MECS Modern Energy Cooking Services

MECS Behaviour Change Project Report (public version)

Understanding Pay-As-You-Go LPG Customer Behaviour

Bboxx

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By Tash Perros, Paul Buettner and Dr. Priti Parikh

Loughborough University

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Contact Details:

Tash Perros, Doctoral Researcher
Dr. Priti Parikh, BBOXX/Royal Academy of Engineering Senior Research Fellow
Engineering for International Development Research Centre
Bartlett School of Construction and Project Management
University College London
Gower Street, London
WC1E 6BT

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1 Executive Summary

Bboxx is a next generation utility who operated a pay-as-you-go (PAYG) LPG pilot of 90 customers in Kigali, Rwanda, from July 2019 to April 2020. This research study was conducted in March 2020 through a collaboration between MECS, UCL and Bboxx, and aimed to investigate the characteristics and cooking practices of Bboxx's PAYG LPG customers. Understanding the use of charcoal alongside PAYG LPG (fuel stacking) was of particular interest as it perpetuates the negative health and environmental impacts of cooking with biomass. Stacking also threatens cooking-as-a-service business models such as Bboxx's by diminishing technology adoption and therefore commercial viability.

This study used a sample of 62 customers in a mixed methods approach. Data sources included Bboxx's remotely monitored LPG consumption data, charcoal stove usage data collected with temperature sensors, telephone surveys, household interviews, secondary data from Bboxx's sign up survey and participant cooking diaries. Early results from the study showed that participants were reluctant to cook beans on LPG, so we conducted additional experiments to measure the costs and taste differences between different fuel and bean (dried, pre-soaked and pre-cooked) combinations.

Who were Bboxx's PAYG LPG customers?

PAYG LPG customers had a higher income than the average Kigali citizen and were 19% less likely to live below the poverty line. They were well educated; 47% had university degrees, which is four times higher than the city-wide average. 83% said they could have afforded LPG even if there was no PAYG and 34% had cooked with LPG previously, which is high given the low penetration of LPG in Rwanda. 71% used charcoal as their primary cooking fuel before signing up to Bboxx's service and 28% used LPG.

What were customers' experiences of using PAYG LPG?

The most important advantages of PAYG LPG were safety, delivery, affordability compared to charcoal and the ability to buy small amounts of fuel at a time. The lack of upfront cost was least important of the beneficial aspects, which is unsurprising give the customer demographics. Operational limitations sometimes caused delays in processing top ups and cylinder refills, causing customer dissatisfaction.

The PAYG LPG per kg price was 1.4 times that of standard retail LPG in order to amortise the equipment costs. Customers were aware of this and complained about affordability. Despite this, most customers had experienced a modest decrease in cooking fuel expenditure since adopting PAYG LPG, with a self-reported mean monthly saving of RWF 3,240 (£2.60), corresponding to 15% of average cooking fuel expenditure. However, a third reported an increase in fuel spend.

What were the cooking practices of PAYG LPG customers?

51% of events recorded in the cooking diaries were water heating and 49% were cooking food. Water was heated to purify it before drinking, for bathing and for making hot drinks. Meals were usually composed of hot components cooked at home with an average of 2.2 dishes per meal. Six foods accounted for 74% of cooking events and were, from highest to lowest frequency, green vegetables, rice, ugali, potatoes, bananas and beans. The average cooking time for a single dish was 42 minutes, but beans took considerably longer, at 89 minutes. Beans were the only food cooked more often on charcoal and were widely perceived as being incompatible with LPG cooking. Water heating was split evenly between fuels. Cooking events were clustered around mealtimes at 1pm and 8pm.

What were the patterns of fuel stacking?

91% of customers still had working charcoal stoves in their home and 61% said they still used them, but this was likely to be an underestimation of the reality. 25% had electric cooking devices such as kettles. On average there were 18.2 LPG cooking events per week (79% of the total) and 4.9 charcoal cooking events per week (21% of the total), although it is important to note that the extent of stacking varied widely. Self-reported user behaviour did not correlate well to measured stove use, with charcoal cooking being particularly underreported. LPG and charcoal were both used on 34% of days and in 12% of meals, providing evidence that charcoal cooking was not driven solely by the unavailability of LPG. LPG was favoured for frying. Meals cooked with one fuel were composed of 2.1 cooked components on average versus 2.7 for meals cooked with both fuels, implying that the need to cook multiple elements of a meal simultaneously could have driven stacking.

The most cost-effective way of cooking beans was using pre-cooked beans on LPG and was 12% cheaper than the standard of dried beans on charcoal. Soaking beans led to a financial saving of 5%. In taste tests people could not consistently identify the fuel or the bean, and 80% of participants said they would change the way they cooked beans following the experiments. This illustrates that cooking demonstrations can be an extremely effective behaviour change tool.

What interventions could reduce stacking?

Based on the study findings, the following interventions could have reduced fuel stacking in PAYG LPG customers:

- The introduction of flat tariffs that separate out the repayment of equipment and service costs from the LPG price, increasing transparency and making PAYG LPG comparable to market rates
- Increasing the level of operational coverage and automation to provide a service where customers never run out of gas
- Introducing four-burner LPG stoves that allow more dishes to be cooked simultaneously
- Educating customers about the direct health and financial impacts of increased LPG adoption, particularly for children
- Changing the way that people cook foods viewed as incompatible with LPG, such as beans and cassava leaf. This could be done by providing pressure cookers, which can greatly accelerate time spent cooking such 'heavy' foods, or by promoting fuel-efficient practices like soaking beans before cooking. The co-distribution of pre-cooked beans alongside LPG could also be effective. However, these solutions will only be effective if they are accompanied by sufficient efforts to persuade people to adopt these new practices, which are expensive and difficult to scale

It could be economically beneficial for Bboxx to incorporate these interventions into their business model. Only 57% of average total cooking fuel expenditure was on LPG. This led to the estimation that eliminating fuel stacking would reduce the average customer's monthly cooking fuel expenditure by 27% from 18,500 RWF to 13,420 RWF (£14.60 - £10.70), and Bboxx's monthly revenue per customer would correspondingly increase by 28% from 10,500 RWF to 13,420 RWF (£8.30 - £10.70).

What were the impacts of the pilot shut-down and COVID-19 lockdown on cooking practices?

The study was disrupted by the COVID-19 pandemic and by Bboxx's decision to close the Rwandan pilot. The COVID-19 lockdown resulted in insignificant changes of charcoal and LPG use, although people reported spending more time cooking as the whole family were at home. Immediately after the termination of the BBOXX pilot, charcoal cooking increased, although insignificantly. The cooking diaries show that two months after this event, most customers continued to use LPG, presumably by switching to a different retail provider and

continuing to use the equipment acquired through the pilot. This suggests that PAYG LPG could play an important role in shifting biomass users to clean fuels by providing a low-risk way of trialling the technology and a pathway to equipment ownership.

In conclusion, this study provides an important contribution towards understanding cooking practices in urban Rwanda. Most customers saved money when they switched their primary fuel to PAYG LPG, yet continued to stack frequently with charcoal. It revealed a number of ways that stacking could be reduced, resulting in direct health and financial benefits to consumers and increased revenues to Bboxx. Further research is needed to understand the efficacy, scalability and financial viability of these interventions.

1 Introduction

Pay-as-you-go (PAYG) LPG is an emerging internet-connected innovation that allows customers to pay for LPG as they cook rather than having to purchase it in whole cylinders. It also includes an asset financing component, thus making the transition from biomass fuels to LPG more affordable for those with low and uncertain incomes

Under the PAYG LPG model, the customer is provided with the hardware components at little or no upfront cost: a gas canister with an embedded smart meter and valve, an LPG cylinder, a stove and other accessories. Credit is purchased from the provider via mobile money. This allows the corresponding amount of gas to be dispensed from the cylinder whenever the customer wishes to use it. Once the credit has been expended, the valve turns off and prevents any more gas from flowing. When the cylinder is nearly emptied, the provider replaces it with a new one, ensuring that customers always have access to fuel in their homes. The system also enables the provider to remotely track customers' gas consumption, allowing a detailed insight into their cooking practices.

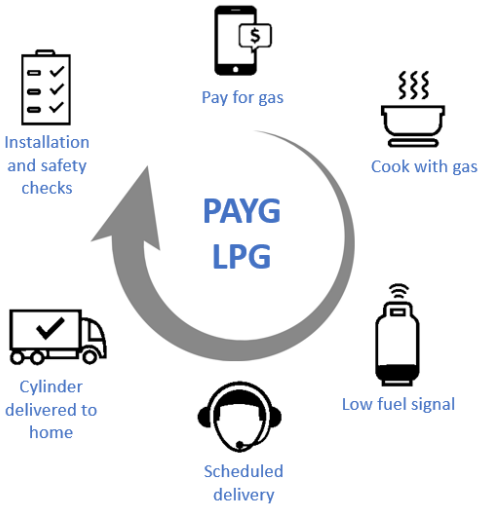

Figure 1: How PAYG LPG works. Adapted from https://envirofit.org/smartgas/

One of the companies trialling this new technology is Bboxx (https://www.Bboxx.com/), the research partner for this project, who design, manufacture, distribute and finance products to enable energy access across the developing world. This project is funded by MECS and linked to the Bboxx/Royal Academy of Engineering Fellowship 'Smart Solar Solutions 4 All'.

1.1. Bboxx PAYG LPG pilot

Bboxx launched their 'Bboxx Cook' initiative in July 2019 with a PAYG LPG pilot of 90 customers in Kigali, Rwanda. Marketing activities were performed to raise awareness about the new product, such as a press launch and the distribution of leaflets through sales agents and Bboxx shops. Customers eligibility was solely based on where they lived in the city, and units were allocated to the first 90 customers that signed up. These customers were located in sectors of Remera, Bumboga, Kucyiru, Kimironko, Rusoro, Ndera, Gisozi, Kicukiro, Gatenga, Nibaya, Kagarama and Kanombe, as is shown in Figure 2 below.

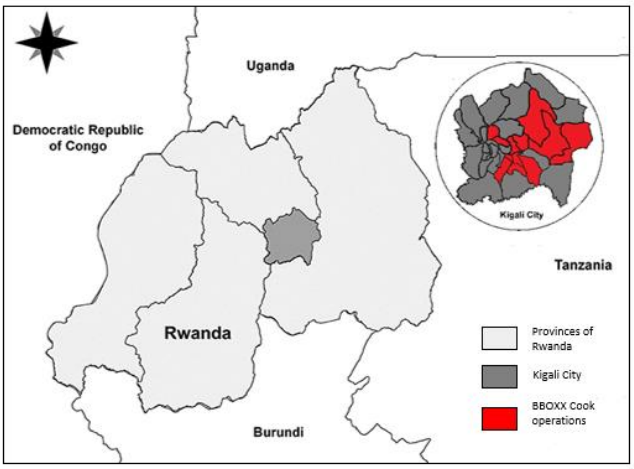

Figure 2: Map of Bboxx PAYG LPG customers

Figure 3: PAYG LPG system in a customers' home. Photo credit: T. Perros

Operations were run out of a hub in Remera with a team of trained technicians. Deliveries of new cylinders and any required maintenance were triggered by customers contacting Bboxx. Customers paid one of three different tariffs (see Table 1) which were designed to make cooking with LPG cheaper than cooking with charcoal.

