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CLEAN COOKING DATA RELEASE REPORT

Findings of a Pilot Project with 100 Electric Pressure Cookers (EPC) in Rural Tanzania

November 2021

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EXECUTIVE SUMMARY

BACKGROUND

This study concerns data from 100 users across six solar mini-grid sites in Tanzania that used electric pressure cookers as part of a fourteen month pilot conducted from March 2020 to May 2021. Users were initially cooking at cost-reflective tariffs, which were reduced in October due to regulatory changes. From January 2021 on, power restrictions were implemented across the sites in order to minimize losses for the utility.

SUMMARY OF FINDINGS

We found that EPC usage was largely affected by the price of electricity, which affected both demand and supply of electricity. The average active user cooked with their EPCs 1 time per week when the electricity tariff was high and 1.2 times per day when the tariff was low. As regulations decreased tariffs, EPC usage increased across all sites. Shortly after, power began to be restricted at sites, resulting in outages that limited EPC usage.

High levels of usage corresponded to reductions in emissions and savings in time spent cooking. At the peak usage period of the pilot, active users of the EPCs reduced their traditional cookstove usage and its associated CO_2, indoor CO, and indoor PM emissions by 60% and saved nearly 2 hours of total cooking time each day.

The amount of EPC usage by a household at a high tariff level was not shown to have predictive power for how much the EPC would be used at a lower tariff level, implying that within this population there is no price-sensitivity factor that influences certain households' cooking behavior moreso than others.

Pilot data was used to create probability distributions for the likelihood that users would cook simultaneously or during a particular time of day. We found that in 52% of instances where someone began to use their EPC during the Low Tariff period, at least 4 other households were already cooking. During this same time period, 17% of cooking events occurred during night hours and 50% of cooking events happened between 10AM and 7PM.

CONCLUSIONS

Our research shows that many households have tangible interest in using electric cooking appliances and that these users can reap positive benefits from the appliance usage. The degree to which a user may access such benefits will depend on the broader context of their environment, such as the regulatory framework, grid design, and applicable electricity tariffs, and we find it likely that electric cooking appliance adoption will occur more rapidly in areas where there are already existing, favorable conditions. More research is needed to understand how specific policies and market conditions affect adoption.

Our work would not be possible without the support of our donors:

IKEA Foundation

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INTRODUCTION

BACKGROUND

Eighteen months have passed since A2EI, in collaboration with Nexleaf, Modern Energy Cooking Services (MECS), and PowerGen, initiated a pilot to answer the question: are electric cooking appliances the future of clean cooking? 100 participants located across six different mini-grid-connected villages were trained on the usage of electric pressure cookers (EPCs) and given EPCs connected to smart meters that monitored their usage.

In December 2020, A2EI released an energy consumption dataset collected by the smart meters during the first nine months. This data illustrated adoption behaviors of new users and included one month of data collected during a period of reduced tariffs.

We are now happy to share an updated and final dataset that covers the full fourteen month pilot. This report accompanies the data release and outlines key findings.

As in the previous report, we use the data to address the following questions:

- How did people cook with their new electric cooking appliances? How often did they really use them?
- What happened at the community level? How have electric cooking appliances affected the grid?
- What is the role of electricity prices in electric cooking behavior? What happens to electric cooking appliance usage when the price changes?

METHODOLOGY

This report analyzes data collected from A2EI's smart meters, which collect power and energy consumption data on five minute intervals and upload the data onto a server. To conduct the analysis, we constructed a cooking event definition and applied this to the dataset to extract a list of events.

At times, network connectivity to the smart meters was lost. During these time periods, energy consumption continued to be measured but was not assigned to a specific timestamp. In these instances, the cooking events were estimated based on the energy consumed and the characteristics of the average measured cooking event.

The data frame used in this report can be downloaded from the A2EI website.

KEY FINDINGS FROM STUDY

#1 HOW DID COOKING BEHAVIOR CHANGE WHEN THE PRICE DROPPED?

Figure 1: Aggregate Cooking Events and Cooking Households for All Users for Fourteen Months

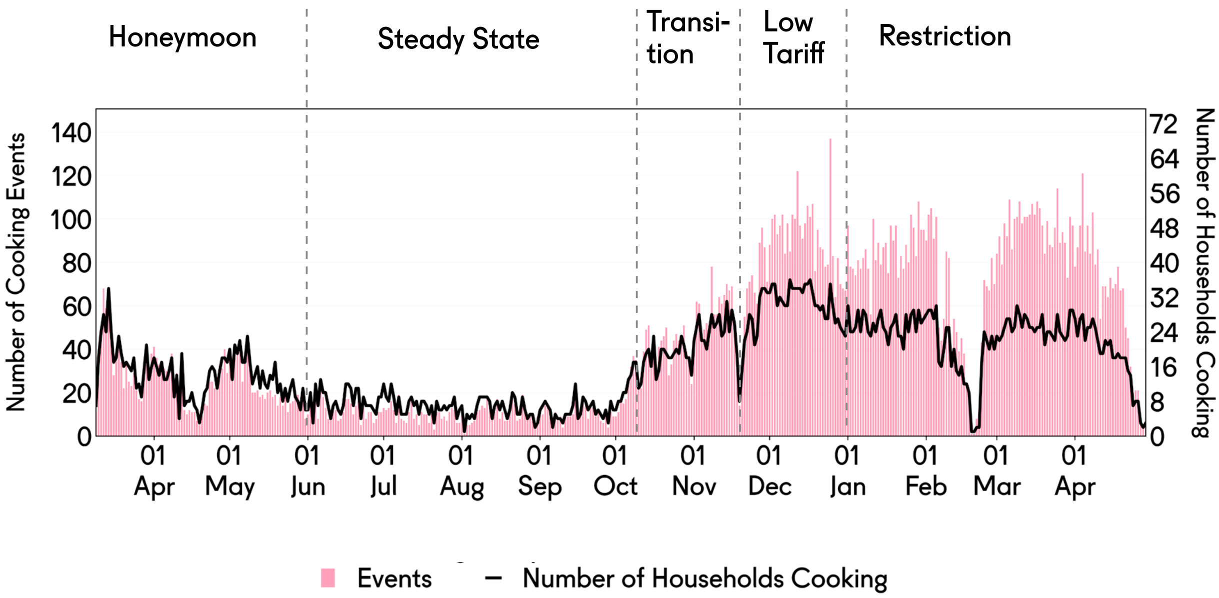


Figure 1 shows the EPC use over the fourteen months of pilot study, with all periods identified (see Annex 1).

