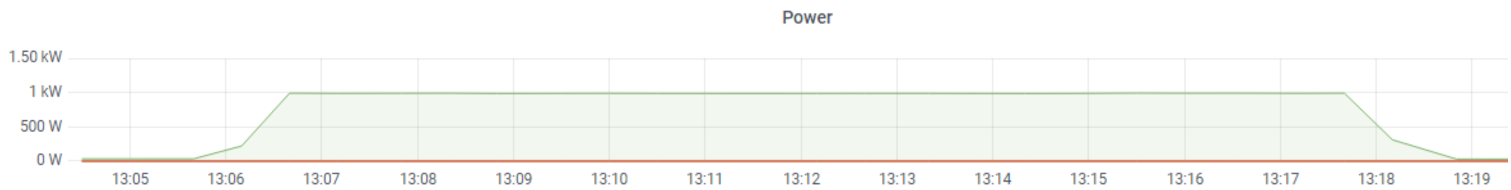
The kettle operated quite well at 160V, being able to boil water in under 15 minutes. This was faster than the Airpot at its specification voltage of 220 V

Worst configuration:

- 110 V

The kettle's switch-off mechanism was never triggered in this configuration. This is not practical as it means a user would endlessly be consuming power unless they remained to watch the water boil visually.

Power Profile for Reference (160V):



Airpot [low powered Kettle] 	Max. Power drawn		Energy consumed
	110 V 160 V 220 V	207 W 465 W 729 W	300 Wh 285 Wh 220 Wh

Intended use:
For boiling and keeping water warm that is meant to be drunk. Used for teas and medicinal drinks.

Best configuration:

- 220V
- 160 V

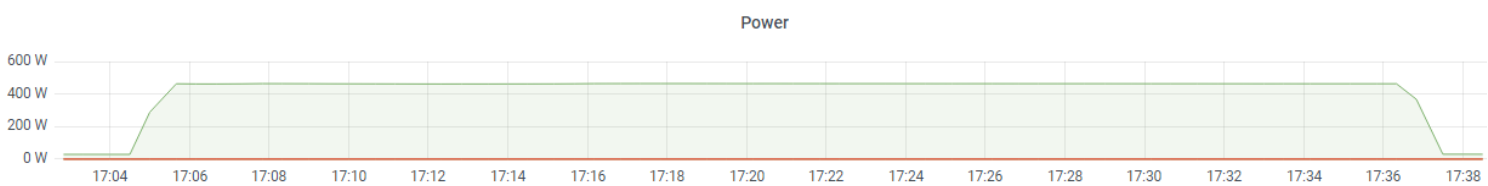
The power being drawn at 160 v and 220 V means that this kettle can be used both in a 12 V and 24 V configuration with Okra systems. And the power consumed is manageable. The time it takes to boil water is 35 minutes and 20 minutes respectively.

Worst configuration:

- 110 V

Similar to the case of the kettle, the Airpot never shut-down to indicate that boiling was achieved.

Power Profile for Reference (220V):



The above data shows comparable results in performance between 160V and 230 V. In addition at 160V it appears from this basic testing that appliances such as induction cookers could be enabled for the Okra's technology. The ideal would have been to provide all households with 160 V AC Inverters to enable less power consumption, enable the use of these off-the-shelf induction cookers and at the same time collect data on running appliances on voltages lower than their performance specifications. However, upon trying to source this inverter, we were informed it would need to be custom made as off-the-shelf inverters tend to be either 110 V AC or 220 V AC and a custom order had minimum order quantities and timelines that exceeded what was budgeted for this study. The alternative strategy would have been to purchase an inverter and a variac transformer for each household similar to what was done in the above test rig. However, this was not a practical solution due to safety concerns and implementation complexity. This limited options to the 220 V AC setup.

The distribution of the appliances that were provided for all the above reasons were the rice cooker, blender and the airpot. Households were provided their choice and Figure 11 shows how households selected and how this was distributed across the different communities.

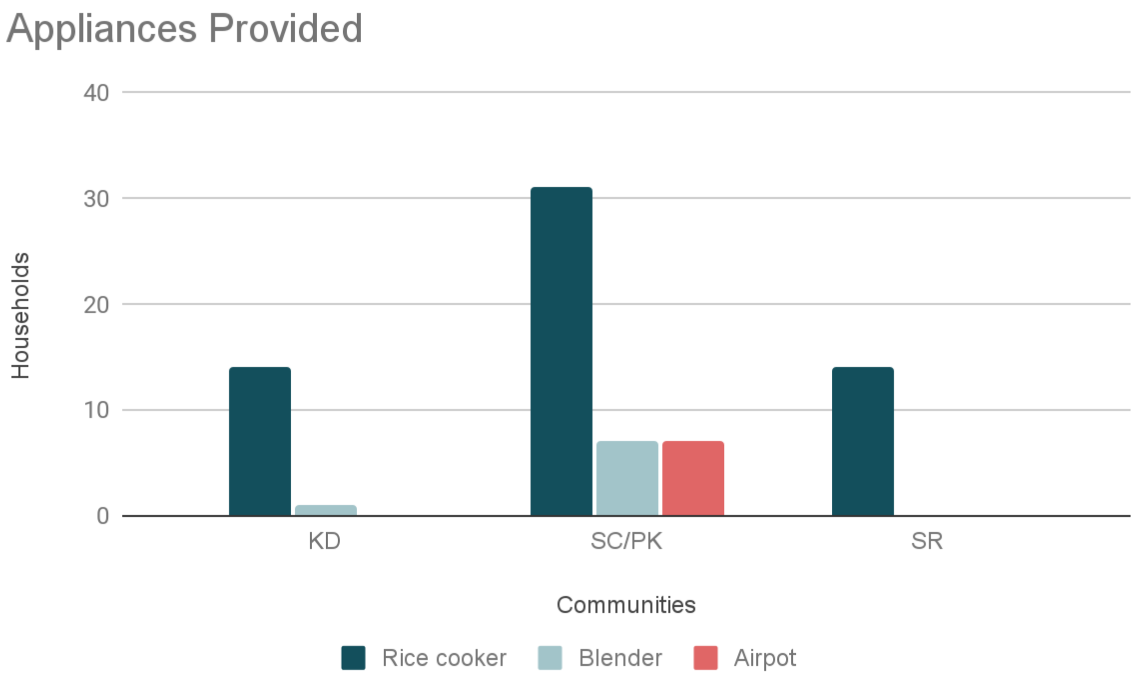


Figure 11: Distribution of Appliances across all 75 Households

Monitoring

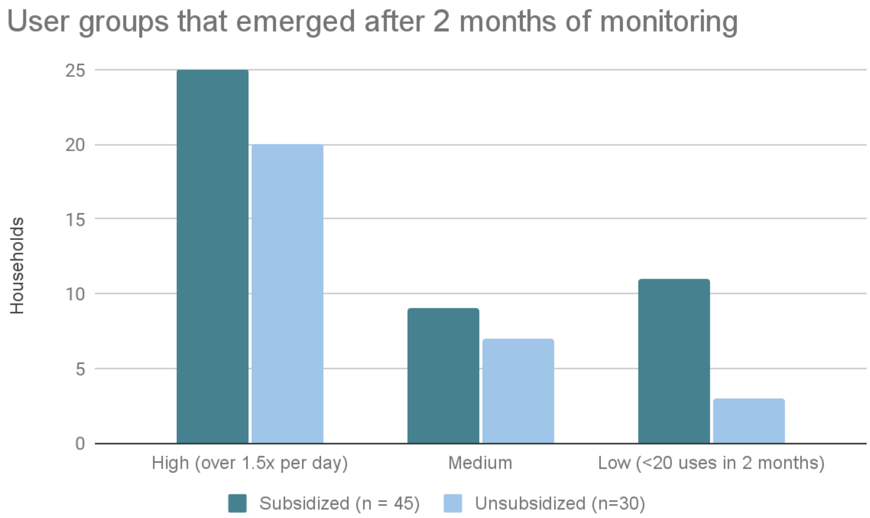


Figure 16: User groups that emerged after 2 months of monitoring

The monitoring data collected over the 2 months duration of household use of the system showed that over 50% of users fell into the High user category. Meaning they used their appliances over 1.5 times per day in both communities. The majority of households fell within the 0.75 to 3 times per day use average.