Tariff	Down-payment	Gas price	Number of customers
Flat	13,500 RWF (£10.70) Includes 2kg credit	1,800 RWF (£1.40) per kg	28
Tier	13,500 RWF (£10.70) Includes 2kg credit	Reduces based on monthly usage from 1,900 RWF (£1.50) for the first 3kg to RWF 1,280 (£1.00) for 10+kg	50
Subscription	10,000 RWF (£7.90) Includes 1kg credit	5,000 RWF (£4.00) for the first kg and 1,280 RWF (£1.00) thereafter	12

Table 1: PAYG LPG tariffs. Source: Bboxx

Customers would own the stove after a six-month period, whereas other equipment (the cylinder, regulator, meter and its accompanying battery) would continue to belong to Bboxx. Customers were provided with a detailed manual on system use, safety, maintenance and payment. A dedicated customer service was set up to provide additional support over telephone.

In January 2020 Bboxx decided to wrap up the pilot at the end of March, by which point ownership of the stove had been transferred to 70% of customers. The SMART meter was removed and customers were gifted the cylinder, stove (for those who had not yet paid it off), regulator and hose so they could continue to use LPG from other retail providers. The decision accelerated this research study, which had originally been planned for later in the year, and was subsequently brought forward to March – April 2020, so that the impact of the pilot closure could also be investigated.

1.2. Aims & objectives

The aim of this study was to understand patterns of fuel stacking in Bboxx's PAYG LPG Rwandan customers. The objectives were:

1. To understand the characteristics of Bboxx's PAYG LPG customers
2. To understand their experiences of using PAYG LPG
3. To examine their cooking practices
4. To analyse their patterns of fuel stacking
5. To develop ideas for interventions to reduce stacking
6. To assess the impacts of COVID-19 and the pilot shut-down on cooking practices

The remainder of the report is structured as follows: Section 2 covers the methodological approach; Section 3 presents the results and discussion according to the research objectives; Section 4 discusses the limitations of the study; Section 5 suggests further work and Section 6 presents the conclusions.

2. Methodology

Ethical approval for this study was granted by the University College London Research Ethics Committee [17653/001] and the University of Rwanda. UCL guidelines for ethics, data protection and informed consent were adhered to throughout.

2.1. Sampling

An initial telephone survey was conducted with 62 customers (TS1). This was used to gauge willingness to participate in the other components of the study: household interviews (INT), the installation of stove use monitors or SUMs (SUM), cooking diaries (CD) and focus groups discussions (FGD), although the latter ended up being replaced by a second telephone survey (TS2) due to COVID-19 restrictions. Customers were randomly assigned to different elements of the study according to their consent profiles, with some participating in as many as four elements in total. The exception was the CD, for which customers were purposively sampled as those who lived in close proximity to the Bboxx office due to the enumerator-intensive requirements of the activity. High degrees of overlap between different parts of the study were incorporated into the study plan to allow for triangulation between the methods. Figure 5 and Figure 4 below show the total number of participants in each activity and their overlaps.

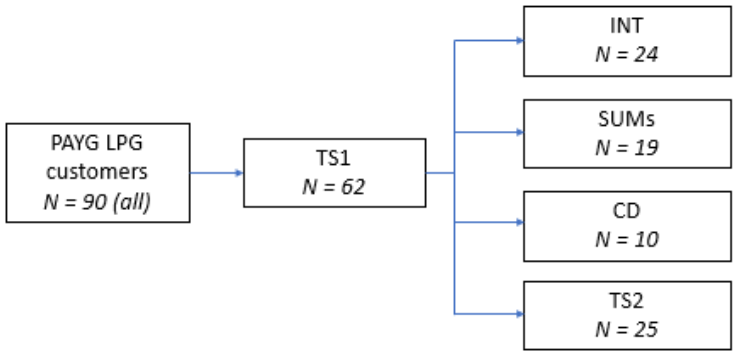

Figure 5: Sampling diagram

Group	N
TS1	17
TS1 & TS2	14
TS1 & INT	7
TS1 & INT & SUM	5
TS1 & INT & SUM & CD	5
TS1 & SUM & TS2	4
TS1 & INT & TS2	4
TS1 & CD	3
TS1 & INT & SUM & TS2	3
TS1 & SUM & CD	2
Total	***64***

Figure 4: Overlaps between research methods

2.2. Methods

For clarity this report will use the following terms will to describe the time at which data was collected:

Time period	Definition
Pre-lockdown (**pre-LD**)	Data collected prior to the 21st of March 2020, when Kigali went into COVID-19 lockdown
During-lockdown (**mid-LD**)	Data collected during Kigali's COVID-19 lockdown, from 21st of March to 25th of May 2020
Post-lockdown (**post-LD**)	Data collected after the 25th of May 2020, when Kigali's lockdown eased

Table 2: Terms for referencing time of data collection

2.2.1. Telephone Surveys (TS1 and TS2)

TS1 was performed by two bilingual enumerators and was used to collect quantitative data. The surveys took place in Kinyarwanda and were recorded in English using the Kobo Toolbox online survey tool. Most of the questions were closed and the participants answered by choosing from a fixed range of answers. However, some were open and were later coded for analysis by the researcher. TS2 was similar but was administered by a single enumerator. Analyses was performed in Excel and Python.

Data collection for these study components went to plan, with N = 62 for TS1 and N = 25 for TS2.

2.2.2. Household Interviews (INT)

24 household interviews were conducted by the same enumerator as TS2 and took place at the customers' households. It was a structured interview with both qualitative and quantitative components. The enumerator asked questions and made observations (e.g. about the building material of the roof) to input into the Rwanda Poverty Parity Index (PPI) (Schreiner 2016). This is a country-specific poverty measurement tool consisting of ten questions that are scored to estimate the probability that a household is poor. These calculations were subsequently made in the analysis stage using the PPI Excel Tool to gain an additional understanding of the pilot demographics. The remaining analysis was done in Excel and Python.

2.2.3. SUMs (Stove Use Monitors)

Stove use monitors, or SUMs, measure the use of a stove by taking regular temperature measurements to identify when cooking is taking place (Ruiz-Mercado et al 2012). It was not necessary to use SUMs on the LPG stoves because of the consumption data sets being collected by the SMART meters (known as SMART data set, see Section **Error! Reference source not found.**), so they were only used on biomass stoves to understand patterns of use of charcoal alongside LPG.

20 iButton DS1922Ls were installed in households and were programmed to take temperature readings every 10 minutes. All households used same type of metal artisanal charcoal stove as their secondary cooking device; the SUMs were sandwiched between high-grade silicon insulation for thermal protection and were attached to the handles using tape and wire as shown in Figure 6. Data was manually retrieved using a laptop and was planned to take place every two weeks to avoid memory saturation. This happened for the first four weeks of the study and then was disrupted by COVID-19, which resulted in the sensors being trapped in people's homes until the 18th of May, when restrictions eased sufficiently for them to be collected.

Figure 6: SUM being attached to charcoal stove.
Photo credit: T. Perros

In the end 18 full sets of data were collected as two out of the 20 sensors were lost by customers during the monitoring period. In total 1267 days' worth of SUMs data were collected, of which 223 were pre-LD and 1044 mid-LD.

The SUMs data was analysed using Geocene's SUMSariser tool (https://www.geocene.com/), which employs a machine learning algorithm to identify cooking events from the temperature time series data. This was overlaid onto the Bboxx SMART data using Python to compare charcoal and LPG cooking.

2.2.4. Cooking Diaries (CD)

Cooking diaries (CD) are used to develop a deeper understanding of how people cook (Leary, et al 2019). They aim to generate detailed self-reported data to understand people's cooking habits, the processes that underpin then (e.g. boiling, frying) the niches that different devices satisfy, and were implemented following protocols developed by Leary et al (Leary et al. 2019; Leary et al 2019).

Customers were asked to fill in a meal form every time they used a cooking device either for cooking food or for heating water. The forms collected data on what the device was being used for, the cooking processes being used, duration of cooking, quantities of food, number of portions, time of cooking and number of people eating. Customers were also provided with weighing scales and were asked to measure the amount of charcoal used by each cooking event. At the end of the day, a separate summary form was completed to give an overview of cooking activities that had taken place during the day, included those that were not captured by the meal forms for any reason (e.g. eating at a friend's house, forgot to fill in the form).

A high degree of support from enumerators was planned to ensure high quality data was being collected, with regular household visits and frequent reviews of the forms. However, the cooking diaries activity had only just begun when the Rwandan COVID-19 lockdown was announced, meaning that enumerators were unable to visit the households to collect the data or replenish the paperwork, and the bulk of data collection was delayed until post-LD. In total 157 days' worth of data were collected across 10 customers, with a total of 379 meal forms and 126 summary forms completed. 18 days' worth of data for five customers were collected pre-LD, comprising 43 meal forms and 8 summary forms. Post-LD, 138 days of data were collected across 10 customers, consisting of 336 meal forms and 118 summary forms.

The quality and completion rates of certain fields on the meal form were low so they were omitted from the analysis. These were the weight of charcoal before and after cooking events, the time that fuel measurements were taken, the quantity of each dish cooked, the number of portions of each dish cooked and the use of lids for water heating events. This was ultimately due to the pressures of COVID-19; training was rushed because the lead researcher had to return early to the UK, and the restrictions meant that we were unable to collect the diaries until the end of the study as already discussed. Once these exclusions had been made the meal forms were 93% complete on average.

Summary forms existed for 70% of the days on which meal forms were completed and were 93% completed on average. One customer did not complete any summary forms. On 81/123 (66%) of the days that summary forms were completed the number of meal forms matched the number on the summary form. On 29 days (24%) the actual number of meal forms was less than on the form and on 13 days (11%) there were more forms filled in than expected. The discrepancies could be due to forms being lost, memory recall issues from participants when filling out the summary form or misdating of forms.

2.2.5. Beans Tests (BT)

As the fieldwork progressed evidence mounted that the belief that beans should only be cooked over charcoal was a driver of fuel stacking. In Rwanda beans are traditionally cooked from a dried state by boiling them over charcoal for several hours; pre-soaking the beans, which can greatly reduce cooking times, is not a widespread or accepted practice. The household interviews revealed a reluctance to change the way that beans were cooked; it was important to cook them the traditional way for reasons of taste (something that would be changed by soaking or using LPG) and price (the long cooking times meant using LPG was too expensive).