In our previous data release we saw a sharp increase in EPC usage from October 2020 onwards. This uptake was caused by a reduction in tariff from a cost-reflective rate of approximately $1/kWh down to a rate of $0.044/kWh that was accessed through the purchase of 5kWh bundles. The low tariff was implemented from site to site successively between October 5th and November 18th, which we refer to as the Transition Period.

From November 18th to December 31st, all households at all sites were able to purchase electricity at low tariff conditions. Therefore, we refer to this timeframe as the Low Tariff Period. During this time, we observe high usage of the EPCs relative to earlier periods, making this one of the most interesting periods of the study for understanding the effects of electric cooking if it were to become widely accessible.

Table 1: Overview of Tariff Conditions and Timelines

Time Period Start	Time Period End	Tariff Structure
March 9th, 2020	October 5th, 2020	High tariff, around $1/kWh. Different tariff structures at different sites: Flat, discount or monthly-block tariff.
October 6th, 2020	November 18th, 2020	Mix of High tariff and Bundle tariff, depending on site location.
October 19th, 2020	December 31, 2020	Bundle tariffs at all sites.
January 1st, 2021	April 30th, 2021	Mix of Bundle tariffs with and without grid restricitions, depending on site location.

WHAT HAPPENED AFTER JANUARY?

From the data, we see a decline in cooking beginning in January, a sharp drop in February, and a final decline in April.

After introducing the low tariff bundles at all six mini-grid sites, government regulations were enforced that restricted the mini-grid operator's ability to offer daily bundles and instead directed them to charge per kWh of usage. As the tariff was not cost-covering, the mini-grid operator had to restrict the use of electricity from January 2021 onwards. Consequently, we refer to the period from January 1st on as the Restriction Period.

Different sites were subjected to different restrictions or completely shut down for periods of time during the restriction period. Some of the implemented restrictions were stopping the use of back-up generators in the evenings, which limited the availability of electricity in the evenings, and restricting the power availability to less than 1kW per household, effectively preventing the EPC from being used.

The data shows that EPC usage declined for nearly all users at all locations during February. A sharp decrease in usage is observed in the middle of February, which corresponds to a field visit in which smart meters were collected and therefore not tracking cooking behaviour between February 19 and February 23.

The dataset shows a decline in usage at the end of April, which corresponds to the meters being collected from the field starting on April 24.

We find it likely that the restrictions limited the availability of power and thus decreased appliance usage during this period, however we cannot estimate the magnitude of this effect. Clean cooking research needs multiple months of data collection to uncover behavioral trends, and we do not have a control group that enables us to measure the impacts of policy interventions.

#2 HOW DID INDIVIDUALS COOK WITH THE EPC?

Figure 2: Total Cooking Events per Smart Meter During all Pilot Periods, Ordered by Value

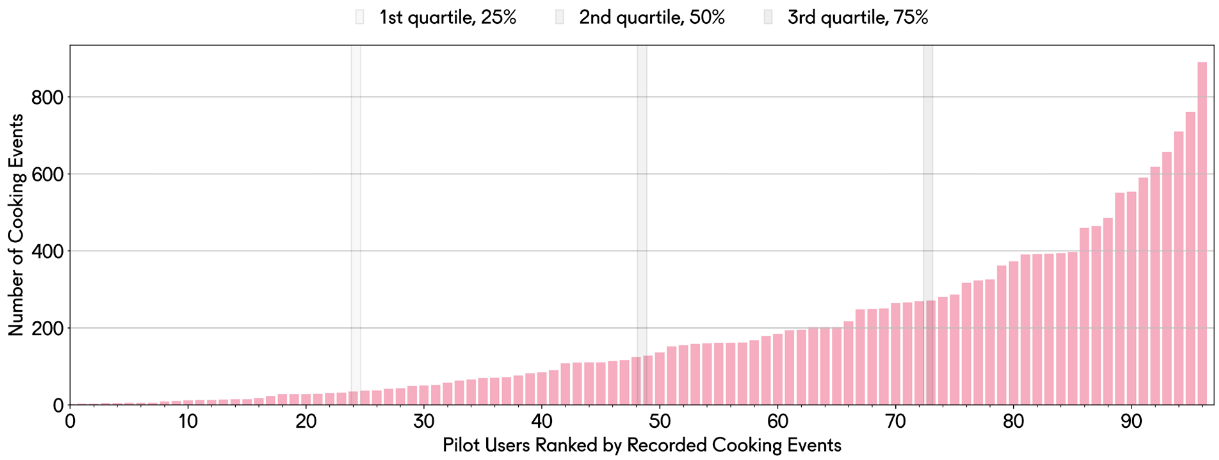


Figure 2 shows the cooking events recorded by the smart meters over the whole pilot period. From Figure 2 we see that until the end of our pilot, many users still utilized the EPC very little: 25% of users only cooked 31 times or less within fourteen months. The greatest share of cooking events still comes from only a small subset of users: the top 25% account for 63% of all cooking events, and the top five users alone account for 25% of all events.

This data shows that, during the 14 month pilot period with seven months of high tariff and four months of grid restrictions, only a minority of users benefited from the electric cooking appliances. Creating a favorable operating environment for users and electricity providers may enable more people to benefit from this technology.

Table 2: Cooking Events per User, Divided in Quantiles.