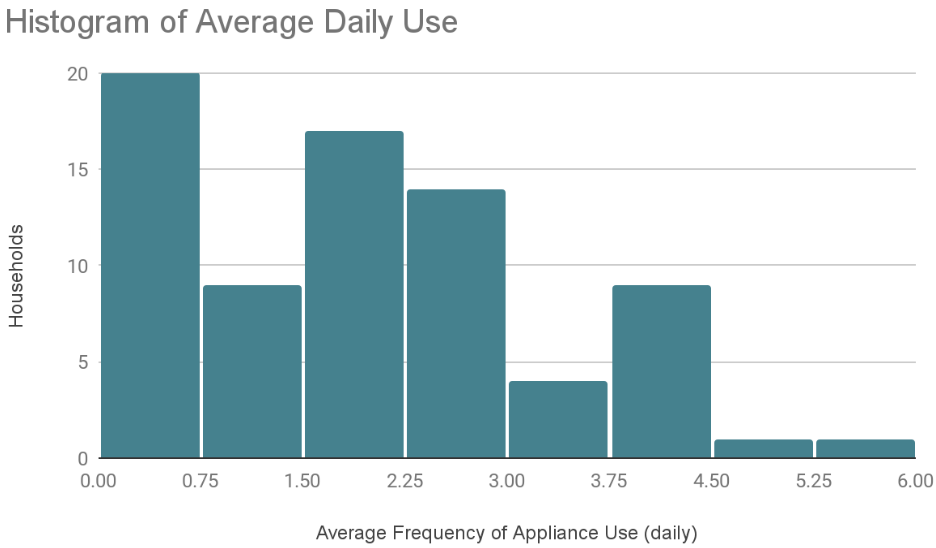


Figure 17: Distribution of Average Daily use

The following charts are screenshots from the Okra data visualization tool that shows the power utilization profile over different time periods for reference purposes. The full data set & access to the tool are captured in Appendix VI

Figure 18: 6 month period snapshot of a randomly selected household in Samroung Village (Household Nr. 22)

Total 6 month Load: 117. 2 kWh / Peak Productive Load: 1.16 kW

Figure 19: 6 month period snapshot of a randomly selected household in Stueng Chrov Village (Household Nr. 22)

Total 6 month Load: 133.28 kWh / Peak Productive Load: 862 W

Even though these households were selected randomly, their 6 month energy profile is representative of the profile for other subsidized & unsubsidized households in this study. In Samroung Village, which was unsubsidized, demand for energy was quite low prior to the study. Figure 18 shows a single productive peak in the three months prior to the study. This is in stark contrast to Stueng Chrov Village (subsidized) where households were from day 1 using productive power as shown in Figure 19.

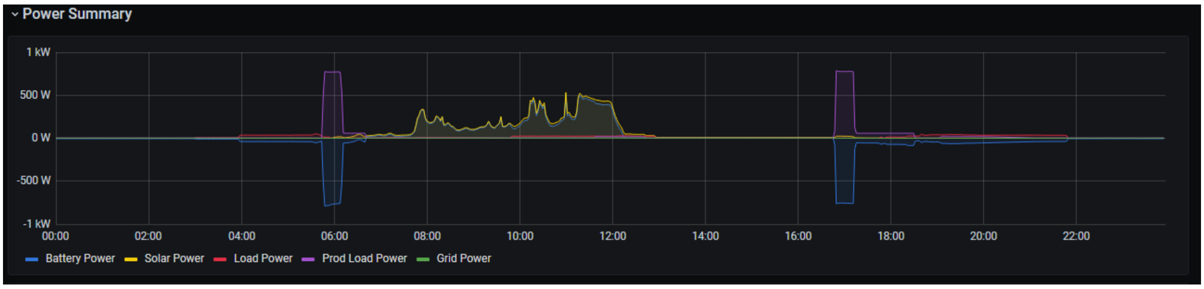


Figure 20: 1 Day snapshot of household in Samroung Village (Unsubsidized Village)

Figure 21: Day 1 Snapshots on alternative Days for comparison (1) 12 / March / 2021 (2) 06/ April 2021

Monitoring data captured the day-to-day use behaviour of each household. For example, in the 1 Day snapshot in Figure 20 it can be observed that the users would use their productive power twice on that day. In the morning punctually at 6 am to presumably make rice and again in the evening at around 5 pm. A comparison with two other randomly selected days in Figure 21 shows that households would typically cook around similar times with minor variances in the evening. More variance was observed in the cooking time in the morning. The pattern suggested after a larger number of days were reviewed was that energy availability was a factor that determined when breakfast would be made. It appeared that users would delay breakfast cooking to ensure that the battery could be charged a little by the morning sun. The monitoring data can be accessed on Okra's online platform with permission from the MECs Team.

The cumulative consumption across the village spiked significantly with the provision of e-cooking appliances. This is best visualized when the communities are compared against a control village, in this case Prey Pdao as seen in Figure 22.

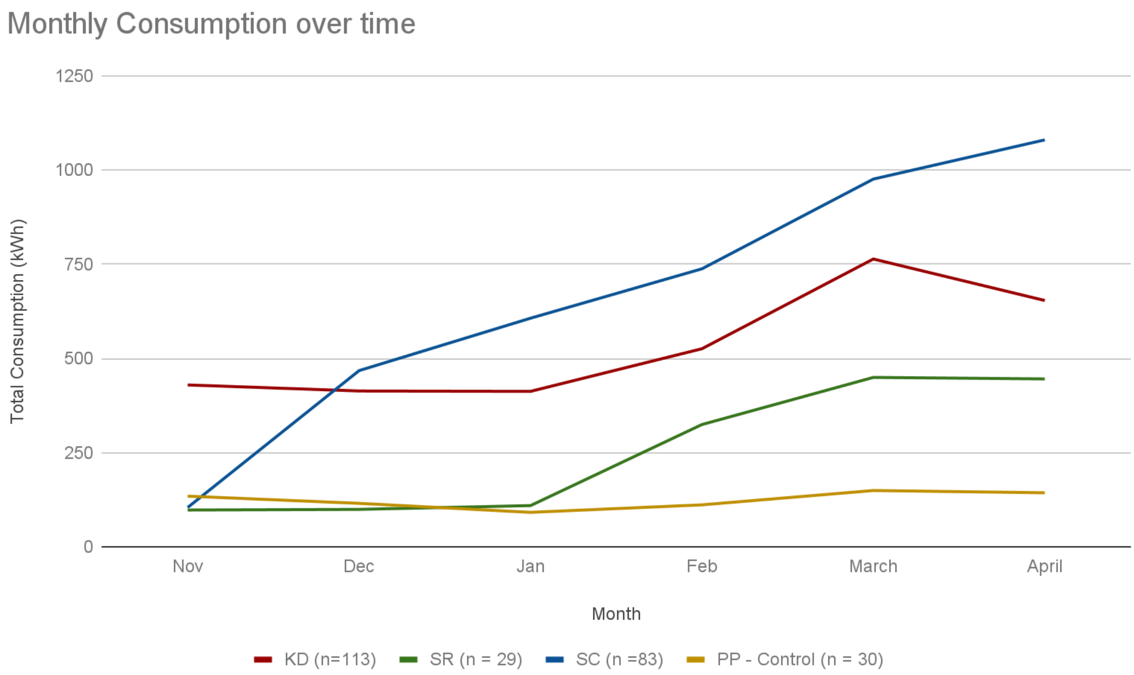


Figure 22: Month Power consumption in kWh over 5 months in the 3 Study communities & a separate DC meshgrid powered community

The chart even shows consumption starting to tail off, following the ending of the study for Samroung and Kbal Damrei, as people declined to continue with their appliances due to the high overall cost. Below is a screenshot of the Okra harvest dashboard depicting key performance indicators for the Steung Chrov communities.