Dried beans & LPG	Soaked beans & LPG	Pre-cooked beans & LPG
Dried beans & charcoal	Soaked beans & charcoal	Pre-cooked beans & charcoal

The pre-cooked beans were a commercial product sourced from a company called The FarmFresh Food Company LTD ("Farm Fresh", https://www.farmfresh.rw/) and donated to support this research. They are pre-cooked in electric pressure cookers and are more expensive than standard dried beans. They simply need to be heated following instructions on the packet. Soaked beans were immersed in water for 24 hours prior to cooking.

Measurements were taken of: the time taken to cook each bean & fuel combination, the amount of fuel used and the cost of ingredients. The equivalent of 900g of dried beans were cooked in each test (corresponding to 1.4kg of pre-cooked beans), which is the amount that households normally cooked. Two tablespoons of salt were added to each cooking pot to normalise taste.

Three nearby households already known to the enumerator through other components of the study participated in the BT. The tests took place over three consecutive days, with each household conducting one charcoal test and one LPG test simultaneously, and the tests rotating daily so that each household cooked every bean and fuel combination. The process was supervised by an enumerator who had been trained in how to cook the different products. The research project paid for the cooking fuels upfront.

Each day, once all six samples had been cooked, members of the participating households and their neighbours were invited for blind taste tests. The beans were coded with letters and served in plastic cups. Participants did not know which letters corresponded to each bean and fuel. They were asked to fill in a form ranking the six samples of beans in order of preference and to guess which bean and fuel corresponded to each sample. On the third day a brief interview was also conducted with the participants.

Figure 7: Blind taste tests of different bean / fuel combinations
Photo credit: Moise Dushime

The tests were conducted to plan over three days pre-LD. 102 forms were collected as part of the taste tests and 10 interviews were completed, half of which were with respondents who considered themselves to be the main cook in the household.

2.3. Incentives

Incentives were paid to participants in the SUMs, household interviews and cooking diaries using mobile money. Payments were made once data collection had been completed. The size of the incentive depended on the level of effort required from participants and was decided in consultation with Bboxx, who have extensive experience conducting research in Rwanda. Table 3 shows the incentives used and their equivalents in GBP.

Research activity	Incentive (RWF)	Incentive (GBP)
INT	2000	1.60
SUM	6000	4.80
CD	4000	3.20
BT	6000	4.80

Table 3: Incentives for research participants
1 RWF is the equivalent of 0.0008 USD in March 2020 (https://www.xe.com/)

2.4. Secondary Data Sources

Bboxx conducted a short survey with all of their PAYG LPG customers when they first registered to use the service. This included questions about their primary cooking fuel, how they heard about the product and their motivations for signing up.

2.4.1. Bboxx Registration Surveys

Bboxx conducted a short survey with all of their PAYG LPG customers when they first registered to use the service. This included questions about their primary cooking fuel, how they heard about the product and their motivations for signing up.

2.4.2. SMART Data

The SMART data was a time-series data set collected for all PAYG LPG customers. For each unit, a reading was taken every 10 minutes of total amount of LPG used to that point (a volume measurement called 'pulse count') and the amount of credit remaining.

By subtracting the pulse count at time t from time t-1, it was possible to identify when cooking was taking place. Testing showed that it was possible for cooking to occur in a 10-minute interval without a pulse registering. Therefore, the data was aggregated into 20-minute intervals prior to analysis, to minimise the chances of a single instance of cooking being counted as two separate events. This analysis was conducted in Python.

The SMART data, was collected for all customers until: a) the remote monitoring component was removed by Bboxx at the end of the pilot or b) until the PAYG LPG ran out, which was the case if Bboxx did not manage to do visit the customer to retrieve the monitoring hardware pre-LD. The LPG runout date for customers falling into the latter category ranged from the 29th of March to the 20th of May. From the 1st of March onwards, there were 530 days of SMART data collected pre-LD and 455 days of data collected mid-LD. Pre-LD, there were 218 days where both SUMs and SMART data had been recorded, and 249 days of this overlapping data mid-LD.

2.5. Disruption due to COVID-19

The COVID-19 pandemic caused considerable disruption to the study. The lead researcher, who was overseeing and field managing the data collection, had to travel back to the UK earlier than planned. The Rwandan government subsequently announced a full lockdown on the 21st of March (Nkurunziza 2020), which meant that enumerators were no longer able to visit customers. The restriction began to ease on the 4th of May (Uwiringiyimana 2020b) and data collection was able to resume in the middle of May. The main impacts to the research are described below and are also shown in Figure 8:

- **SUMs**: 3 weeks of data were successfully collected before the COVID-19 lockdown. The SUMs were subsequently trapped in people's homes until the restrictions eased and they could be collected on the 20th of May. For all of the SUMs, 4-5 days' worth of data was lost between the 18th and the 24th of March due to memory saturation

- **Cooking diaries:** Data was collected for 10 participants rather than the planned 25. Two weeks of data were collected pre-LD instead of four as planned. A further two weeks of data were collected after the easing of the lockdown, from the 18th – 31st May. During this time the enumerators were unable visit households as in-person interactions still had to be minimised. Daily support calls were made to participants instead, and the enumerators filled in the summary forms instead of the participants. All the meal forms were then collected from the households at the end of the study.

- **Focus groups**: These were cancelled and were replaced with 25 additional surveys that were conducted over telephone during lockdown (TS2).

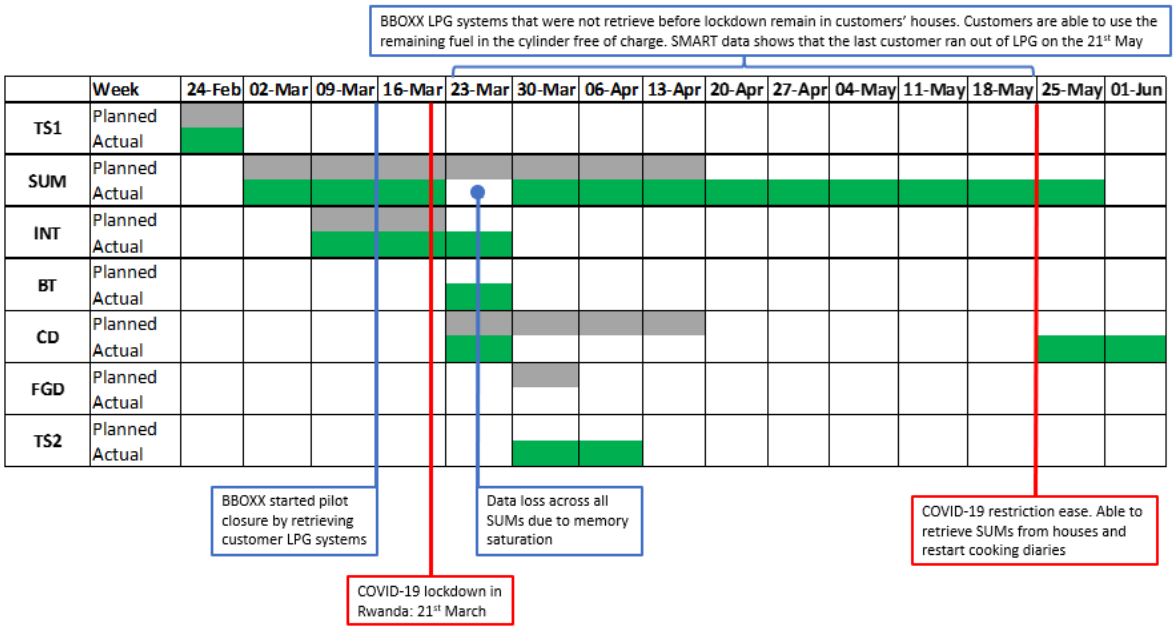

Figure 8: Impact of COVID-19. Key: TS1 = telephone survey 1, SUM = stove use monitors, INT = household interviews, BT = beans tests, CD – cooking diaries, FGD = focus group discussions, TS2 = telephone survey 2

2.6. Triangulation to investigate the impacts of COVID-19 and pilot closure

Bboxx's customers experienced some significant changes during the research project (losing access to PAYG LPG; COVID-19 lockdown; easing of the lockdown), and, as shown in Figure 8, the data was unevenly distributed throughout pre-LD, mid-LD and post-LD. This raised concerns about the extent that the data was impacted by these externalities. However, it was possible to estimate these effects by triangulating between data collected at different points in time, as is detailed below. The results of this approach are presented in Section 3.6.

2.6.1. Cooking Diaries

Comparing the CD data for the customers who completed the CD both pre- and post-LD allowed an assessment of the validity of the majority of the CD data to non-COVID times. A comparison of the primary fuel choice recorded in the CD post-LD to that reported in Bboxx's baseline survey meant that it was possible to examine if the experiences of participating in the pilot and gaining the equipment had facilitated a transition to LPG that outlasted Bboxx's involvement. This is illustrated more clearly in Figure 9 below.

Customer ID	Primary fuel before PAYG LPG (from BBOXX baseline survey)	# days CD data during pilot	# days CD data after COVID-19 lockdown easing (and end of pilot)	Primary fuel after COVID-19 lockdown easing (and end of pilot)
1	LPG		15	Results from Cooking Diaries data analysis
16	Charcoal		14	
27	Charcoal		12	
34	Charcoal		15	
60	LPG		14	
86	Charcoal		30	
45	Charcoal	5	14	
94	Charcoal	5	15	
95	Charcoal	5	13	
111	Charcoal	5	15	

Comparing these data sets determines how affected the rest of the CD data was by COVID-19 + pilot end

Comparing these data sets shows the impact of the pilot on people's choice of primary cooking fuel

Figure 9: Triangulating with the CD data

2.6.2. SUMs + SMART data

Comparing different overlaps between the SUMs and SMART data for each customer allowed an assessment of the impacts of: 1) the COVID-19 lockdown on charcoal and PAYG LPG use; 2) the COVID-19 lockdown and not paying for fuel on PAYG LPG use; and 3) the impact of running out of PAYG LPG on the use of charcoal. This is shown in more detail in Figure 10 below.

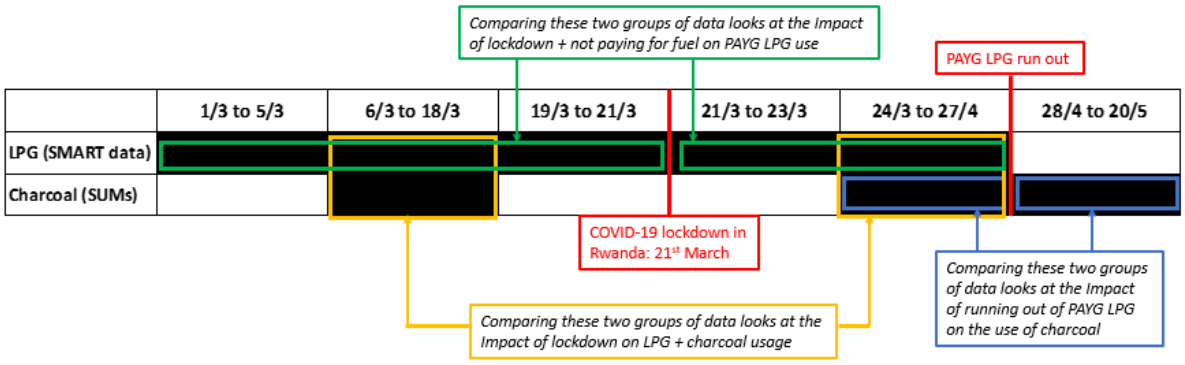

Figure 10: Triangulating with the SUMs and SMART data

3. Results and Discussion

The following results are presented according to the research objectives. The brackets after each finding indicate the method that was the source of the data.