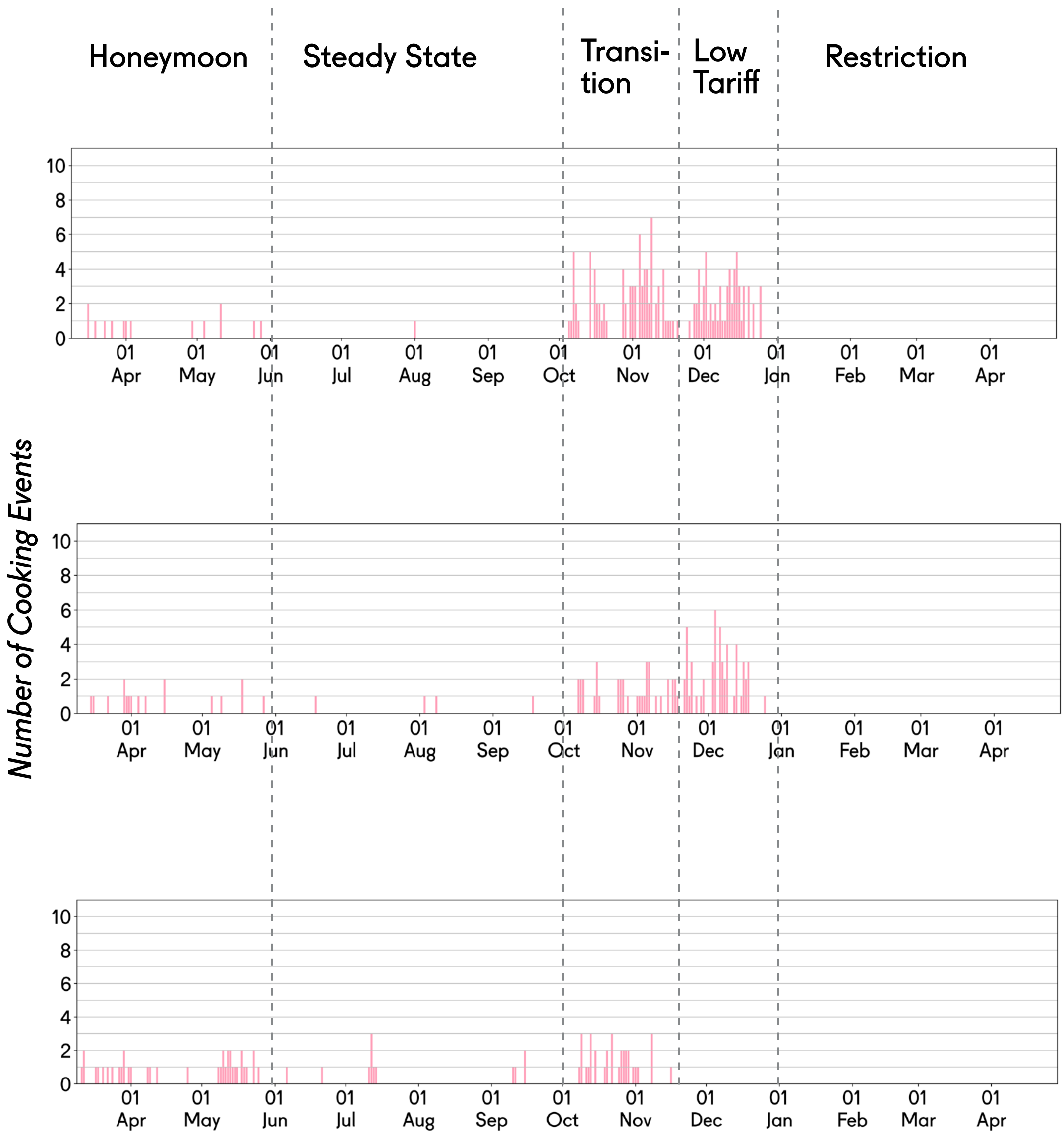
Quartile	Smart Meter	Cooking Events	Share of Cooking Events up to Quartile (%)
0%	#3	0	0.0%
25%	#29	31	1.6%
50%	#54	116	11.0%
75%	#79	269	36.5%
100%	#100	890	100.0%

#3 WHAT HAPPENED TO OUR REPRESENTATIVE USERS FROM THE LAST REPORT?

SELECTING REPRESENTATIVE USERS

In the following section, we present data from users selected in our last data release report that represented the range of cooking behaviours from our pilot group. The users were selected by summing up the total cooking events of each user during the Honeymoon and Steady State periods and sorting these users by number of cooking events.

Figure 3: Cooking Events and Energy Consumption during all Pilot Periods for Three Representative Users (I) from Mainland Sites



Low User (I)	Events	Energy (kWh)
Honeymoon	14	2.5
Steady State	1	0.1
Transition	81	14.4
Low Tariff	64	10.6
Restrictions	0	0.0

Medium User (I)	Events	Energy (kWh)
Honeymoon	17	4.1
Steady State	4	1.0
Transition	37	10.4
Low Tariff	53	15.8
Restrictions	0	0.0

High User (I)	Events	Energy (kWh)
Honeymoon	37	8.5
Steady State	12	2.9
Transition	33	8.6
Low Tariff	0	0.0
Restrictions	0	0.0

In our last data release, we noted that representative Low User (I) started to cook more than the Medium User (I) and High User (I) when the tariff was reduced. We hypothesized that this may be an effect related to the price-sensitivity of users, but were unable to draw conclusions given the limited data available after the reduction of the tariff.

Now with the full dataset, we are able to investigate our price-sensitivity hypothesis. We do this by ranking the users by number of cooking events during the Honeymoon and Steady State Period and comparing this to the same ranking from the Low Tariff Period to find the rank correlation. From this, we found there is no significant correlation between the two rankings, thus disconfirming our hypothesis: when considering all users across these periods, we find no evidence to suggest that the reduction in tariff affected certain users more than others.

Coming back to our three representative users, we observe that all three stopped cooking from January 2021 on. All three users are located in mainland sites, namely sites four and five, which experienced severe effects on power availability as a result of the restrictions: all thirty households located in those two locations stopped cooking by February (Annex 4).

#4 HOW DID USERS THAT WERE LESS AFFECTED BY RESTRICTIONS CONTINUE TO COOK?

Our three previously selected representative users (designated with an "I") were all located on mainland sites, but we observed different cooking behaviours amongst the households located on island sites where fewer restrictions were introduced and where there are different economic activities and food preferences. Using the whole fourteen months of data, we pick a new set of representative users (designated with a "II") from our island sites.

Figure 4: Cooking Events and Energy Consumption during all Pilot Periods for Three Representative Users (II) from Island Sites

Low User (II)	Events	Energy (kWh)
Honeymoon	7	2.6
Steady State	11	2.2
Transition	2	1.0
Low Tariff	5	0.9
Restrictions	47	26.4

Medium User (II)	Events	Energy (kWh)
Honeymoon	32	6.6
Steady State	4	1.0
Transition	5	1.4
Low Tariff	30	7.3
Restrictions	146	33.7

High User (II)	Events	Energy (kWh)
Honeymoon	69	12.7
Steady State	60	16.9
Transition	54	9.8
Low Tariff	114	21.5
Restrictions	189	34.3

Figure 4 shows that the representative High User (II) from the island site increased her cooking activities in November and kept them at a constant level until the end of February. Likewise, for the Low User (II) and Medium User (II) we see an increase in cooking activities in Transition, Low Tariff and Restriction Periods, but these increases are not constant in nature. We assume that grid downsizing and load restrictions placed on bundles resulted in these patterns.