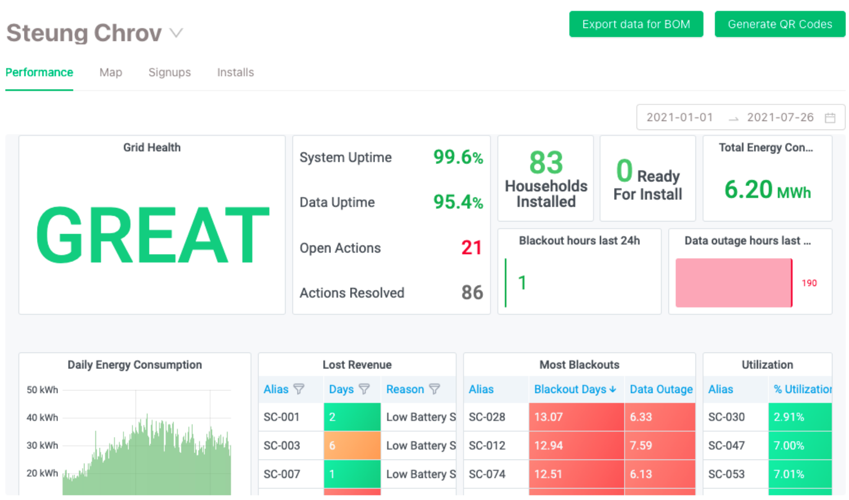


Figure 23: Harvest Dashboard for the Stueng Chrov community over a 6 month period

The above dashboard summarizes the Network Performance over the first 7 months of 2021 which includes the 2 month stretch during which households were monitored as part of this study. The chart is meant to depict two main things:

1. All in all households had over 99.6% uptime and great energy service in the mesh-grid network consuming a cumulative 6.2 MWh over the period.
2. It wasn't all smooth sailing. Blackouts occurred for various reasons. Household Sc-028 suffered a total of 13 days of blackouts over the 7 month period. This being the first time mesh-grids were tested with AC load output required a lot of learning and problem solving to ensure households could continue to use power.

Figure 24: Mrs. Say Pheak photographed in her kitchen making lunch

Reason why they liked and disliked the appliance

Three appliances were offered to participating households either; rice cookers, blenders or airpots. At the endline survey participants were asked their likes and dislikes with the products. Across all participants 'Saving Time' and 'Ease of Use' are highlighted as the most prominent benefits of the provided appliances, followed by 'reducing labour'.

Rice Cookers were the most used appliances. Out of the 59 households who tried rice cookers, the most common answer to the question of what were the things you liked most about the appliance was "time saving" and "Easy to use".

Interestingly, multiple households noted the taste of rice had improved due to cooking it in a rice cooker over a wood stove. In previous clean cooking projects[5] the change of taste of rice has been a barrier to transitioning from traditional cooking methods to rice cookers.

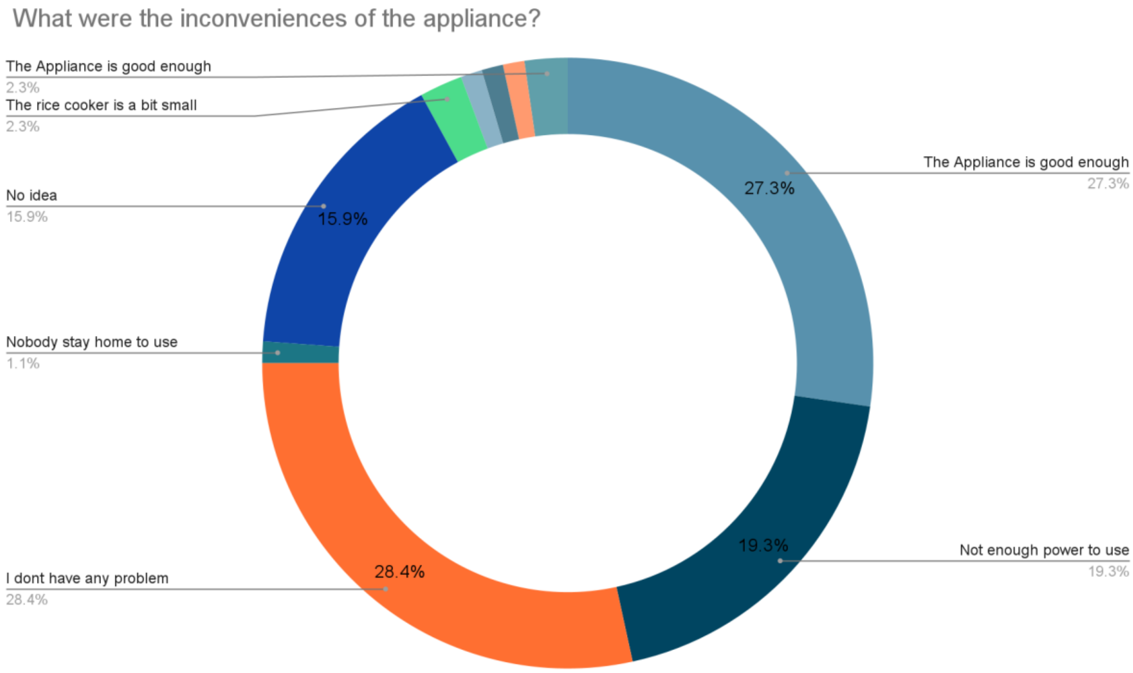


Figure 25: Breakdown of the answers of inconveniences of the appliances

Product Inconveniences

Participants were asked, "what were the inconveniences of the appliances?" 72 participants responded to the question, with 49 saying they had no issues, leaving 32.94% of participants saying they had an issue with the appliance within the three-month study period. Figure 25 breaks down the results of the question. 19.3% of respondents' inconvenience was linked to energy accessibility and not the appliance. While power was provided to the participating household, there was a limit to how much power was made available, allowing cooking tools to be used only twice a day before households overgo their energy allowance. Participants were equipped with a recipe guide as part of their appliance manual (Appendix VIII), 35% of households utilized the recipes and used the rice cooker to create whole meals. Interestingly, multiple households noted that the rice cooker was "a bit small" highlighting that to truly enable rural communities to transition to clean cooking appliances study designs need to take into account the required sizing of the appliance.

[5] MECS-TRIID Exploring Future of Alternative Cooking in Cambodia

Impact over time

Income

The data on the impact of clean cooking appliances and access to reliable energy on income was inconclusive. Data suggests an average income increase of 69.16% from the baseline survey to the endline survey. With income adjustments varying from a decrease of 84.94% to an increase of 1522.32%, this broad range indicates the data has too many external variables to produce viable results. Many of the households do not have a steady flow of income, but rather experience seasonal fluctuations. House SC-054 for example, in the baseline survey noted they earned $208 monthly income and in the follow-up survey noted a monthly income of $4,250. Analysing these inputs further with the participant it was understood that $4,250 is what they earn in a five month period during harvest season. The families rely on the income from harvest all year round. Many households did not know what they made month-to-month but rather their seasonal income. Future studies should make additional efforts to understand if the answers from participants are seasonal, monthly, annually and gain information on the households income flow over time.

Time saved

Participants were asked "'When you think about how much time is required for cooking with the rice cooker, would you say it is less, about the same or more as the amount of time that was required before, when you did not have a rice cooker?" 84.7% answered that they spend less time than before on cooking, 10% answered that the time spent cooking stayed the same, with two participants answering they did not know if the appliance had changed cooking time and one participant saying they now spend more time cooking. None of the households used the rice cooker to directly generate revenue.

Participants that noted the appliance reduced cooking time were asked what they did with the time saved. This question was multiple choice with households able to pick multiple answers. Figure 26 shows how households utilize the time saved by using electrical appliances. 31.67% answered they used the time saved to clean the house, with 50% saying they used the time saved to work in the fields. This data highlights the impact of clean cooking appliances on giving end-users the opportunity to spend more time on revenue-generating activities and to spend more time with their children.