3.1 Who were Bboxx's PAYG LPG customers?

3.1.1 Sociodemographics

The PPI showed that the probability of a Bboxx customer being beneath the Rwandan poverty line was 2.6%, which is significantly less than the Kigali-wide figure of 22% (The World Bank 2015). Self-reported data collected in TS1 found that the average monthly income was 250,000 RWF (£198), which is 53% higher than the Kigali median income in 2017 of 162,500 RWF (£129) (Bower et al. 2019). The modal monthly income bracket was 100,000 – 200,000 RWF, as shown in Figure 11, which is consistent with the Kigali median, but the high proportion of respondents who chose not to say indicates that the PPI findings may be more reliable. 39% of respondents in TS1 reported having house help and 61% had incomes that varied from month to month (TS1).

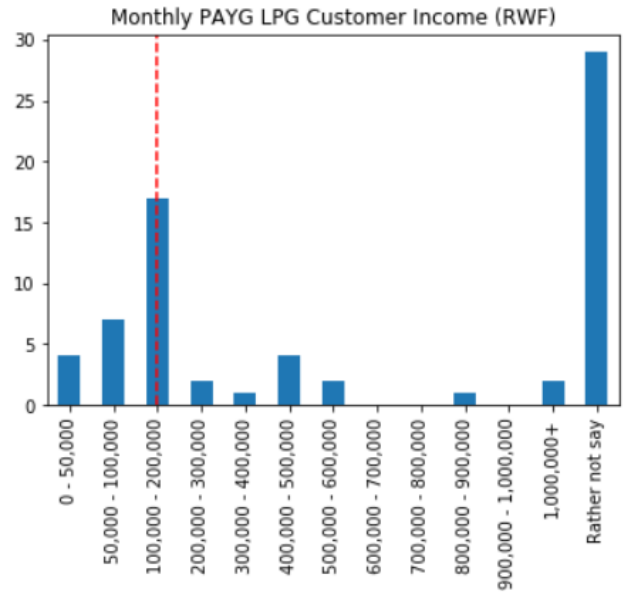

Figure 11

The average number of adults in each household was 2.4 and children 1.1, giving an average household size of 3.5, which is similar to the 2017 Kigali mean of 4.0 (Bower et al. 2019). The average age of the head of household was 33, which is slightly below the Rwandan urban mean of 38 (National Institute of Statistics of Rwanda 2019), and the highest level of education in the household was mostly secondary or university, as shown in Figure 12. 47% had university degrees, which is considerably higher than the Kigali-wide statistic of 11% (National Institute of Statistics of Rwanda 2014).

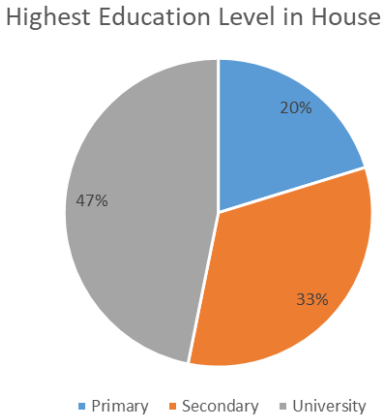

Figure 12

All customers had access to electricity and were on the grid, which was unsurprising as the pilot was based in the capital city. 17% reported being members of SACCOS savings groups and three people said that members of their group had used SACCOS to buy cooking equipment (INT).

Cooking tended to be a female-led task, as shown in Figure 13 (note that the housekeeper is usually female), and men were responsible for cooking 29% of the time. Yet the PAYG LPG contract was in the name of a male in 80% of cases (Figure 15). This could demonstrate a power imbalance between the genders in domestic decision making, which has been previously identified as a constraint to scaling the clean cooking sector (Hart and Smith 2010). It could also reflect an inequity in mobile phone ownership between the genders as this was a requirement for having a PAYG LPG contract. Figure 14 and Figure 15 show that twice as many females signed up to PAYG LPG as were heads of households, suggesting that women had agency over these decisions in at least some cases.

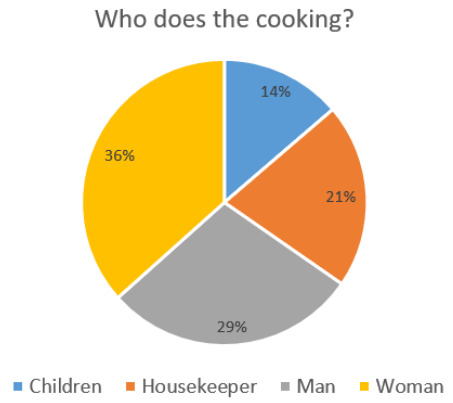

Figure 13

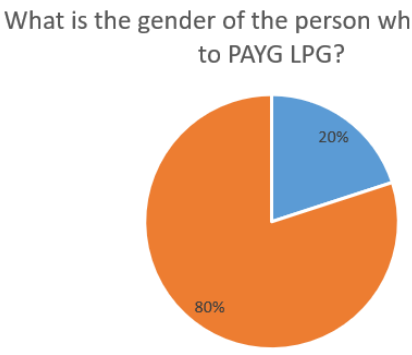

Figure 15

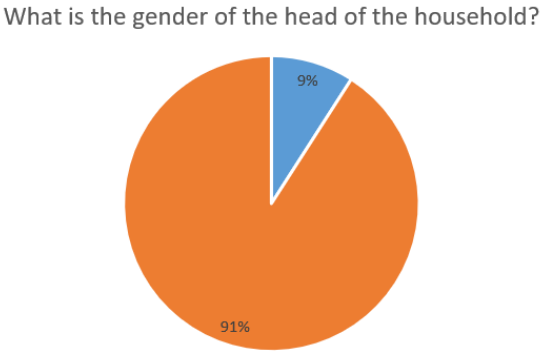

Figure 14

3.1.2 Purchasing decisions

The gender gap in Figure 14 and Figure 15 suggest that men had more control over purchasing decisions than women. Figure 16 and Figure 17 below display data from the household interviews showing PAYG LPG customers usually discovered new products through word of mouth, and that the opinions of friends and family were most valued. This is further validated in TS1 where most customers said they heard about Bboxx through a friend of neighbour (Figure 18).

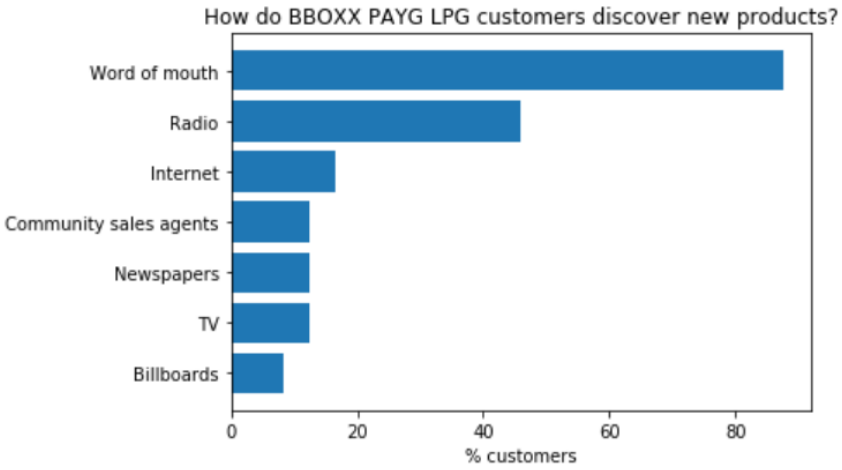

Figure 16

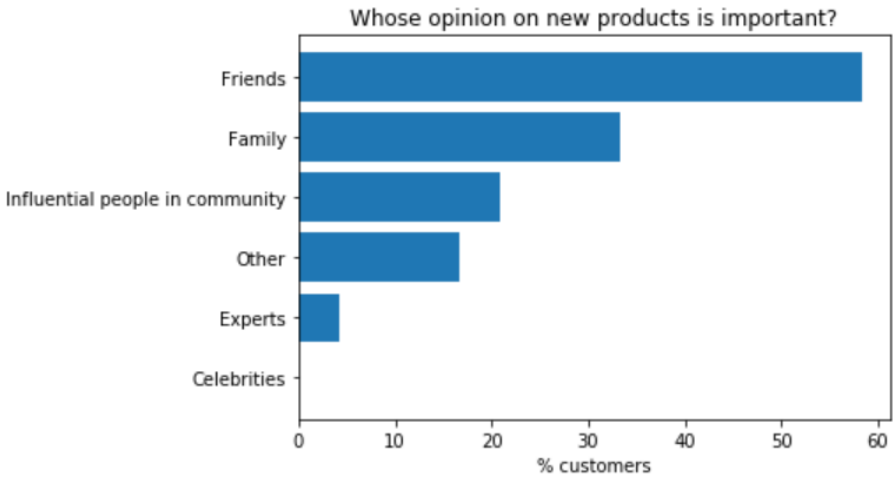

Figure 17

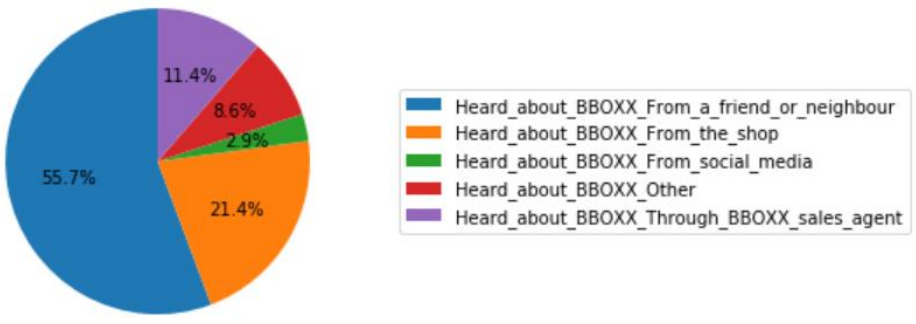

Figure 18: How customers heard about PAYG LPG

92% (N = 22) of respondents in the INT considered themselves to be early adopters of new technologies. The most important aspect of a new product was price (see Table 1) and purchases were usually made to upgrade an item that was already owned (92%, Figure 19).