When investigating the Low Tariff phase, we find our High User (II) cooking typically two times a day, with peaks up to six events per day, which would result in a large impact on time, health, and CO_2 savings if we assume that a great share of biomass cooking has been replaced.

#5 WHAT DID EPC COOKING LOOK LIKE AT SCALE?

Figure 5: Aggregate Cooking Events and Energy Consumption during All Pilot Periods

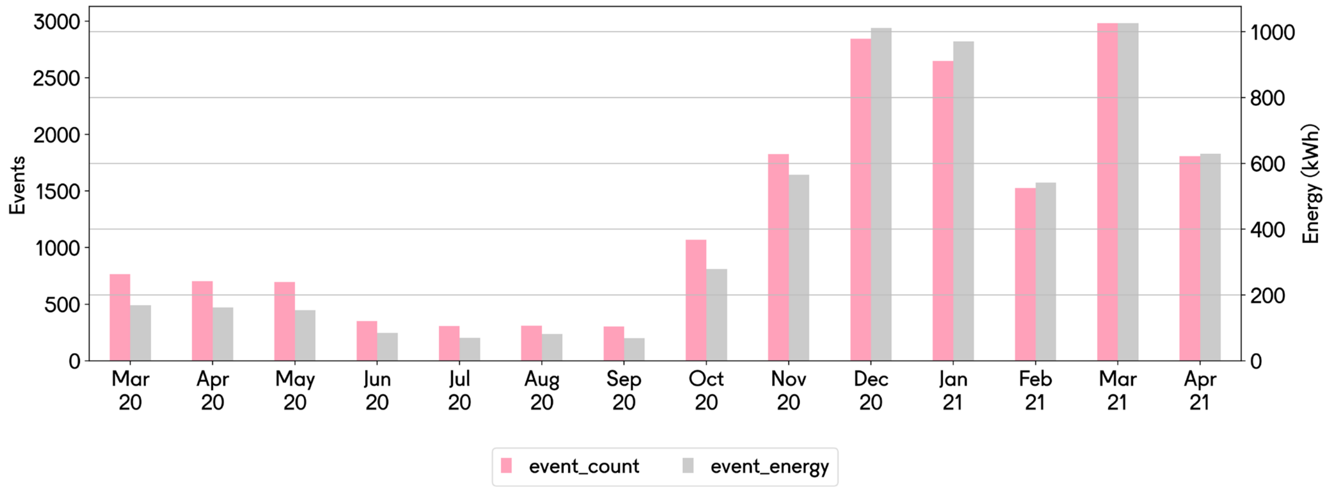


Figure 5 shows that from October onward there is an increase in cooking activities, with a peak in March 2021. We hypothesize that the trend of increasing energy consumption observed toward the end of 2020 might have continued if the grid had not been restricted. Instead, as restrictions affected different sites and households differently, we see a decline in cooking activities especially in February and April.

Table 3: Events, Energy, Cooking Minutes and Days per Period.

Phase	Days	Daily Cooking (minutes)	Daily Events	Daily Energy Consumption (kWh)	Number of active households (cooking)
Honemoon	84	688	26	5.8	87
Steady State	126	286	10	2.5	67
Transition	45	1491	46	12.7	67
Low Tariff	43	3244	84	29.6	69
Restriction	126	2805	75	26.6	64

During the Low Tariff Period, the average daily energy consumption from the EPCs was 29.6 kWh. At the low tariff of $0.044/kWh, this resulted in an average $1.30 in revenue per day across all users.

We can translate this energy consumption into a reduction of CO_2 emissions. Prior research found that stacking an EPCs with charcoal cookstoves reduces traditional cookstove usage by 33% [1]. Based on this, the 84 EPC events per day displaced 28 traditional cookstove events each day during the Low Tariff Period. Assuming that one firewood cooking session outputs ~765g of CO_2 [1, 2, 3], the EPC usage across the 69 active users reduces CO_2 emissions by 21.4kg each day.

The EPC usage also reduces cooking time for users. In a previous report, we found that pilot users cooked an average of 276 minutes each day without the EPC and that each minute the EPC is used reduces traditional cookstove cooking time by 3.5 minutes [1]. From this, we estimate that traditional cookstove usage was reduced by 189 hours each day and the group's total daily cooking time was reduced by 135 hours each day. Thus, each active user reduced their traditional cookstove usage by 164 minutes (60%) each day and saved almost 2 hours (39%) of total cooking time each day.

The reduction in cooking time also translates into a reduction in carbon monoxide and particulate matter, which are harmful to the health of users. Assuming EPC users were otherwise using a Tier 0 type cookstove with indoor CO and PM rates of 0.97 g/min and 40 μg/min respectively [3], the EPC usage resulted in a total of 11.0kg of CO and 454mg of PM reduced indoors each day during the Low Tariff Period. Based on our estimates of traditional cookstove usage reduction, each user reduced their daily emissions by 60%, making their daily emission rate lower than that of someone who cooks with LPG despite any continued fuel stacking with traditional cookstoves.

#6 WHAT WAS THE EFFECT OF COOKING ON THE GRID?

When looking at the effect of cooking on the grid we focus on the Low Tariff Period when EPC usage was highest and the grid was most likely to be overwhelmed by the power demand.

Figure 6: Number of Cooking Events per Hour for Sum of All Users on Average Day in Low Tariff Period