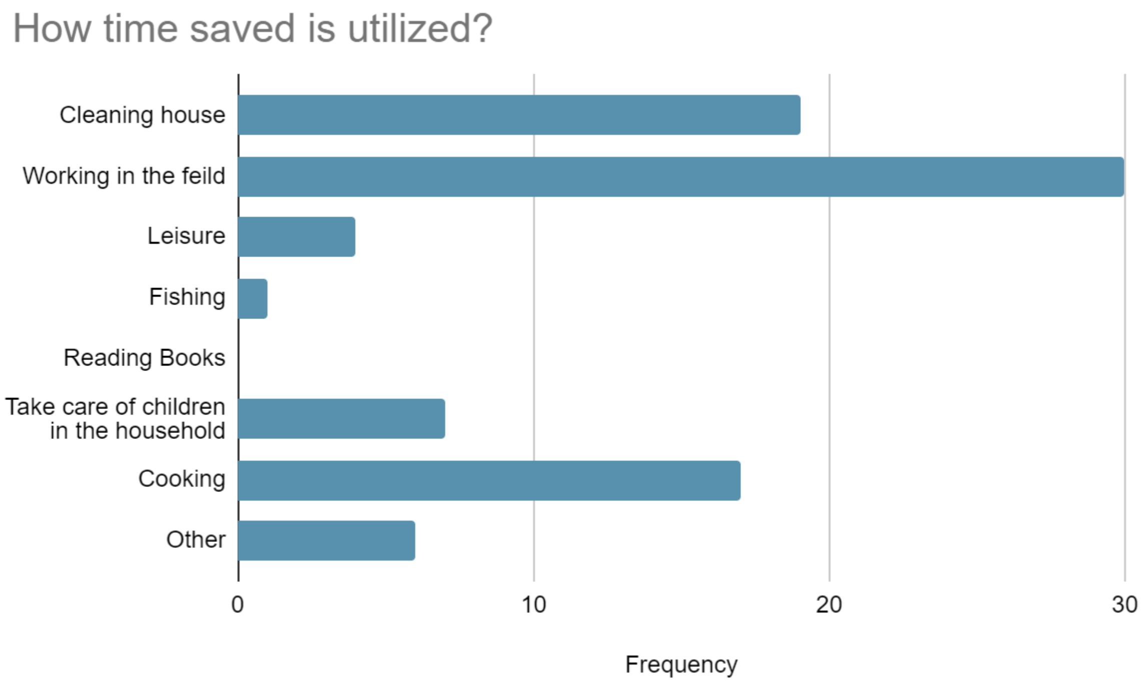


Figure 26: Breakdown how time saved in utilized

Money saved

It is well researched that solar electrification and modern clean cooking appliances are more cost effective than traditional methods[6]. To test this benefit in the study, participants were asked "When you think about the total amount of money you have spent on fuel in the past two months since you got the solar energy, would you say it is less, about the same, or more than the amount of money you spent on fuel before you had the solar energy?" 67 participants answered the question. 67.2% noted they spend less money on fuel since being electrified with solar energy, 28% noted no change to their fuel expenditure and 2.9% noted their fuel expenditure went up. This question is not without its limitations, the answers are based on the participant's self-perceived energy consumption expenditure and, does not take into account shifts in energy consumption due to changes in seasons.

The participants that said they had spent less money on fuel were asked what they did with the money saved from the energy transition. The findings of this can help us understand the long-term impacts of rural electrification and clean cooking technology. The answers seen on Figure 27, highlight how rural electrification indirectly contributes to end-users' purchasing power and gives them greater capacity to invest in healthcare, food and improvements around the home. Note households could select multiple answers for this question.

[6] http://cleanenergycambodia.org/

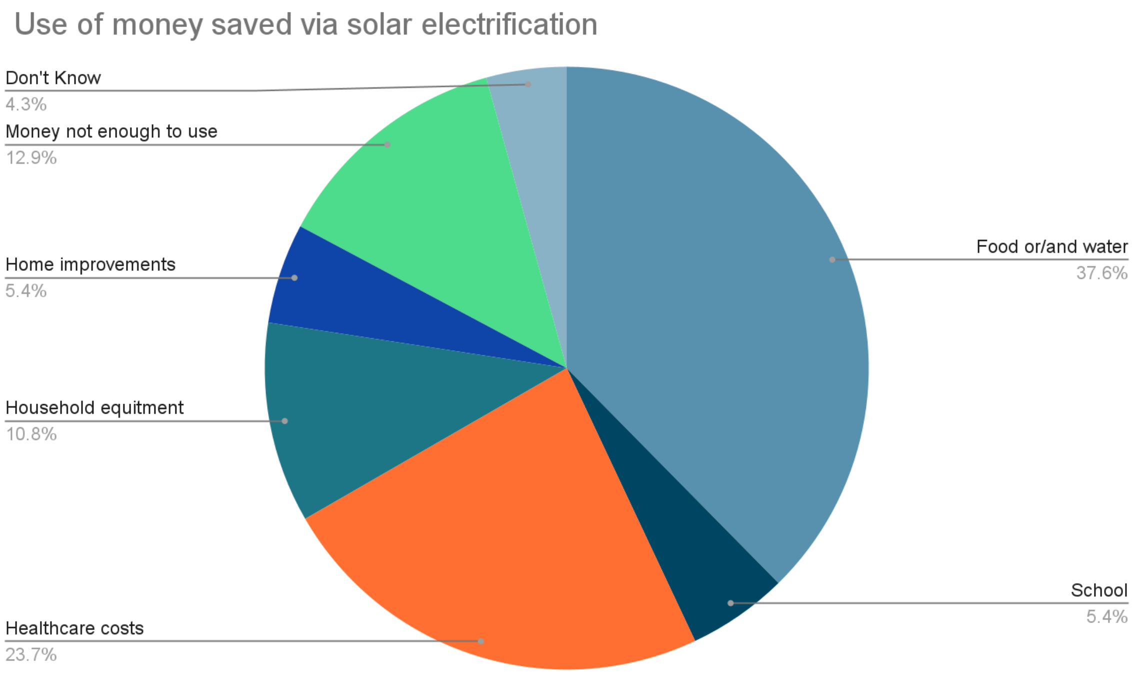


Figure 27: Use of money saved via solar electrification

Looking forward

The endline study asked participants what electrical appliances they would like to purchase in the future, what they would use the appliances for and if they know how to use the said appliance. These questions offer an opportunity to see how the population perceives energy access and what barriers they face to appliance usage. Figure 28 showcases what electrical appliances participants want to purchase in the future, with Fridges, Airpots, TVs and Blenders being the most popular appliances. DTV enables satellite TV shows and KTV speakers that enable microphones to be attached and used for karaoke. When asked what they would use the appliance for, the second most popular answer was “Improve my living standards”. This data highlights that off-grid communities know the potential of electrification and have a clear understanding of how this will benefit their lives, but are often trapped, without electricity access due to slow rural electrification efforts by energy utilities, governments and international entities. As shown in Figure 29 a significant number of participants acknowledge that energy access and access to appliances will support their existing work or help them generate additional income. Lastly, participants were asked if they knew how to use the appliances they would like to purchase in the future. 46.7% of participants said No, I do not know how to use it. This finding highlights an important barrier in the adoption of clean cooking appliances in rural communities. Communities should be educated on not only the benefits of clean cooking appliances but how to use them and to take care of them. Without sharing this knowledge rural communities will remain at a disadvantage.

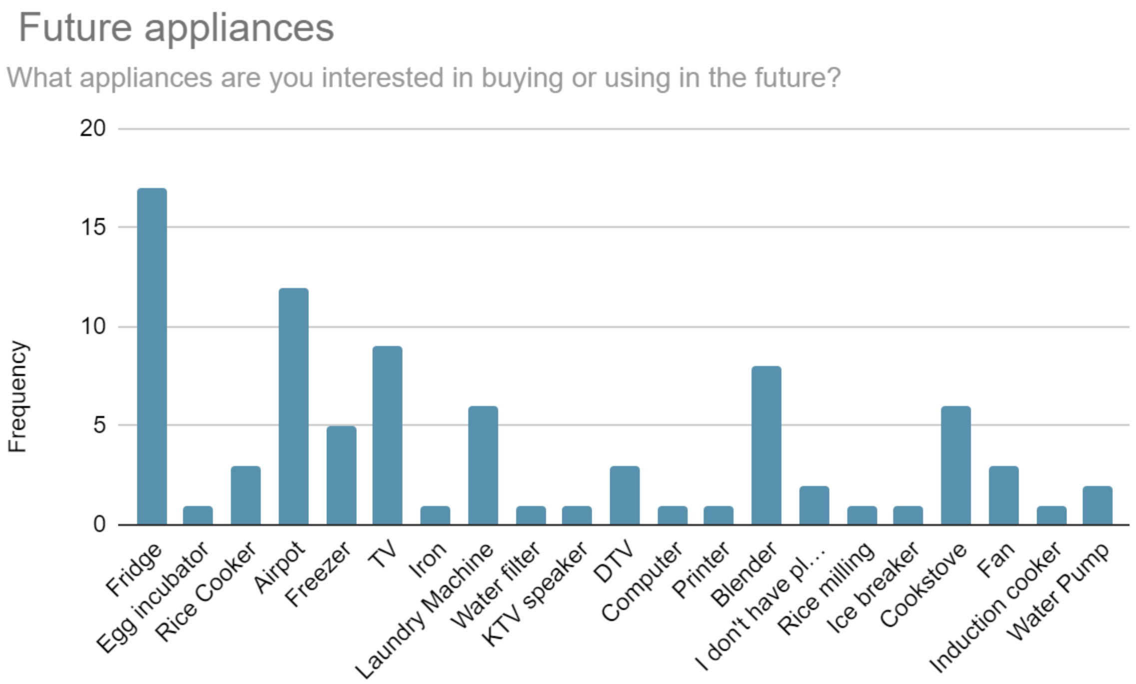


Figure 28: Breakdown of appliances participants are interested in using in the future.