Aspect	Mean rating
Price	1.9
Service	2.7
Warranty	3.1
Aesthetics	3.6
Brand	3.7

Table 4: What aspects of a new product are most important? (1 = most important, 5 = least)

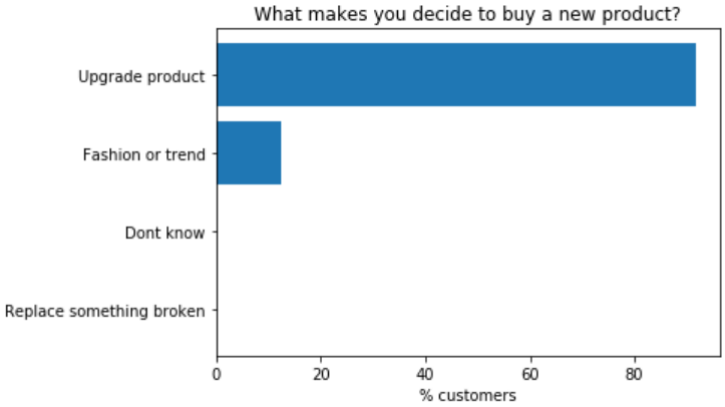

Figure 19

3.1.3 Cooking before PAYG LPG

TS1 found that the term 'clean cooking' was mostly understood to relate to physical cleanliness, as is shown in Figure 20, which is often considered as one of the greatest benefits of clean cooking (Ronzi et al. 2019; Williams et al. 2020). Figure 21 shows there was an understanding of the health benefits of clean cooking, with 67% of respondents recognising the link between clean cooking and disease. Of this 67%, half were able to specify that the associated diseases were respiratory in nature. There was also a good understanding of the environmental benefits of clean cooking, particularly with regards to deforestation (Figure 22). Customers' understanding of the benefits of clean cooking was higher than has been found in other studies (e.g. Evans et al. 2018; Lewis et al. 2015) which could be attributed to the success of Bboxx's education and awareness raising activities.

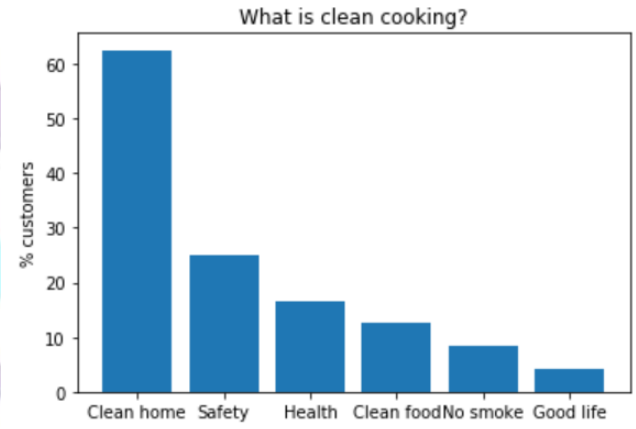

Figure 20

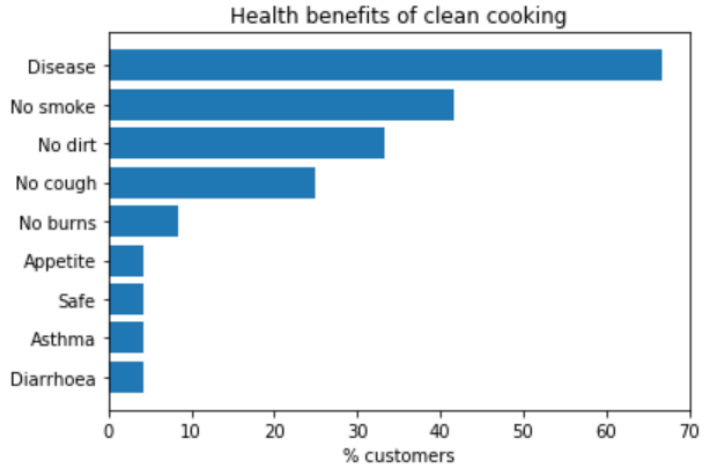

Figure 21

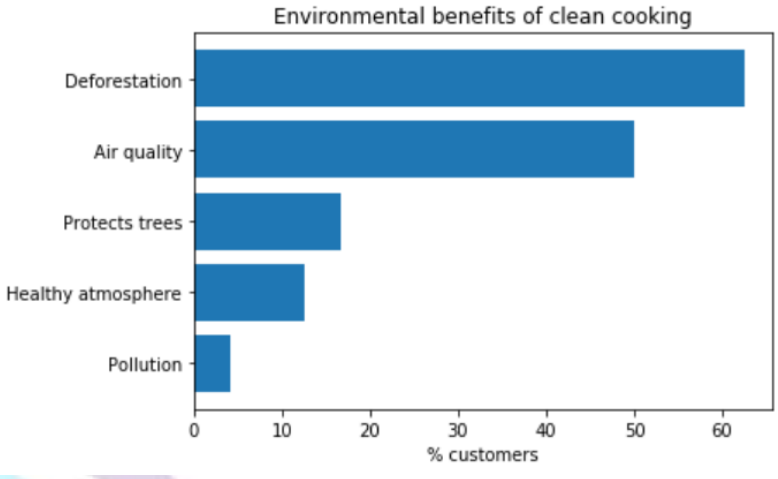

Figure 22

83% of the INT participants (N = 20) said they could afford LPG if there was no PAYG offering from Bboxx. A third of customers (N = 22) had cooked with LPG before (Figure 23). Of these customers, 17 used purchase gas from a store and 5 had it delivered. 8 customers said they still use their LPG equipment, indicating stacking of multiple LPG stoves. Reasons that the old equipment was no longer used included refills being too expensive (N = 1), the customer had switched to Bboxx gas (N = 2), refills no longer being available (N = 3), broken equipment (N = 1) and safety concerns (N = 2).

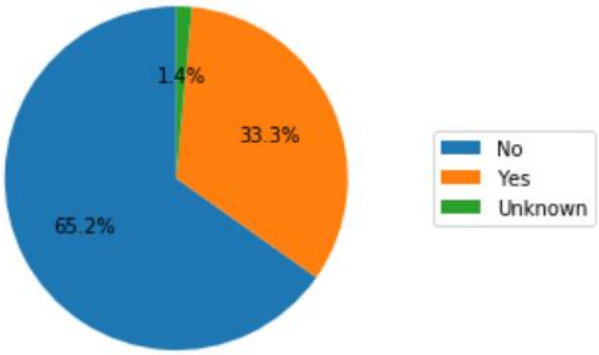

Figure 23: Had customers cooked with LPG before?

Every customer knew at least one other person who cooked with LPG, as shown in Figure 24. The low penetration of LPG in Kigali (Ministry of Infrastructure 2018) suggests these figures are higher than expected, and were likely to predispose the customer base to become early adopters of PAYG LPG.

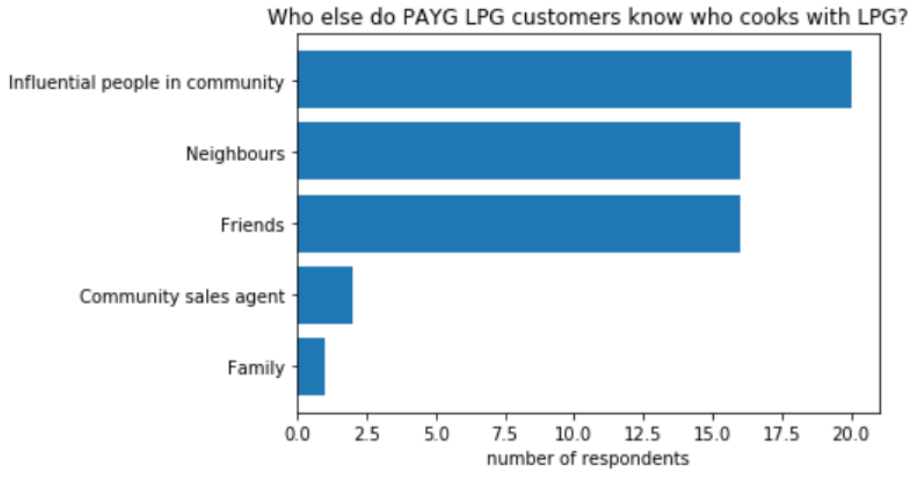

Figure 24

Bboxx's baseline survey showed the primary fuel before signing up to PAYG LPG was charcoal (Figure 25). In TS1, several customers reported having experienced health issues when cooking with charcoal (Figure 26).

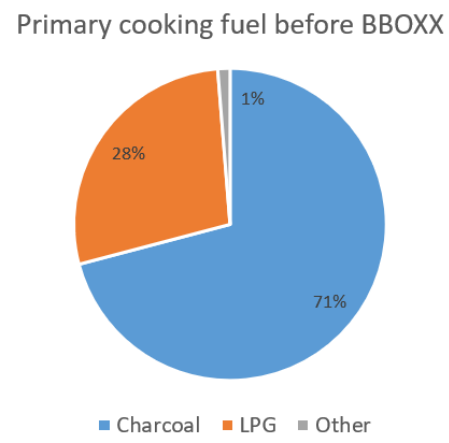

Figure 25

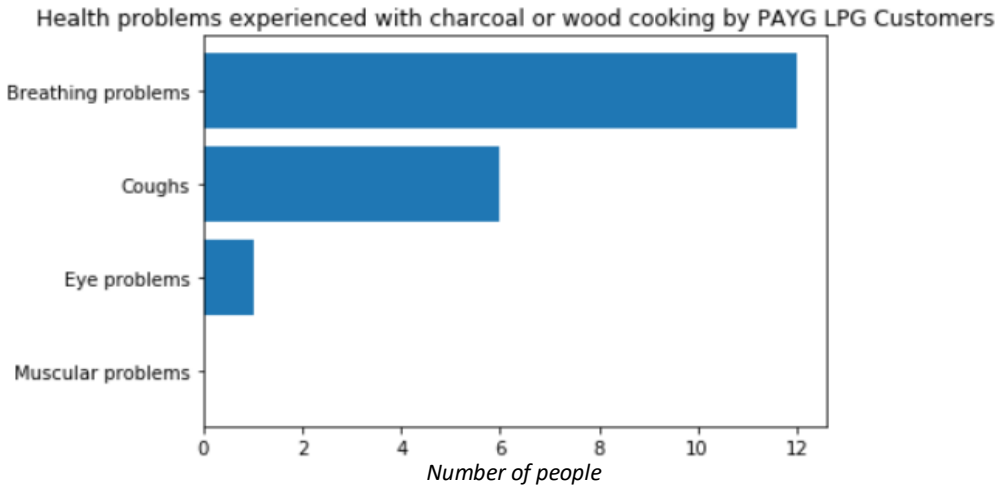

Figure 26

3.2 What were customer experiences of using PAYG LPG?

3.2.1 Perceptions of PAYG LPG

TS1 found the cook was perceived as benefiting the most from cooking with PAYG LPG, but 23% of people recognised that the whole household is positively affected, as shown in Figure 27. One customer reported experiencing a burn caused by using LPG. Nobody else (N = 67) had any health issues with the technology.