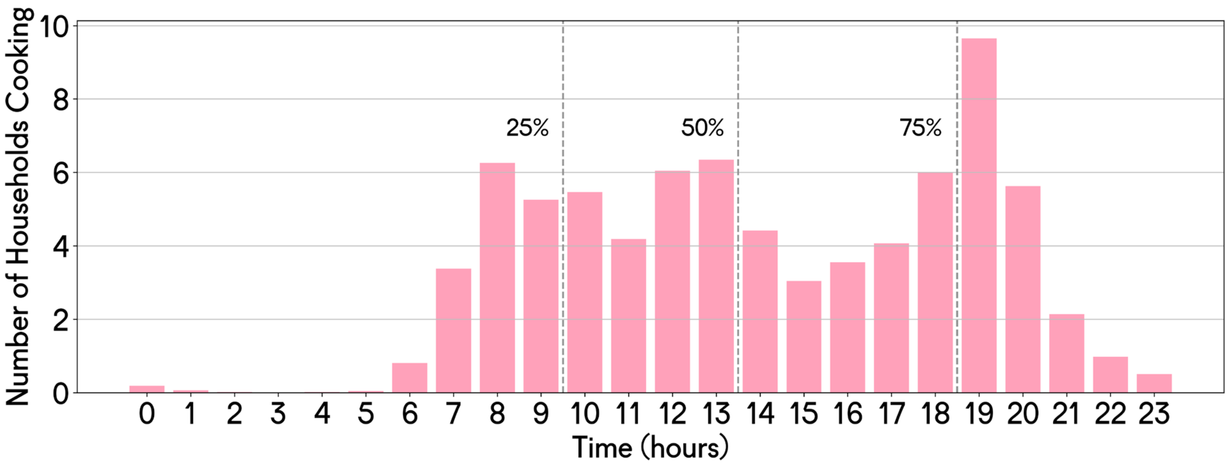


Figure 6 shows at which time during the day the pilot households cooked. We find 17% of cooking events took place at night, which in the considered region is before 8 AM or after 8PM, and 50% of cooking events took place between 10 AM and 7 PM. For grid systems using renewable energy like solar or wind, this data is useful for designing systems and understanding how batteries and back-up generators may be required.

Figure 7: Probability distribution that a number of households are cooking simultaneously during the Low Tariff Period

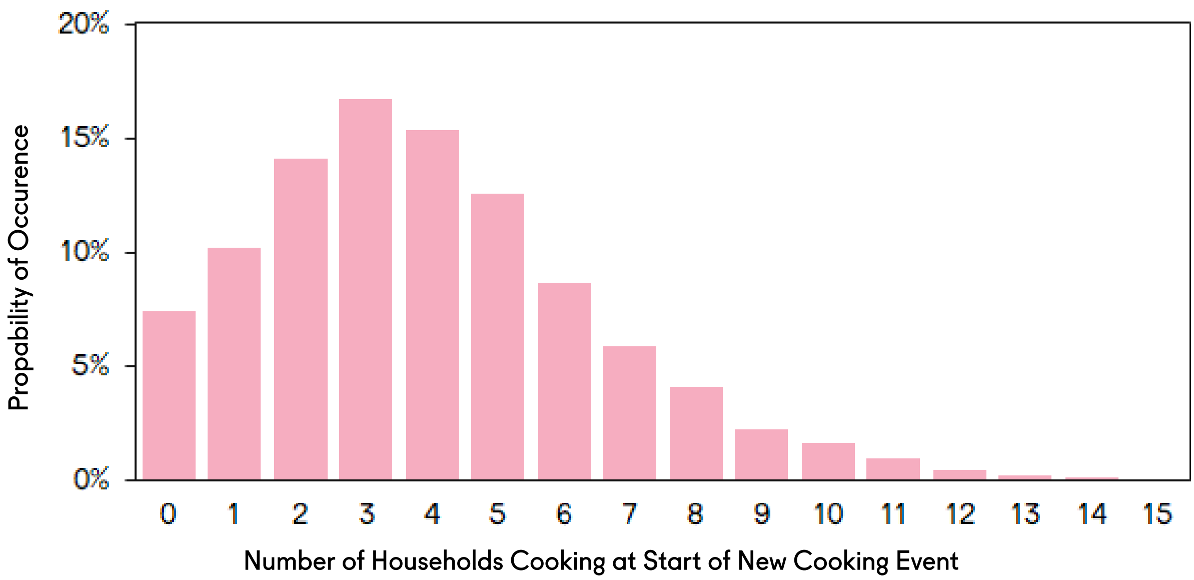
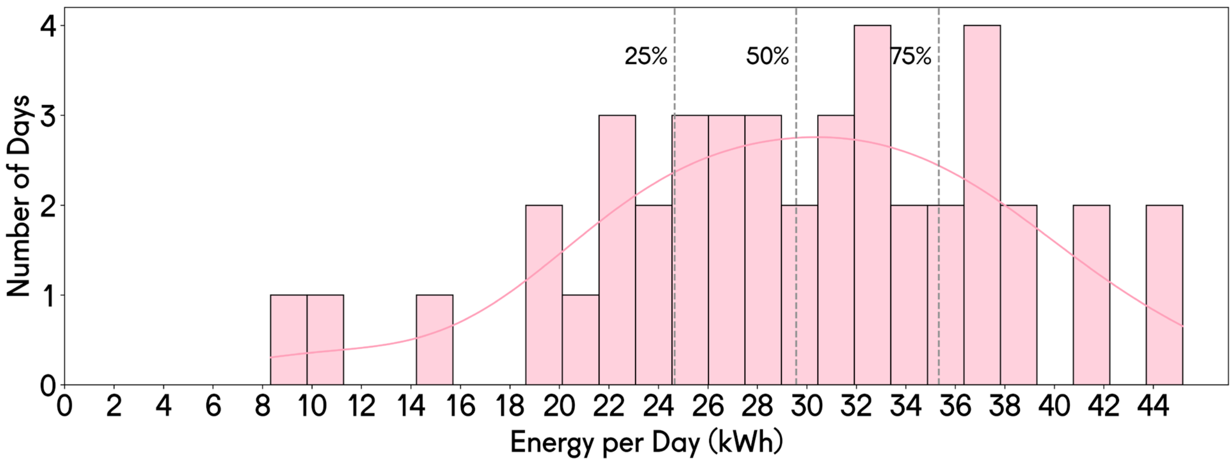


Figure 7 shows the probability distribution that a given number of other households would be using their EPCs at the start of a new cooking event during the Low Tariff Period. We found that 17% of the time someone began to use their EPC, three other households were already cooking (resulting in four households cooking simultaneously). In 52% of instances, at least 4 households were cooking at the start of a new cooking event, and in one single instance there were 16 households cooking simultaneously. The average number of households already cooking at the start of a new cooking event was 3.9 and standard deviation of 2.5. This data can be used by utility providers to estimate the likelihood that a grid would be overloaded by the introduction of electric cooking appliances.

Figure 8: Distribution of Aggregated Daily Energy Consumption during the Low Tariff Period



To understand the effect of the pilot users on the grid as a whole, the aggregate daily energy consumption was found and plotted in Figure 8. Here we see that in 50% of instances, less than 29kWh are consumed in a day and the maximum energy consumed in a single day was 44kWh. This data is useful for designing solar grid systems, which must generate sufficient energy each day in order to meet the needs of users.