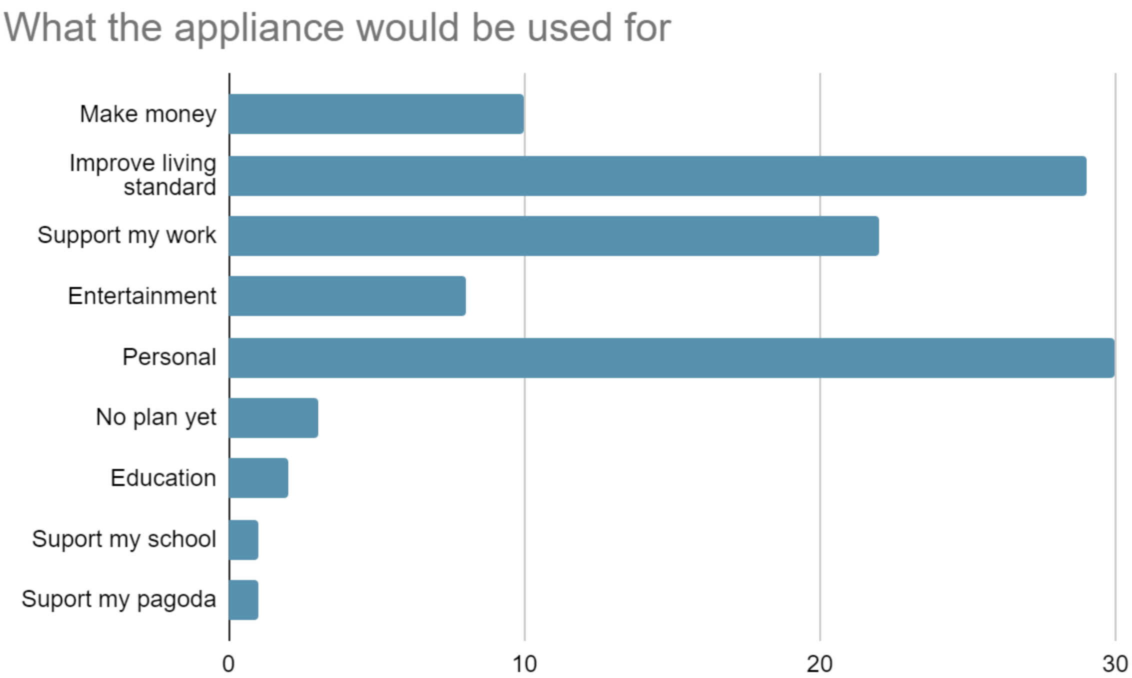


Figure 29: Breakdown of appliances what appliance will be used for

Adoption of e-cooking appliances

100% of households in the Stueng Chrov community have all opted to continue their payments following the ending of the survey and as of the writing of this report over 60% of appliance costs have been recovered. This may suggest that the need to top-up for energy and coupling energy with appliance repayments is leading to more reliable repayments of the appliances.

On the other hand, 100% of households in the privately owned networks were not interested in the initial Phase 1 offering as it was presented in Table 2. The reasons for rejection included:

- The key reason was that they had just been informed (a week before we came) that the National Grid was being extended to their community, resulting in cheaper access to power than this private provider.
- Many of them had said they could not afford the appliance and could not afford the cost of power to use the appliance. They said there was a lot of free wood and they were even in the business of selling wood to other communities.
- Some were satisfied with their energy system which simply provided them with access to a lamp and fan. But it appeared this was also because they did not think they could afford more. A few households said they think that food tastes better with wood and charcoal and would lose taste if cooked electrically – a common misconception that cookbooks help to dispel.
- Several were scared of the appliances and had never seen them before. They were worried they would get electrocuted.

To still be able to collect data that could be compared against the Steung Chrov community, households were provided access to the Phase 2 offering as captured on Table 2. Doing this meant 30 additional households could be selected and tested as part of the study. The intent was to observe the use behaviour considering energy was provided for free but also to gauge if the convenience of the appliance would raise the value proposition of the service offering in a try-before-you-buy type scheme.

However, after the study period households were asked if they would like to now pay the new monthly subscription for the entire service provided and 100% of households declined.

4. Analysis of the results

The study set out to trial AC off-the-shelf appliances on Okra's DC system and review the factors that affect adoption of e-cooking appliances.

The findings show Okra's systems can power off-the-shelf AC cooking appliances, but the type of appliances powered is restricted by the energy capacities of the systems. Both in the controlled testing and the field testing, the data shows that the Okra pod was able to power the Rice cookers, Blenders and Airpots successfully. Testing these appliances at lower voltages than they were intended to be used at yielded interesting results specifically at 160V and as it pertains to the induction stove. Induction stoves provided to remote communities could meet a large part of households' cooking needs in one appliance. These test results should drive the search for further testing with 160 V AC output Inverters to understand the long-term effects of using off-the-shelf Induction stoves at this voltage. In addition, a search should be performed for more efficient induction stoves to be tested with the Okra mesh-grid.

In regards to end users, the findings show a strong willingness by communities to adopt e-cooking appliances and a willingness to pay for appliances. With an average satisfaction level of 7.29 out of 10 and 63/75 households noting they would recommend the program to a friend. Close to 50% of participants noted the appliances improved their quality of life. 84.7% of respondents stated they saved time by using the appliances and 67.2% saying they spent less on fuel since using the appliances highlights the positive impact of appliances. Data shows that the majority of households were using their provided appliances on average 1.5 times every day with over 10% using their systems over 3 times on average.

The combination of the selected off-the-shelf AC e-cooking appliances and Okra's mesh-grid was successfully demonstrated to be feasible in this study.

The findings of this study also suggest that some of the factors that drive the adoption of these e-cooking appliances include:

- Appliance Financing
- Energy Tariffs

This study showed that the communities that were offered Okra's appliance financing, had significantly higher energy consumption in comparison with sites with less access to e-cooking appliances. Steung Chrov, Kbal Damrei and Svay Rieng all had significant consumption increases in the period of the trial when compared to Prey Pdao control community that had been electrified but without the proactive introduction of clean cooking solutions. The difference is most clear between Prey Pdao and Svay Rieng, which have a comparable number of electrified households. The amount of energy consumed doubles by the end of the study period. The community in Steung Chrov, which had fewer total households electrified than Kbal Damrei, has seen the most significant growth in consumption over the selected timeframe. It should be noted that Kbal Damrei had been electrified for over a year before the intervention and yet after the first month of installation households were already using more power in Steung Chrov.

It should also be noticed from the single-day Power consumption profile shown in Figure 18 - 21 that the majority of power consumption would typically occur intermittently during the day, presumably around cooking times. Typically in the morning between 6 am and 8 am and in the evening between 5 pm and 7 pm. This use behaviour mimics what most mini-grid developers come to expect from very remote communities (however with much lower power consumption i.e., lighting & fans at night). This is one of the factors that drives mini-grid developers to preferentially electrify communities that have commercial power demand or already dependency on generators that can be displaced by the mini-grid. And also a reason why several remote communities where that commercial demand does not exist get neglected. Designing mini-grids around daily short periods (of power demand) will lead to oversizing and significant cost that will not be recuperated in an acceptable fashion. This is an inherent flaw of the mini-grid infrastructure and can be seen as an important advantage of the mesh-grid infrastructure. Households having simultaneous energy demand will not lead to a need to increase generation, storage or transmission.

These findings suggest that providing financing for e-cooking appliances upon deployment of a project will lead to faster load growth when compared to the traditional ‘install infrastructure and wait’ model. This faster load growth will make these projects profitable and more attractive, encouraging even more developers to go out to these remote communities and electrify them. Providing appliance financing could substitute to an extent the need to depend on the presence of commercial loads. It must however be acknowledged that this strategy may have limited success for mini-grid infrastructures due to the need to scale up to accommodate the higher power demand at concentrated times during the day. This could offset the gains made in faster load growth.
This strategy is much more effective with mesh-grid type infrastructures.

Figure 30: End user in Stueng Chrow, turning on her system to go and cook

Energy Tariffs had the most direct impact on adoption according to the findings of this study. In Steung Chrov, where households were paying $0.15 (and were offered appliance financing) all households have decided to continue with the program, and none have defaulted on payment. This indicates that appliances are correctly priced at a manageable daily rate and enable low-income communities to have consistent access to clean energy appliances. Thus, highlighting e-cooking via mesh-grids and mini-grids is a viable, bankable and sustainable solution which can be deployed to reduce high-pollutant fuel consumption. By designing a program where households pay for appliances, clean cooking adoption is not dependent on grant funding but can be deployed by energy utilities to improve energy consumption of remote communities, generating greater revenue for energy utilities and enabling communities to transition to clean fuels.