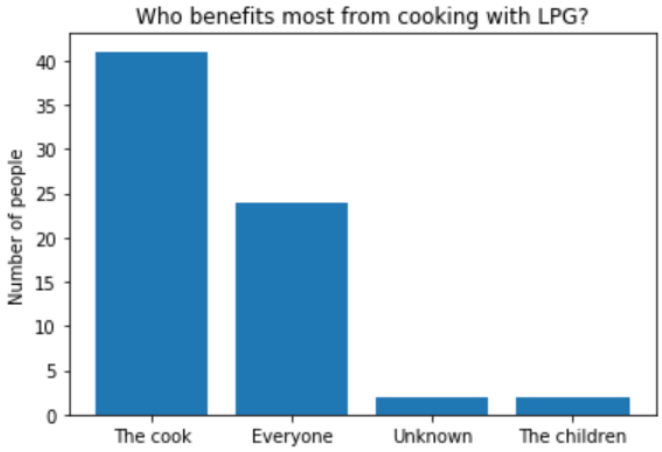

Figure 27

TS1 revealed a number of reasons why PAYG LPG was seen as better than standard LPG, such as the ability to buy small amounts of fuel and affordability (Figure 28). PAYG LPG was worse than standard LPG because of delivery delays (Figure 29). The 'other' category shown on this graph pertains to other operational limitations with the pilot, such as time delays in replacing batteries that powered the meters.

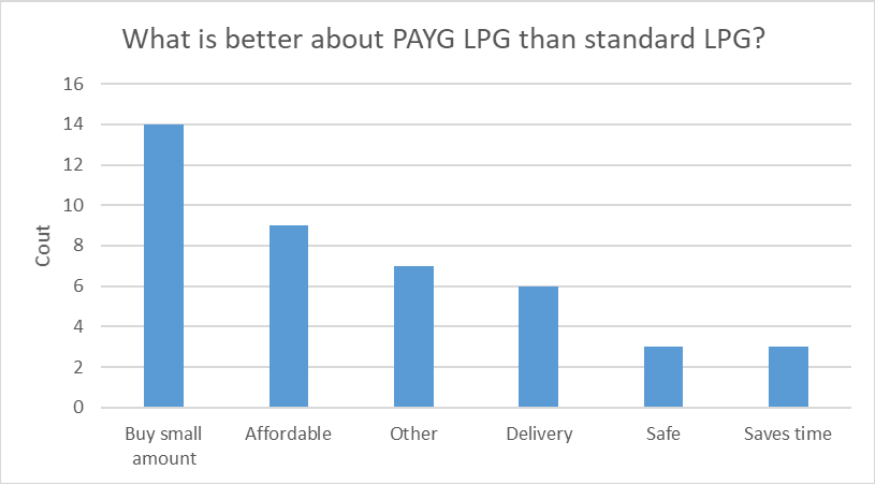

Figure 28

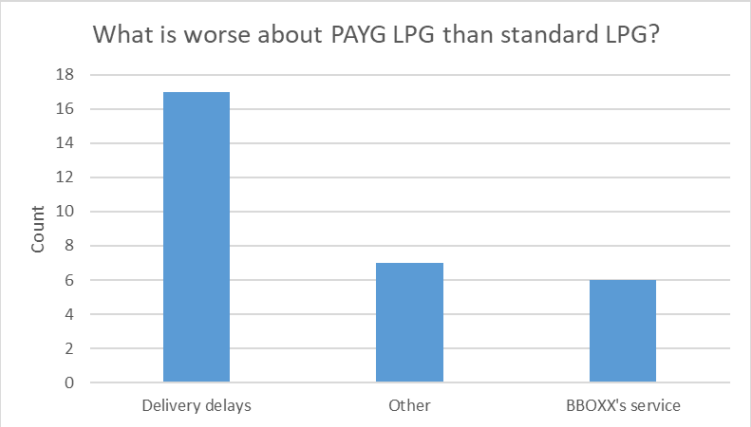

Figure 29

Participants in the household interview were given 10 coins and were asked to place them on a list of advantages of PAYG LPG to depict the value the attributed each one. Participants were free to split the coins as they pleased, and could place them all on a single aspect if they so wished. Data from all the participants was then used to calculated a mean value for each aspect. Safety and delivery were valued the most and the lack of upfront costs the least, as can be seen in Figure 30. This prioritisation is unexpected given that many of the customers said they could afford LPG if there was no Bboxx product, but it contradicts results from TS1 (Figure 28), which found that the main advantage was being able to buy fuel in small amounts. It is likely that the findings from TS1 are more reliable as they came from a larger sample size.

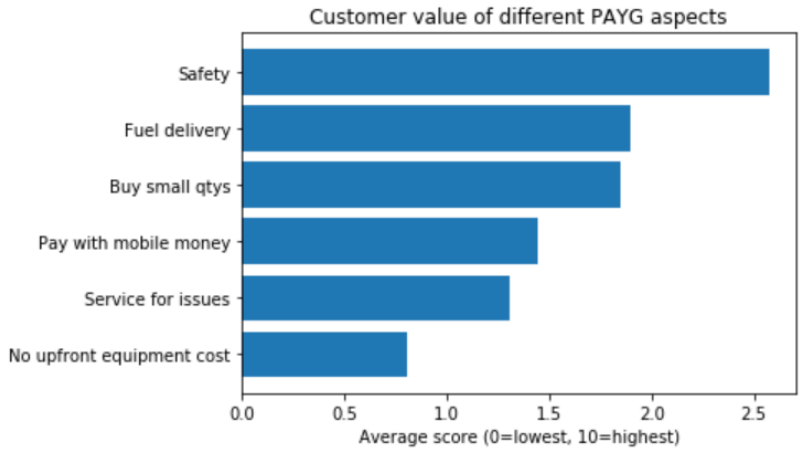

Figure 30

In TS1 respondents were asked whether they agree with five statements about PAYG, which are shown in Figure 31 along with the results. Only 32% of respondents (N = 8) agreed that PAYG LPG was affordable; yet nine customers listed affordability as a benefit in an earlier question, pointing towards this being a polarising topic. 94% said that if Bboxx had better service they would use more LPG, which agrees with the disadvantages of PAYG LPG already discussed (Figure 29). 94% believed PAYG LPG was safe, which was found to be the most prized aspect in the coin exercise (Figure 30), and 90% would recommend PAYG LPG. The latter is a very high number, especially given the low perception of affordability. Even though procedures were in place to ensure the participants understood the research was independent of Bboxx, is possible that bias still arose from the belief that participants could influence the service they received with their responses.

It was interesting that only 74% of participants in TS1 believed it was possible to cook only with PAYG LPG, suggesting a high prevalence of fuel stacking within the customer base. This is explored in more detail in Sections 3.4 and 3.5.

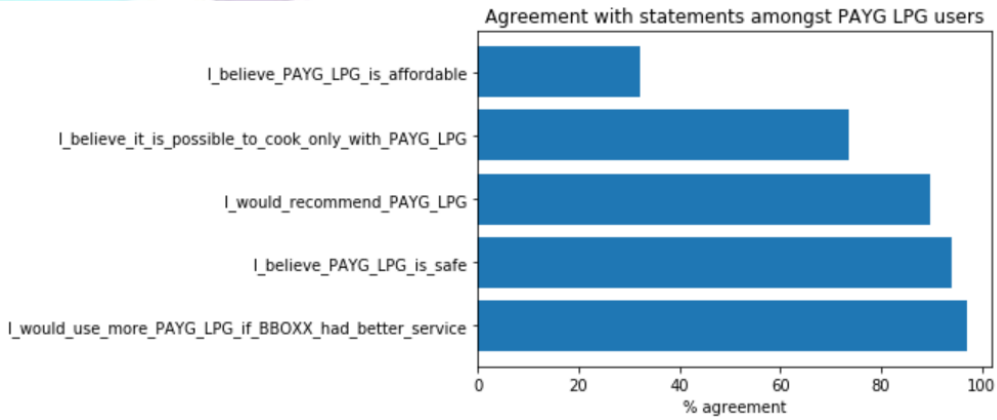

Figure 31

3.2.2 Financial impacts

Despite the commonly held perception that PAYG LPG was unaffordable, most customers reported a modest decrease in cooking fuel expenditure since they started using PAYG LPG (

Figure 32, data from TS1). They reported a mean saving of 3,240 RWF per month (£2.60), corresponding to 1.3% of customers' median income, or 15% of cooking fuel expenditure (calculated assuming an average total cooking

expenditure when using PAYG LPG of 18,500 RWF, as explained in Section 3.4.3). Yet 34% of customers did report an increase in cooking fuel spend (N = 23), as shown in Figure 32. It is unclear why this variation arose, especially as cross referencing with Bboxx's baseline survey showed customers with an increase in expenditure used a mixture of LPG and charcoal as their primary fuel before PAYG LPG.

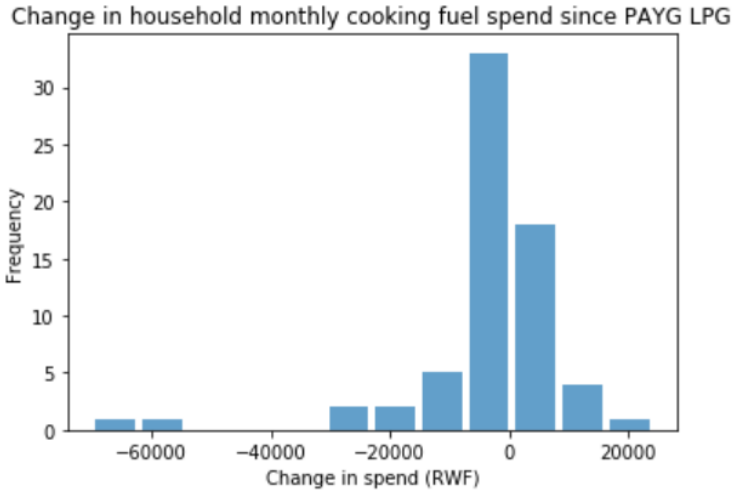

Figure 32

3.3 What were the cooking practices of PAYG LPG customers?

Cooking usually took place in the kitchen (TS1, N = 51, 82%) or the living room (N = 12, 19%). 72% of INT participants (N = 18) said charcoal is good because it heats the home, but in TS2 customers clarified that charcoal is never lit solely to provide heating in homes.

In the household interviews it was observed that sometimes the participants would fetch their charcoal stoves from a neighbour's house to show it to the enumerator. It was found that six (25%) of INT customers shared their charcoal stoves with their neighbours, but only two (8%) shared their LPG stoves. This was further investigated in TS2, where it was found that charcoal stoves were shared more than LPG stoves due to portability reasons and LPG being regarded as an expensive piece of personal equipment that should not be shared. TS2 also asked if customers would be interested in communal LPG systems that allowed multiple users to have their own credit quotas, with a lower gas price than the PAYG LPG tariff. No customers expressed interest in this system; challenges identified included property access and scheduling issues that would arise at meal times.

76% of INT respondents (N = 19) said they perform other tasks in parallel to cooking (Figure 33).