CONCLUSIONS

How did people use electric cooking appliances? How often did they really use them?

When the EPC was introduced, people used it frequently. After becoming familiar with the costs and benefits of the technology, usage decreased and stabilized. When the cost of energy was reduced, people began using their EPCs more than before. Eventually, electricity regulations restricted power availability, which limited opportunities for usage.

In the context of our pilot, the average active user cooked with their EPCs 1 time per week when the electricity tariff was high. When the tariff was reduced, the average active user cooked with their EPC 1.2 times per day. Throughout the study, roughly 30% of all pilot users were not actively cooking with their EPCs, regardless of the tariff.

What happened at the community level? How have electric cooking appliances affected the grid?

In this particular pilot, the grids were largely unaffected by the introduction of electric cooking, but did require the usage of diesel generators to handle the increased load. Using the probability distributions from this study, it's possible to estimate the probability that a given number of households will use electric cooking appliances simultaneously for a given population size.

What is the role of electricity prices in electric cooking behavior? What happens to electric cooking appliance usage when the price changes?

When prices were lowered, we saw a sharp rise in demand for electricity as many people started cooking. We disconfirmed a previous price-sensitivity and found that how a user responds to a change in electricity price cannot be estimated from their prior cooking behavior.

We found that electricity pricing also affected energy supply, such that low prices ultimately restricted energy access and limited cooking. It is crucial to find a price point which favors both utility companies and users in order to maximize the benefits to users and the environment.

TEASER: THE MARKET FOR EPCs

At the end of our pilot, we conducted a willingness-to-buy test by selling the EPCs to the participants. All of the surveyed respondents stated their willingness to purchase an EPC on credit, but ultimately all participants who purchased the EPC paid with cash and none purchased on credit. Stay tuned for more findings on the profile of users that purchased the EPCs and what factors may have determined that outcome.

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[1] Kweka, A., Clements, A., Bomba, M., Schürhoff, N., Bundala, J., Mgonda, E., ... & Scott, N. (2021). Tracking the Adoption of Electric Pressure Cookers among Mini-Grid Customers in Tanzania. Energies, 14(15), 4574. Page 21, Page 9, Table 4, Page 18.

[2] Energy Sector Management Assistance Program. 2020. Cooking with Electricity : A Cost Perspective. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/34566 License: CC BY 3.0 IGO. pages: 124 figure C.2, page 140 Table C.2.

[3] World Bank, 2014. Clean and improved cooking in sub-Saharan Africa: A landscape report, Washington, D.C. Available at: http://documents.worldbank.org/curated/en/879201468188354386/pdf/98667-WP-P146621-PUBLIC-Box393179B.pdf [Accessed June 1, 2017], pages: 143, Table 7.2.

ANNEX 1: PILOT PERIODS

Period	Dates	Description
Honeymoon	March 1 - May 31	This period has an initially high usage rate that declines over the period, presumably related to the novelty of owning a new appliance.
Steady State	June 1 - October 4	This period has a low and relatively constant usage, possibly reflecting that users have gained sufficient clarity of the costs and benefits of using the EPC and are able to make rational decisions about its usage.
Transition	October 5 - November 18	Usage increases as block tariff structures are implemented across sites, reducing the cost of cooking.
Low Tariff	November 19 - December 31	This period involves relatively high levels of EPC usage that increase over the period as users enjoy low-cost cooking.
Restriction	January 1 - April 24	High usage persists across sites, but power availability becomes an issue at several sites. Firmware updates on remote monitoring devices result in periods where no data is captured.

ANNEX 2: SITE DETAILS AND TARIFF STRUCTURES

Table 1: Mini-grid sites in A2EI pilot

Tariff Structure	Description	Applicable Sites
Flat	Customers are charged a flat per kilowatt-hour rate regardless of how much energy they consume.	Site 1 - Island Site 2 - Island
Discount	Customers are charged a Flat Tariff, discounted by 42%.	Site 3 - Island
Block	Customers are charged a Flat Tariff and given a 37.5% discount after consuming at least 3kWh.	Site 4 - Mainland Site 5 - Mainland Site 6 - Mainland
Bundle	Customers purchase bundles of 5kWh at $0.22 or 10kWh at $0.44.	All sites, implemented between October 5th and November 18th until December 31.
Regulated	Customers are charged a flat per kilowatt-hour rate equivalent to that of the national grid.	All sites after January 1.