In Kbal Dameri and Svay Chrum Village where participants were offered the appliances for free to encourage community uptake, 100% of households declined the offer to start paying the resulting fees when prompted following the study period. While at first it appears as a failure of appliance lending, further examination showed that the energy provider would be increasing the energy package rate, required for appliance usage, from $5 a month to $15. As a result of the tariff within the privately owned network, the resulting consumption from using the provided appliance would have a significant impact on the monthly amounts households would pay. However, in addition to this, the owner of the network was charging households on a monthly flat rate basis. This meant that regardless of how much the households consumed they would have to pay $15 every month. This oversight on the testing setup means that, it has not yet been tested, if households would also decline the offering if they had the option to pay as they use, which was the available payment option for households in the public network.

This data point advocates for subsidies to support private developers in reducing their upfront cost whilst binding them to low tariffs for the end-users. The balancing act however anecdotally is that too high subsidies could lead to lower service being provided to the end-user. The goal needs to be to provide financial support in a manner that will make tariffs appropriate for the community and also encourages e.g. provision of appliance financing. This supports the end-user and makes them more willing to consume energy and supports the developer in enabling them to provide the end-user with appliances that they will actually use to consume that energy.

Community adoption of electrical appliances will be restricted unless necessary training and guidance is provided. An interesting finding from the endline survey is that when respondents were asked if they knew how to use the appliances they wanted to purchase in the future, 46.7% stated they had no idea. At the launch of this study, Okra hosted an appliance workshop, giving training to households on how to use rice cookers, blenders and airpots. While all respondents noted they found the appliances easy to use after training, some households still had a fear and lack of confidence in using the appliances. Okra trained and hired a local community member to maintain the mesh-grid and collect energy payments. She supported households which were concerned with fears of electrocution. She often heard tales of the community coming back from the field to eat rice for lunch but the rice was uncooked - no one had pressed the on button. Her on-hand guidance was able to help community members feel more confident in continued use of e-cooking appliances. The fact that such a high percentage of the community does not know how to use the appliances they want in the future, shows that providing electricity and enhancing access to appliances is not enough. For e-cooking adoption to be sustainable, necessary training and support needs to be provided to communities to enable households to feel confident in the transition.

Overall, the study serves as evidence that the Okra DC mesh-grid successfully provides access to off-the-shelf AC clean cooking devices that fall within the technical specification to the most remote of communities. This was substantiated by controlled work, field testing and ongoing usage of those appliances by people in these communities as of the writing of this report. The data collected on a household basis over the study period using Okra's platform will serve future research to inform adoption behaviour at an unprecedented resolution. Furthermore the approach of providing off-the-shelf appliances along with electrification projects will hopefully lead to expedited universal adoption of clean cooking and electrification.

5. Changing the narrative on modern energy cooking services

The answers to these questions will help MECS to change the narrative on clean cooking so we want to specifically highlight them.

Appliance performance and acceptance

- *Did you have any issues with the performance of the appliance during field trials/testing/use?*

We used off-the-shelf appliances that could be sourced from any of the metropolitan areas of the country. The intention was specifically to test appliances that could be easily sourced. During the testing period we had 1 Appliance get "lost" and another ceased functioning, however for the latter we were able to get a warranty replacement. The bigger issue was with Modified Sine Wave Inverters. We have had up to 4 of them get damaged in the span of the last half year. The Inverters are required to convert the DC Power from the sun to AC Power that off-the-shelf Appliances can use. We were able to get Warranty Replacements on these, however the timeframe and supply chain managements associated with sourcing replacements from China do not make it a viable way forward.

- *If you made any modifications to an appliance did these modifications work as anticipated?*

No modifications were made.

- *How do users feel about the product/service?*
    - *Have there been any changes to cooking practices? How sustainable are these changes likely to be?*

We are confident that users feel positive about the product and service. We have been able to detect a real dependence on the new Appliances and an eagerness to use them. They are more convenient than the alternative. The results also suggest that households actually want more of these appliances. E.g. Households with Rice cookers want an Airpot, to be able to boil water very quickly. The main concerns households have struggled with was the limitation in their available power and also maintenance issues associated with the power system that would on occasion lead to interruption in the service provided.

    - *Is the appliance being used as part of a fuel stack? (if yes which other fuels/appliances are used for what purpose?)*

As we only provided the following appliances: Airpot, Rice cooker and Blender, these appliances are unable to meet all the needs of customers. So for other cooking needs, we expected that households would still depend on previous methods of cooking which included cooking on Traditional Stoves / open fires with wood or using small gas stoves. However, their overall dependence on previous traditional forms of cooking would be reduced.

- *Did users adapt easily to the new product/service (e.g. was there a lot of questions/help needed?)*

There was little work needed to train users on the use of the Appliance. The main struggle here was that in a few cases, the person trained was not the person who would be at home all the time to use the appliance. In some cases the wife was trained instead of the grandmother, who was then scared to use the appliance. But in general people did not struggle too much with the appliances. The more significant learning curve was associated with understanding how the Okra service worked. The way we set-up the Appliance Financing to combine it with their electricity billing was initially a little tough for people to understand. Also people grappled with the idea of having Energy Allowances and the flexibility in business models (how much you are charged per kWh?) compared to their neighbours.

- *Are any additional behavioural changes visible at household level – e.g. changes to household decision making dynamics, gendered roles, impacts on children/ vulnerable adults?*

The main thing noticed at a household level is really that in most cases people had more time to do things they wanted to that they didn't feel they had access to simply due to the reduction in amount of time they had to spend attending to their cooking. This additional time had positive benefits on the children as some households spent more time with their kids. There was an occurrence in which the Husband out of frustration, had asked for the system to be removed from his house. However, his wife made him change his mind, because she was dependent on the use of her appliances and would rather have intermittent access due to the issue than not have access to it at all. This was a direct example of the wife making the decision and demanding access.

Market Surveys

- *How do the results from market surveys/customer interactions reflect your original assumptions about the target market for your product/service?*

The difference between the Average Load expectation for rural remote communities was far below what was experienced. Households are expected to only need about 250 Wh of energy per day; however, all the households that were given access to Appliances are pushing averages of above 800 Wh per day over certain periods. This suggests that previous projects on which such low Average Load estimates are based are simply not providing enough power, affordable power, appliance access or appliance training for households to really be using the power to make their lives better. In a very short time frame, we are able to collect data that shows that people will pay to use a lot of power if their needs are actually being considered.

- *What modifications would be required for your product/service to be relevant to your target market?*

There is room to improve the reliability of our Product offering. We have learnt that in specific edge cases the Inverter was killing our Pod. Resolution of these edge cases would improve customer experience; this is something Okra Solars dev team are actively exploring. The cost of electrification needs to be brought down so that reasonable returns on investment can be achieved without having to place too much of a burden on the end-users that will end up limiting their ability to fully take advantage of the power that has been provided to them.

Supply chains

- *Did the supply chain have any impacts on your study (positive or negative)? Please explain in as much detail as possible.*

The Okra Pod, the brain of an Okra system, was originally designed to be used with our customers' own choice of Batteries and panels. This was designed to allow a customer to simply plug in the Okra pod as the brains of their new network and use locally sourced Batteries and Panels, to simplify their supply chain. However, the system that was provided by a supplier in Cambodia, ended up having several low-quality battery cells in the batch, which affected households' overall experience of the system. This was reflected in people often giving feedback about not having enough power. Whilst in some cases households simply had reached the limits of their capacity designed, because they were using so much power in other cases this was simply due to the battery we had been supplied. This situation led to Okra deciding to source our own tried and tested batteries and panels and to offer our system in kits instead of just as a standalone pod.

The second issue was with using Modified Sine Wave Inverters. It was clear from the beginning that these are known to be less reliable. However, locally sourced variants of these are significantly less reliable than the ones we sourced. This meant that certain households if their Inverters got damaged, had to wait for 2 weeks minimum to get replacement pods.

The final issue was covid related, households were provided with AC - Inverters to allow them to be able to use an AC output with the Okra Network which distributes in DC. There were delays with getting this equipment to households during peak times of the pandemic.

- *Is it feasible to scale up the supply chain under the current (excluding covid-19) circumstances – if yes what would it take to achieve the scale up? If no what is currently hampering scale up (apart from Covid-19)?*

Yes, it is feasible to scale up the supply chain. In fact purchasing larger quantities of pods, batteries, panels and inverters (Pure Sine Wave inverters, this time) would bring down the cost of manufacturing which would reduce the overall costs. Appliances would be sourced locally in the country and after-sales can be locally managed.