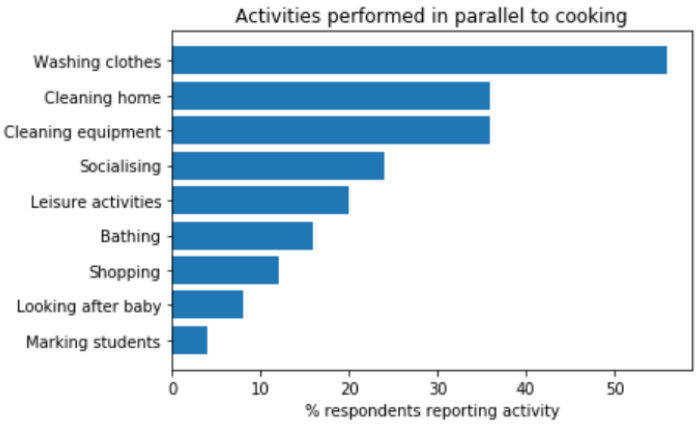

Figure 33

Here 'socialising' comprises interactions with friends of family on the phone, in person or on WhatsApp, and leisure activities include reading, listening to the radio and watching TV.

3.3.1 Heating water

A considerable amount of cooking energy was expended on heating water; in the CD 51% of recorded cooking events were heating water and 49% were making food. 68% of the INT customers boiled water before drinking it. 80% heated water for bathing, with most (70%) doing so daily. Given the prevalence of water heating, TS2 was used to gauge interest in solar water heaters (SWH). 48% (N = 12) expressed interest in owning their own SWH but only one customer was interested in a communal PAYG SWH.

The CD showed that water was most commonly heated to make hot drinks, such as tea and coffee, or for bathing, as shown in Figure 34. When charcoal was the cooking fuel of choice, the last of the fire was used to heat the water in 59% of cases. This is an example of the efficiencies that can arise when cooking with charcoal; minimal additional fuel would have been used to heat this water. Water was generally not saved in a flask until later; some of it was saved 38% of the time and all of it was saved 10% of the time (Figure 35). Water was most often heated to boiling in medium pots that were quarter-half full, as can be seen in Figure 36 and Figure 37 below.

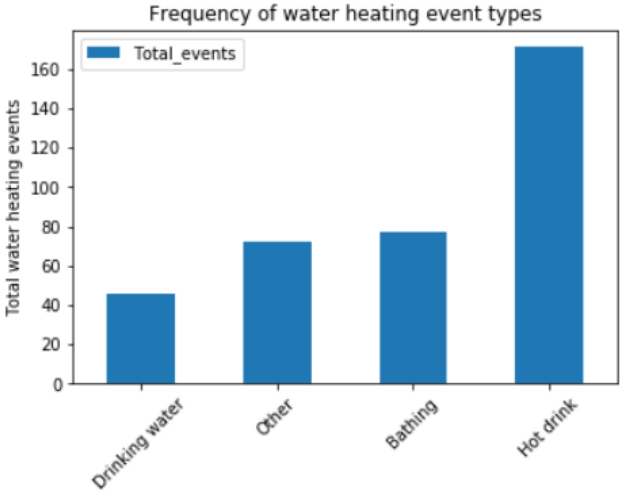

Figure 34

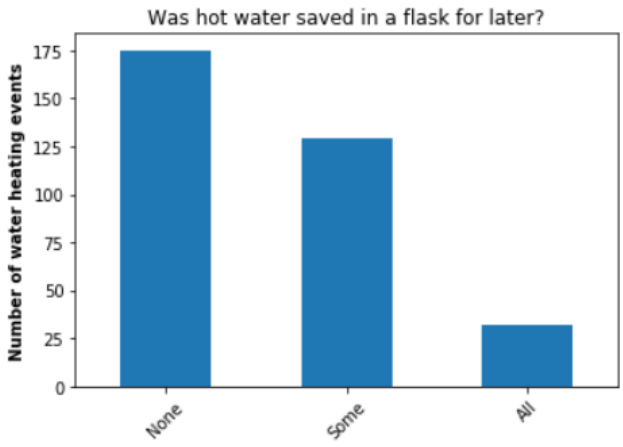

Figure 35

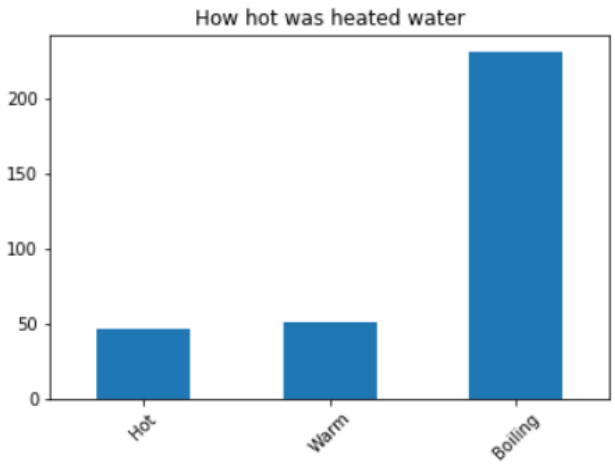

Figure 37

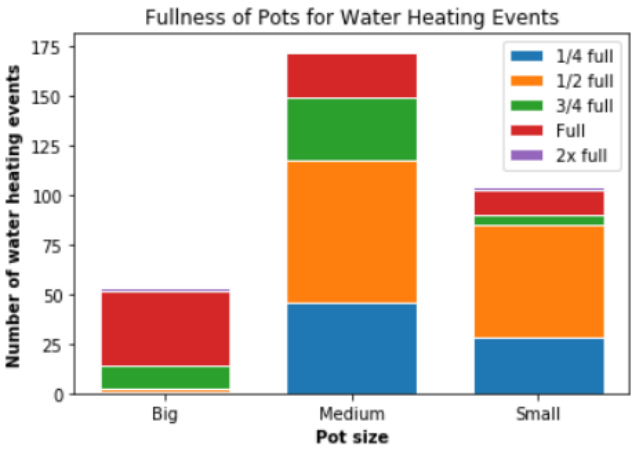

Figure 36

3.3.2 Cooking food

Meals were usually composed of two separate dishes, with a mean of 2.17 dishes. More information about the meal form contents is displayed in Table 5.

Meal Form Content	Frequency
1 dish	76
2 dishes	176
3 dishes	67
4 dishes	35
No. Bathing	77
No. Drinking	44
No. Hot drink	158
No. Other	83

Table 5: Summary of CD meal forms content

In the vast majority of cases there were no unheated components to the meal (94% of meals recorded). People's diets were reasonably consistent and the most common foods were: 1) green vegetables; 2) rice; 3) ugali, a maize porridge that is a regional staple; 4) potato; 5) bananas; and 6) beans. These six foods are highlighted in this report because they accounted for 570 out of 769 recorded food cooking events in the CD (74%); typical preparation methods for these foods are shown in

Table 6 and a frequency plot of all foods is shown in Figure 38.

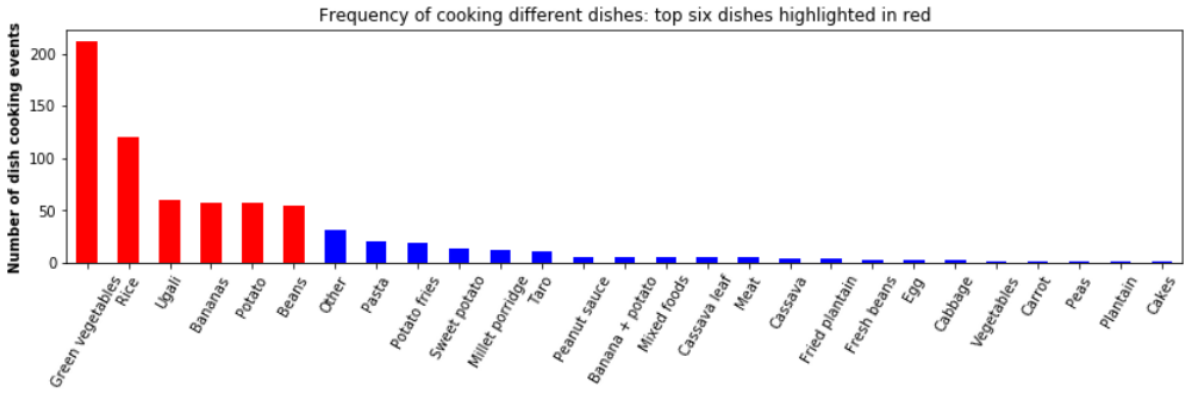

Figure 38

Dish	Preparation method 1	Preparation method 2	Time to cook
Green vegetables (*imboga*)	Rinsed, chopped, fried. Sometimes other ingredients are added such as tomatoes, carrot and onions		30 mins
Rice	Rinsed and boiled or steamed	Fried with ingredients like onions, grated carrots and pepper, put rice, add boiled water	1 hour
Ugali	Boil water, add maize flour, stir quickly until fluffs up		30 mins
Bananas	Peel and boil with ingredients such as salt, tomato and cooking oil	Peel, rinse, cut into small piece and fry (30 mins)	Method 1: 1 hour Method 2: 30 mins
Potato	Peel and boil with ingredients such as salt, beans, tomato and cooking oil	Peel, rinse, cut into small piece and fry (30 mins)	Method 1: 1 hour Method 2: 30 mins
Beans	Rinsed and boiled with salt	Fry beans that have already been cooked by boiling with other ingredients such as onions and salt. Beans can also be added to other dishes such as potatoes or bananas	Method 1: 3 – 4 hours Method 2: 10 mins

Table 6: Preparation methods for common dishes

The CD showed the most common cooking processes were frying and boiling, as shown in Figure 39. Note 'gusonga' is the term used for cooking ugali and consists of slowly heating and stirring. An error meant that 'grilling' was incorrectly translated into Kinyarwanda as

'guteka', which is a general term for reheating or cooking food and is shown in Figure 39 as 'cook'. Surprisingly few people recorded using multiple cooking processes, despite

Table 6 showing that the most common dishes consisted of several cooking steps, and other cooking diaries studies conducted in countries with similar cuisines finding a high prevalence of multiple processes (Leary et al. 2019; Scott et al. 2019a, 2019b). This suggests that people tended to record the dominant cooking process only.