ANNEX 3: SITE-SPECIFIC PLOTS

Figure 1: Site 1 - Island

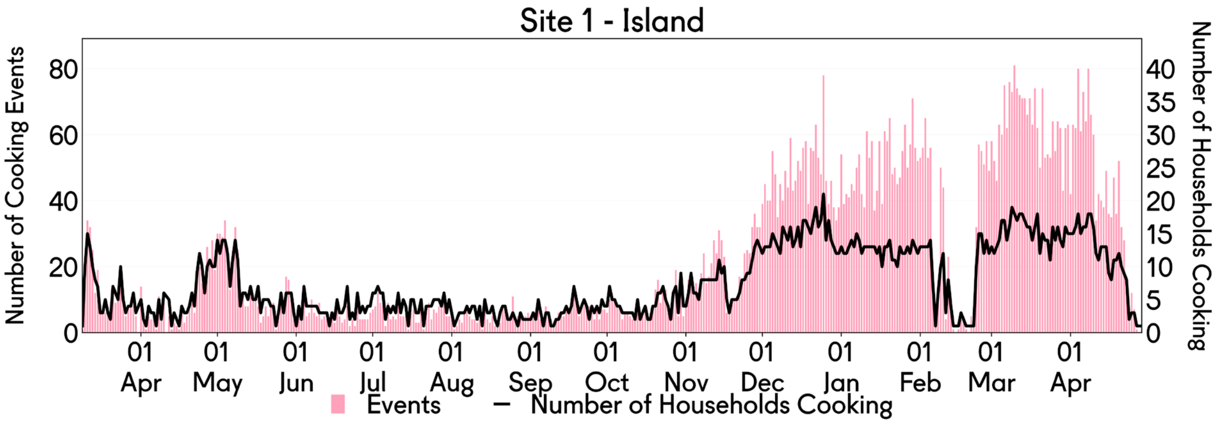


Figure 2: Site 2 - Island

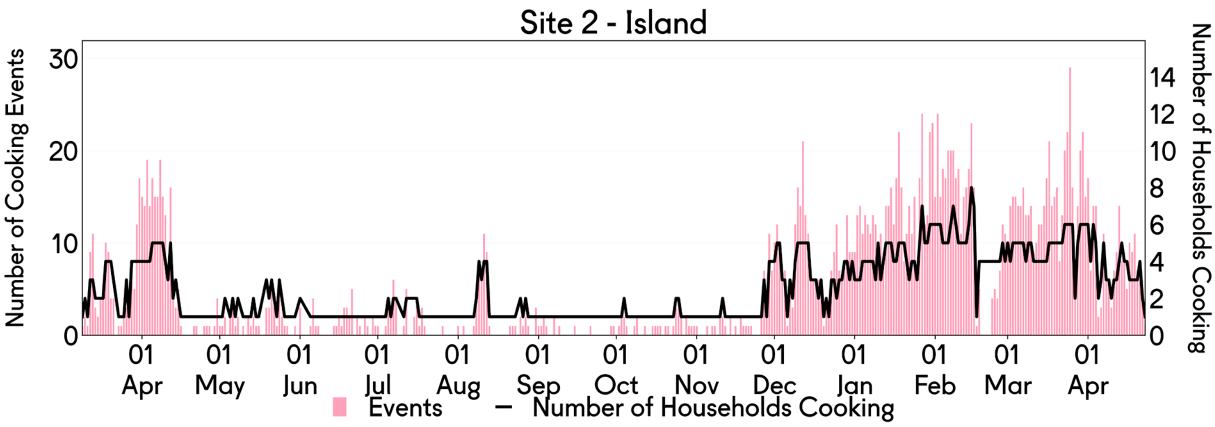


Figure 3: Site 3 - Island

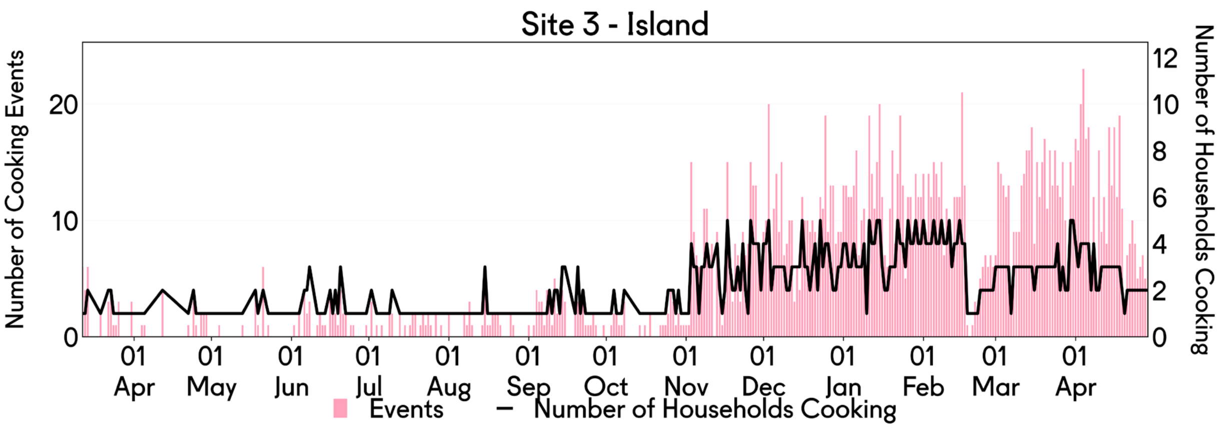


Figure 4: Site 4 - Mainland

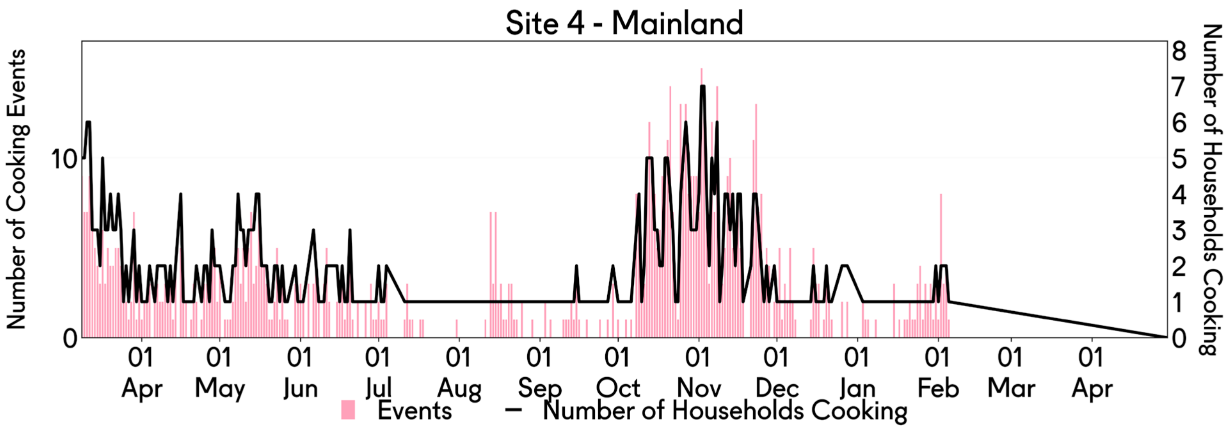


Figure 5: Site 5 - Mainland