- *How can the appliances be maintained? Was maintenance needed on any of the appliances/systems during the study? (if yes please add additional detail on type of maintenance needed, how it was managed etc).*

As the appliances that were offered were off-the-shelf and ubiquitous brands, the process of maintenance was relatively straightforward. When deploying an Okra network, we typically recruit a local representative and task him with being the top-up agent and resolving issues. So if there were any issues, this person was given the appliance and would send it to us to then replace it at the Store. In the future however this process can be managed without our intervention making it more scalable. The Agent would simply be provided the resources to buy the Appliance and then can either manage the warranty for the household, or the household would manage the maintenance directly with the local store themselves.

Monitoring electricity supply and use

- *Did load profiles of cooking match what you expected? How did the energy demand of cooking practices match energy supply?*

Households definitely wanted to use more power and cook more frequently. However, each household had a designed energy limit. On average each household should have been able to use their rice cooker or airpot twice a day. However households had the option to use a feature called the Boost, which would allow them to exceed their household limits and pull power from the network. The amount they can pull depends on how many households are sharing and of course on the availability of energy for all of those households. However, considering most households cooked twice a day even with power remaining, this would suggest that energy supply was mostly sufficient.

- *If grid connected, what is the stability and experience of the grid (voltage drops etc)*

Not grid connected

- *Time of use – did you provide time-shifted access or limit cooking to ensure a more reliable supply? How did participants react to this change?*

We did not have to provide time-shifted access, households could use power whenever they pleased. They had a specific amount of energy allowance per day. And they could use that energy whenever they pleased.

- *Datalogging technology and analytics: what was used? (e.g. data loggers, cooking diary matched with electrical data read from appliance-level sub-meters) how effective were they for the task?*

The Okra Pod is in itself a meter, so no additional tools were required on our Harvest Platform. We were able to collect incredible data on when people used the appliances through the pod. The limitation with the meter is that it cannot intrinsically detect what the appliance being used is. However, as part of the study, we knew that the appliances we were providing were the highest-powered appliances these households had access to and so if the load profile was consistent, we would be able to tell when households were using our appliances.

Finance and affordability

- *Were your systems/products considered affordable by your target market?*

The affordability aspect was split along community lines, with the vast majority of people in the community where power was affordable considering the offering to be affordable. In the community with a private energy network 50%+ claimed they thought the appliance they used itself was affordable. However, 100% of them would not sign-up to the private network, because the cost of power per use within this private network they considered to be too high, and they said they could not afford to pay the power bill.

There could have been potentially other reasons, the community where the subsidy occurred, was considered to potentially be a little wealthier, in addition, the time of the year could have played a factor. For the subsidized community, they paid and bought their equipment just after a harvest period, when they have the most resources during the year, however at that same time, the offering did not appeal too much to the unsubsidized community. At the end of Quarter 1 2021, when we asked the second community, would have been a period when in many cases the profits from the last harvest would not have a lot left.

- *Is there anything that would have made them more desirable/more affordable?*

In the specific case of the unsubsidized community there would have been two ways to make our offering a bit more appealing:

- The owner of the network had been up until that point instituting a Flat Rate model, wherein households paid a flat rate for a specific package per day and per month. If they exceeded their capacity, they would be charged an excess rate. For this reason, after the trial under E4A, the customers were then offered a higher tariff structure, which would require them to pay on average 2x the monthly flat-rate fee they were currently paying and all but 2 households declined. It became clear that a quick way to mitigate this would be to offer a different payment tariff i.e. not a flat rate fee, however that would require some new communication and training that the private owner of the network has decided to undertake, however was beyond the scope of this study. The private owner intends to still offer the same per kWh rate, however people only pay on a per kWh basis, after people have gotten used to that payment structure the intent is to re-offer them the opportunity to have more energy capacity to be able to use the appliances they had grown to enjoy as part of the study.
- Providing cost subsidies for the investors of such projects allows them to scale much faster. Without subsidies then all the cost of the Electrification Capex and Appliances to boost load usage will have to be borne by the end - users and households in these communities simply cannot bear that burden. Subsidies make such models much more attractive for private investors as they recuperate some of their costs quickly and then can spend the next year providing valuable service to keep the deployment ongoing to recuperate the rest of their costs and their profits.

- *If you did tariff experiments*
    - *Is it sustainable in the long term? (for suppliers and customers)*

We think that even unsubsidized electrification is sustainable for the most remote of communities.
Whilst our evidence suggests that Households are reluctant It would be difficult to electrify at $0.15 per kWh in Cambodia without a subsidy to reduce the overall CapEx spend.

- *Are policy/tax changes needed to make it feasible on a larger scale?*

In places like Nigeria, where the regulators are allowing private developers to agree on prices with the community, expedited electrification can be expected especially when additionally incentivized with subsidies. These developers will then go-ahead to set up business models that provide appliances such as clean cooking technology and charge low enough to encourage high usage.

- *Was full cost recovery achieved? Could it ever be achieved by everyone? If you used a financing mechanism of some kind*
    - *How effective was this mechanism?*
    - *Was it acceptable to people?*
    - *Is it sustainable in the long term?*
    - *Are policy/tax changes needed to make it feasible on a larger scale?*
    - *Was full cost recovery achieved? Could it ever be achieved by everyone?*

Over 56% of the total Appliance cost has been paid for so far. It is expected that full cost recovery can be achieved. The model presented to households was Energy - as - a - Service with Appliance Financing coupled to it. This means that households pay a small fee to get connected to the Service. After this, a full system would be installed in the household. The household is not paying to own the system, the system will forever belong to the Provider. The household is simply paying to use the power provided. Every time the household wants to use power, they top up their system. Then the system bills their account every day based on how much power they use. The appliance mechanism worked similarly. If a household decided to buy an Appliance on finance, that appliance would be linked to the household's system. The household would simply need to just top-up their system as usual, however during the billing an additional amount would be deducted from their accounts which amounts to the daily rate of their appliance repayment. From a household's perspective, rather than saving up to pay $8 every month for a 12-year period, they could just top up their system with energy and be billed at a much more manageable daily rate of $0.27.

This method was initially a little difficult to explain to the households; however, once they understood it, it was much more appreciated. On the other hand, if a household refuses to pay for the appliances they are putting their energy access at risk, which makes it more likely that they will continue to pay and makes a more certain investment for suppliers as well. If a household refuses to pay and loses its energy access, the next house will get the Energy system and the appliance and will finish off the payment.

We believe this model is sustainable in the long term as long as the network continues to be run and driven for profit. The network in SC has been handed over to the community to manage themselves and the hope is that they continue to drive towards maximising revenue and use that revenue to purchase more appliances to provide to households on financing which in turn will generate more profits thereby making sustainability more realistic.

- *If you upgraded existing home systems*
    - *How effective was this mechanism?*
    - *Was it acceptable to people?*
    - *Is it sustainable in the long term?*
- *Are policy/tax changes needed to make it feasible on a larger scale?*
- *Was full cost recovery achieved? Could it ever be achieved by everyone?*

The people in SR and KD were already on an Okra network; however, it was a much smaller system which was DC and also could not power the Appliances that were being provided as part of the E4A study. Therefore, it took an upgrade of the generation and storage capacity and the addition of inverters in every household to enable households to be able to use power. Households wanted to have AC access, so they appreciated the upgrade. However, without a subsidy providing the level of power would mean low Investment return rates, even though these systems would last a long time

Stakeholder interactions

- *Which stakeholders/people were important to any successes in the study? How did you engage with them? What were their roles?*
- *Did you meet any resistance/opposition from any stakeholders to the study and, if so, explain why? How did you respond to this opposition? What was the outcome? Any ongoing challenges?*
- *Were you surprised by something someone said (positive or negative)? Please explain why you were surprised.*

The stakeholders involved in the implementation of this study can be broken down into three main groups:

- Regulatory
- Financial

- Community

Our regulatory stakeholder was the Ministry of Mines and Energy. All decisions and implementation required their approval, as typically electrification in Cambodia would require licenses and this would not be achievable in the short-term, however, they were interested in understanding the possibilities of Okra technology as a solution to electrifying the remainder 3% of villages that were difficult to reach with the national grid and their alternative electrification technologies. In addition, they provided support by being an authoritative body that the community respects which made it easier for the community to trust and take our offerings seriously.