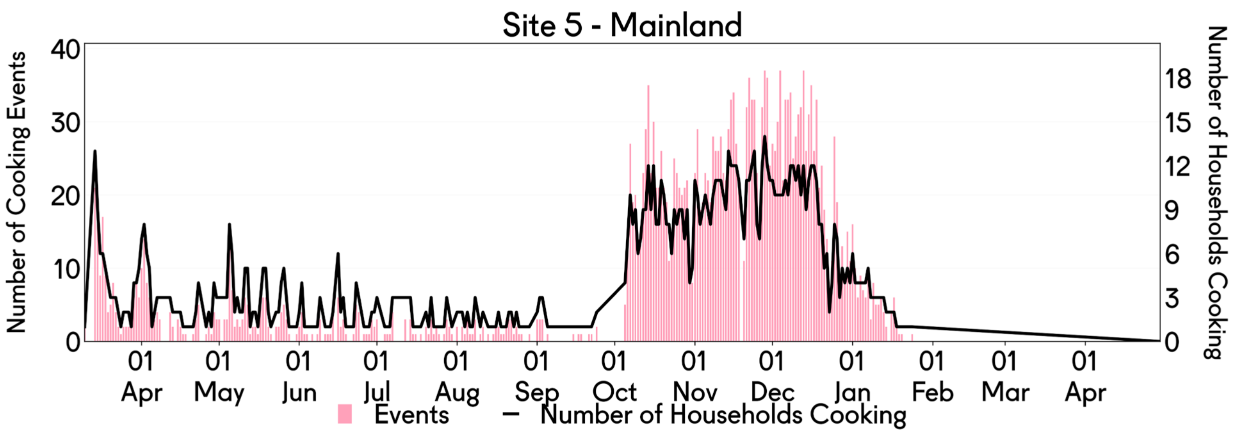
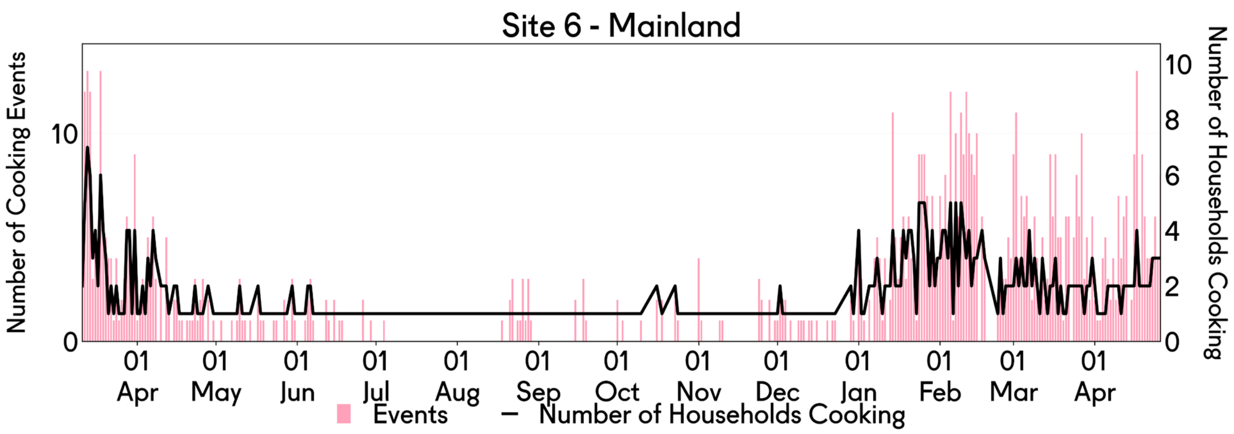


Figure 6: Site 6 - Mainland



ANNEX 4: GEOGRAPHY-SPECIFIC PLOTS

Figure 7: Site 1-3 - Island

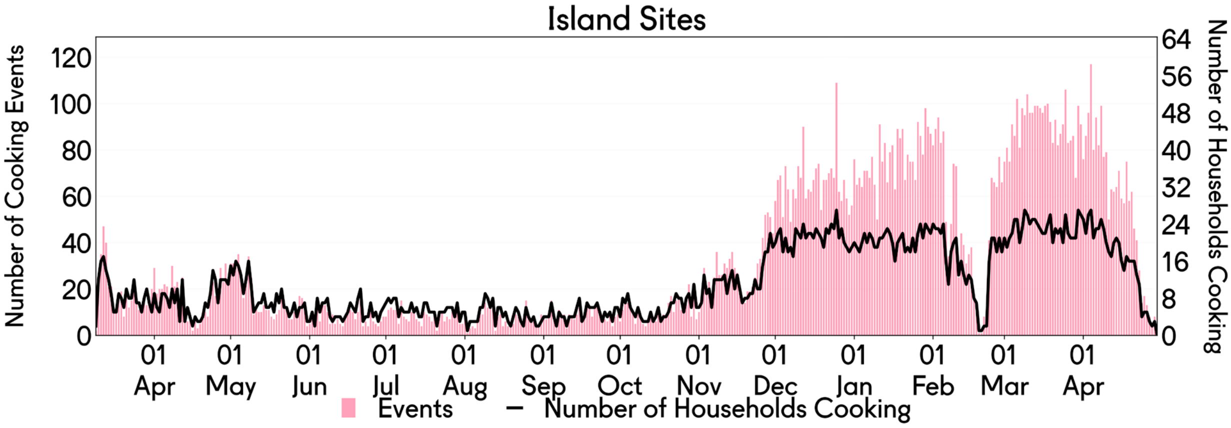
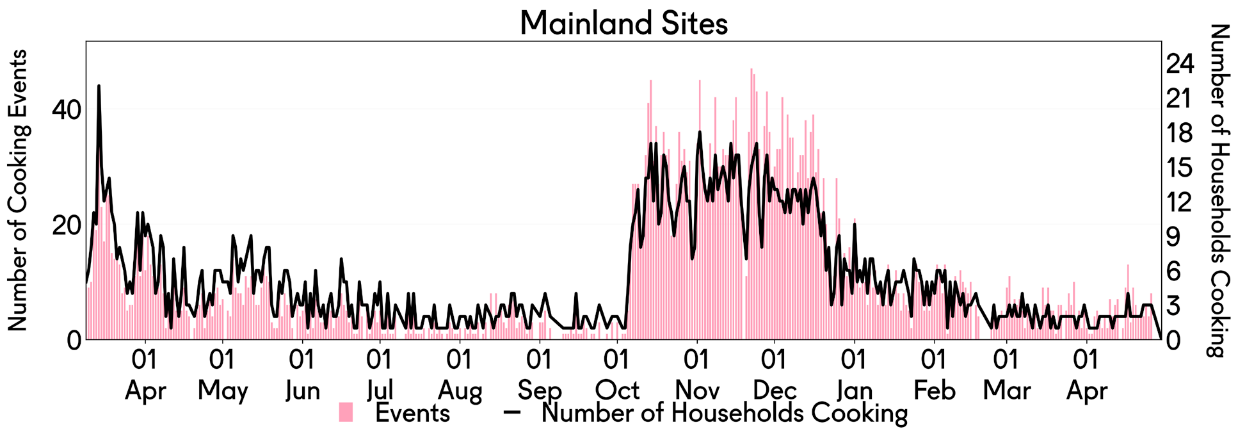


Figure 8: Site 4-6 - Mainland



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