Our financial stakeholders were UNDP and MECs. UNDP provided the funding for the installation of some of the households and MECs provided the funding for the appliances and additional households beyond the scope of the UNDP study but within the same community. UNDP has a real interest in supporting Cambodia to reach full electrification and sees Okra's technology as a viable solution. MECs provided guidance and decision making on the Appliance front in their objective to drive modern cooking service to such communities.

For both stakeholder groups Okra would frequently provide information, update and request decisions be approved prior to implementation.

Within the community, the most important stakeholders were the village heads. It was important to ensure they understood best the offering and services to be provided. For that reason, their households got electrified first and they were provided Appliances a couple of weeks before the Launch Event. This meant that households had a demonstration to observe. Having nodes such as the village chiefs involved leads to much faster adoption.

Scaling up electric cooking

- *How is a transition to clean energy cooking likely to occur in your focus country?*
- *Which stakeholders do you think will be important to facilitating the scale up of clean cooking and why?*
- *What needs to be done to facilitate the scale up of clean cooking in your focus country that isn't being done at the moment?*

Cambodia as mentioned in the introduction has made incredible progress towards fully electrifying the country. But at the same time reports suggest that up to 70% of power consumption in Cambodia is still biomass and that is primarily used in cooking. The two key changes required for Cambodia to transition to 100% clean cooking is :

1. The price and fear of the risks of LPG declines significantly over the next few years and the supply chain to the remote corners of the country is consistent and stable.
2. If affordable and productive electricity is made ubiquitous

The latter seems more achievable at Cambodia's current pace. There would be substantial benefits in the Clean Cooking Industry and Electrification industry in Cambodia form a united front. It would be interesting to see if Cambodia were able to drive electric cooking starting with the remaining 3% of the most remote villages being the innovators.

6. Social inclusion and Impacts

Please describe how social inclusion of the poorest, marginalised and most vulnerable groups were incorporated into the completion of this study – this includes the integration of equity, people with disabilities, remote communities, elderly, children, and lowest income households. Please describe any impacts from your study that can contribute to social inclusion.

This study offered low-cost solar energy to three low-income underserved communities. These households are located in hard-to-reach rural areas; due to their location it is high-cost to roll grid access to these sites. Thus, while Cambodia's economy has grown, these communities have been stuck in 'Stubborn' poverty, with no energy access or access to the modern economy. By providing energy access, appliance workshop training and Appliance Financing this study aims to serve remote low-income communities.

This study improves social inclusion in the following ways:

- **Access to reliable electricity, enhancing safety, longer business hours and additional study time.** Two household launched smoothie blending businesses with the appliances provided.
- **Increased access to the internet, enhancing access to news, information and education.** With mobile internet access being readily available across the sites, reliable energy access enables households to charge their mobile devices from home, enhancing access and opening opportunities.
- **Access to affordable clean cooking appliances.** An often-overlooked barrier to clean cooking is the high cost of electrical appliances, this study trials Appliance Financing, enabling households to use a rice cooker for $0.74 a week, enhancing access to clean appliances and encouraging an energy transition.
- **Decreased need for high pollutant cooking fuels that are linked to medical complications.** Traditional tools such as Kerosene lamps produce hazardous and carcinogenic gasses, which have been linked to decreased lung function. Endline data shows that households are using significantly less kerosene and diesel in and around their homes. The medical long-term health benefits of transiting to clean energy are intergenerational.
- **Reduced cooking time. 84.7% participants said the appliances reduced their cooking time,** giving them more time to do other things. One household noted "before this solar study, I had to wake up at 4am to cook [for my children before school]. But after I've had this solar power, I don't have to wake up early to cook anymore… then I have more time prepare the stuff for sale and to do other things".
- **Decreased expenditure on fuels, enabling the money saved to be used to improve quality of life.** 67.2% of participants said they have reduced fuel expenditure since moving to solar energy access, with over 60% of

participants said they used the saved money to purchase additional food and water with 40% spent money saved to access healthcare.

- **Enhanced understanding of electrical appliances, enabling households to utilize technology.** During household sign up for the study, candidates were asked if they knew how to use the electrical appliance they selected. 108 out of the 116 potential candidates said no, they did not know how to use the appliance. Through the appliance workshop and the study, the community's familiarity with electrical appliances grew. Several households in the study noted fear of using electricity, with one household refusing to use the appliance until her "daughter, from the city came home" to give additional guidance. With demand for electricity growing annually globally and the rise of technology, the longer communities stay unelectrified the larger the inequality and social exclusion gap grows - Okra is working to prevent this.

7. Gender

Fuel collection for stoves is a burden that predominantly falls on women and girls. Okra's baseline data indicate that women spend up to four hours a day collecting fuel, time which could be spent on income-generating activities, education or relaxation. By offering households clean cooking appliances, the study reduces the need for fuel collection. Additionally, women are often tasked with cooking. Due to off-grid communities using harmful fuels for cooking, women and girls are more at risk of experiencing medical complications due to pollutants[7] - indicating the significant long-term impact clean cooking will have on women and girls in rural areas.

Both men and women were encouraged to come to the appliance finance workshop to learn how to use the electrical appliances, 64% of attendees were female. Clean cooking appliances benefit women by reducing the burden of fuel collection, in addition to reducing the task of using, cleaning and caring for the clean cooking appliance which is often placed on Women. 87.84% of households said Women or Girls were responsible for the appliance, with 28% of households noting the responsibility was shared between Men and Women. Four households noted it was the responsibility of the husband to care for and use the appliance. With the appliance reducing the burden of fuel collection and reducing cooking time, in addition to the appliances needing a little day to day care. At the end of the program 75.6% of participants said the program has improved their standard of living, saves time and/or provided them with affordable energy access. Thus, it

[7] https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

can be assumed that the appliance has resulted in minimal negative consequences.

8. Next steps

Please describe the next steps you will take to scale up the results of your study. Please outline any partners, funding opportunities and utilisation of results to enable this.

For Okra, enhancing access to E-cooking appliances via rural electrification and Appliance Financing has shown huge potential. This study showed that not only do AC appliances work on Okra's DC system but, by spreading the cost of e-cooking appliances over time via Appliance Financing households adoption of clean cooking appliances is enhanced, clean energy consumption increases and there are positive effects on women empowerment.

Since the study closure Okra has continued to offer Appliances Financing to energy developers and during site roll-outs. We tailor the appliances we offer to the needs of the communities we serve. In Okra's study in Marchand Dessalines, Haiti for example; households noted they wanted to have enhanced access to TVs, fans and rice cookers - thus, households can now spread the cost of appliances across a year by paying a low daily fee.

Okra will use this study to show Energy Utilities that by providing affordable access to E-cooking appliances, clean energy consumption more than doubles. The rise in energy consumption enhances the profitability of electrifying rural communities, making it more attractive to investors and potentially kickstarting investment in rural development.

To prove the long-term sustainability and impact of Appliance Financing of E-cooking appliances Okra would like to conduct a longer-term, multicounty study on the impact and usage of enhanced access to e-cooking appliances via rural electrification. As Okra branches out to West Africa and Haiti, it would be interesting to compare the usage of appliances across continents.

The findings from a cross-sectional study would show:
- The long term impacts of access to e-cooking appliances
- Growth demand for appliances
- Sustainability of Appliance Financing

9. Conclusions

Overall, this study proved that AC appliances can work on DC mesh-grids with the necessary inverters and by enhancing access to e-cooking appliances households reaped significant benefits. The time saved due to e-cooking appliances and the money saved through transitioning to clean fuels reduces the burden on low-income households enabling them to spend time and resources on revenue generating activities.

Through tools such as Appliance Financing, access to clean cooking appliances not only reduces the need for deforestation, reduces exposure to harmful fuel and saves time and money - but it increases the commercial viability of rural electrification and could be used as a tool to accelerate rural electrification.

Following on from this study, Okra Solar has begun encouraging energy developers to deploy appliances in partnership with electrification projects. Appliances vary from fans, TVs to blenders and rice cookers depending on the needs of end-users.

To learn more about the capabilities of mesh-grids on clean cooking adoption, further trials are needed to test induction stoves and other multipurpose cooking appliances on DC solar mesh-grids.

10. Appendix

Please attach any additional relevant evidence – such as survey data, participant feedback, impact studies, etc.

- Appendix I: Appliance Evaluation & Specification
- Appendix II: Baseline Survey
- Appendix III: Follow-up Survey
- Appendix IV: Follow-up Survey – HHs not interested to continue
- Appendix V: Appliance Manual