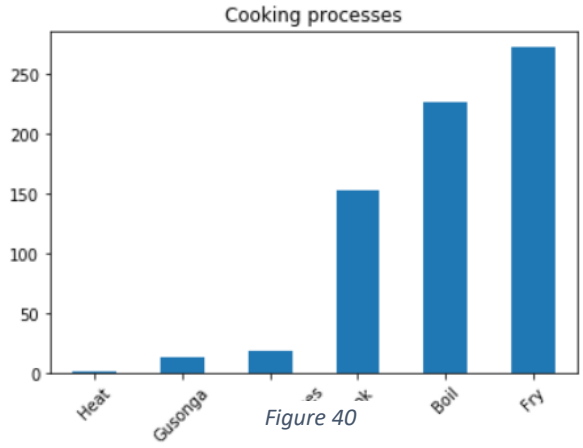

Figure 40

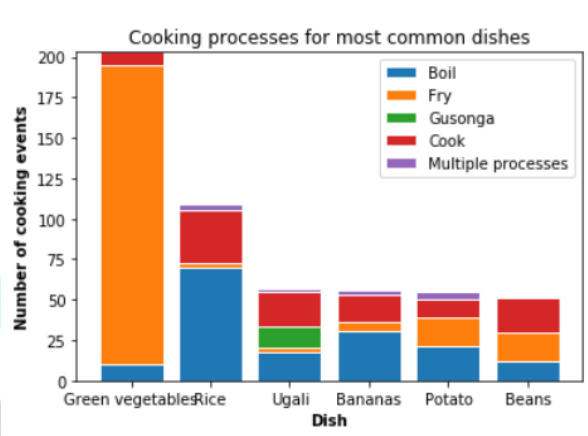

Figure 41

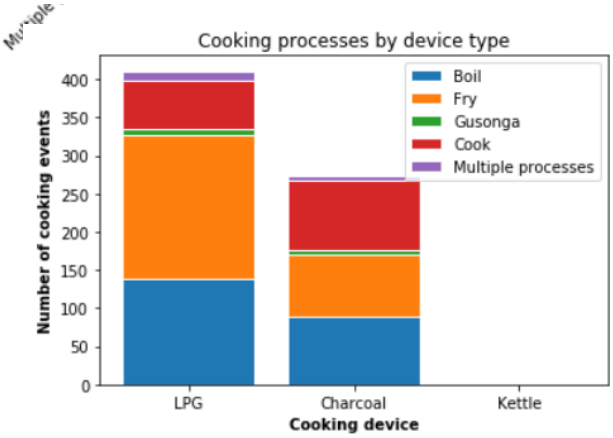

Figure 39

Figure 40 and Figure 41 show how these cooking processes were split between the top six foods identified above. LPG was clearly favoured for frying; boiling represented 33% of cooking events on both fuels. Charcoal was preferred for cooking, but as this was a translation error it should be discarded, and was only included in the graphs to show the total number of cooking events.

3.3.3 Duration and timing of cooking

Overlaying the SUMs and the SMART data showed two peaks for both LPG and charcoal stove use (Figure 42). Both LPG cooking peaks occurred about an hour earlier than the charcoal equivalents, which could be because cooking with LPG takes less time. The graph also shows that charcoal cooking occurred most often in the middle of the day and LPG in the evening. Bearing in mind that most of the charcoal data was collected mid-LD and

most of the LPG data pre-LD, this could be more of a reflection of the impacts of COVID-19 lockdown than of temporal preferences for different cooking fuels. The impacts of COVID-19 are explored further in Section 3.6.2.

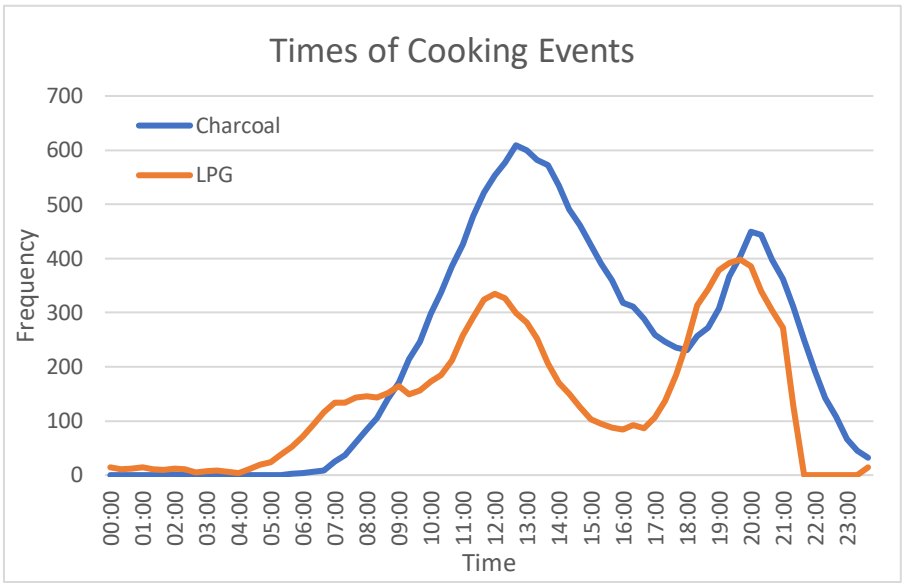

Figure 42

Data from the CD Summary Forms agrees with Figure 42 and finds that that cooking device use was skewed towards the end of the day, as shown in Table 7. Very few meals were eaten cold (N = 5, 0.6%), in another house (N = 7, 0.8%) or were purchased outside of the home (N = 7, 8%).

Did you use a cooking device?	Early morning	Breakfast	Mid morning	Lunch	Mid-afternoon	Dinner	Evening	*Totals*
No	53	47	14	2	98	2	12	*228*
Yes and I cooked it at home	65	65	108	110	16	114	105	*583*
Yes, I ate food that I prepared earlier, but I did not reheat it	0	0	0	4	0	1	0	*5*
Yes, I ate in another house	0	3	0	2	0	2	0	*7*
Yes, I bought food	0	3	0	2	0	1	0	*6*
Totals	*118*	*118*	*122*	*120*	*114*	*120*	*117*	

Table 7: Contents of CD summary forms

The self-reported average times spent cooking each meal are shown in Figure 44 below (INT). The results are not dissimilar to the self-recorded cooking times in the CD, which found that the mean cooking time for a single dish was 42 minutes. The distribution of dish cooking times is right skewed, and is shown in Figure 43.

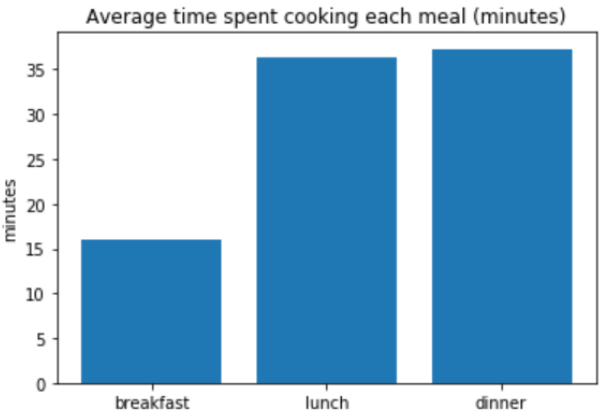

Figure 44

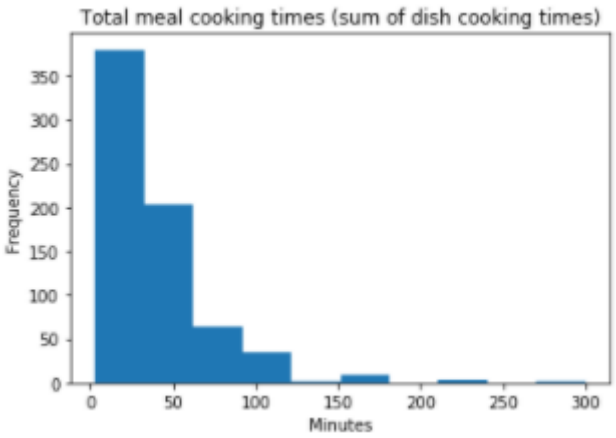

Figure 43

This was further investigated by using the CD data to investigate the cooking times of the top six dishes (Figure 45). Beans had the longest average cooking duration (89 mins) - almost twice that of the next longest cooking foods, ugali and potato (52 min and 44 mins respectively) – and are likely to be responsible for the tail of longer cooking events in Figure 43 above.

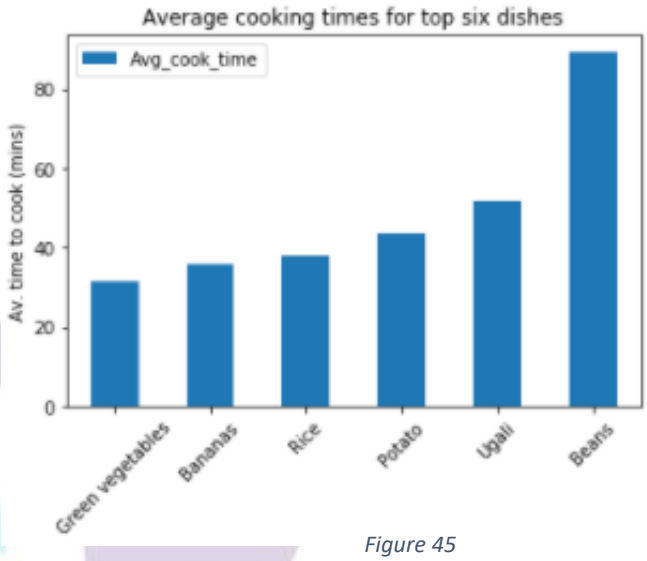

Figure 45

The CD showed the total time actively spent cooking each meal was 76 minutes, with a standard deviation of 33 minutes. This does not mean the average meal would have taken 80 minutes of the cook's time, because dishes could have been cooked in parallel. This was particularly likely to have been the case for meals cooked with LPG as the stove provided by Bboxx had two burners. In contrast, the charcoal stoves that were used universally by Bboxx customers could only hold one pot at a time. This suggests that transitioning to LPG could have significantly compressed the time spent cooking. Figure 46 below shows the average cooking event durations by fuel type, according to the CD, showing that charcoal cooking events took twice as long as LPG ones.

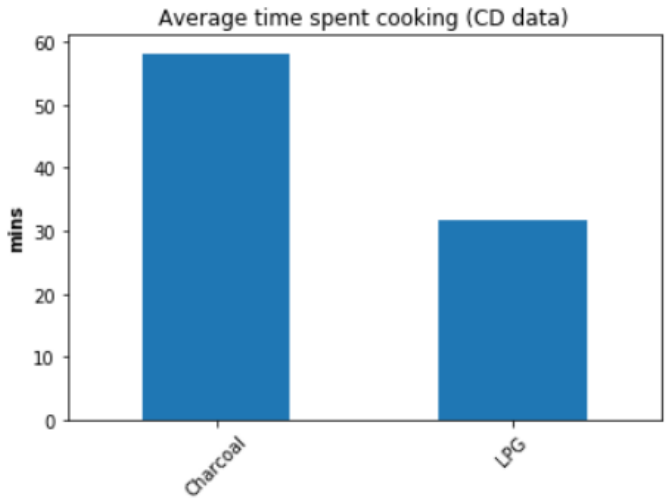

Figure 46

3.4 What were the patterns of fuel stacking?

3.4.1 Cooking devices

In TS1, 61% of customers who cooked with charcoal before PAYG LPG said they continued to use it alongside PAYG LPG (Figure 47). 91% of customers still had a working charcoal stove in their house and 12% said they had a secondary LPG stove. Some electric cooking devices were also observed during household visits for INT, namely kettles (N = 5) and juice makers (N = 1).

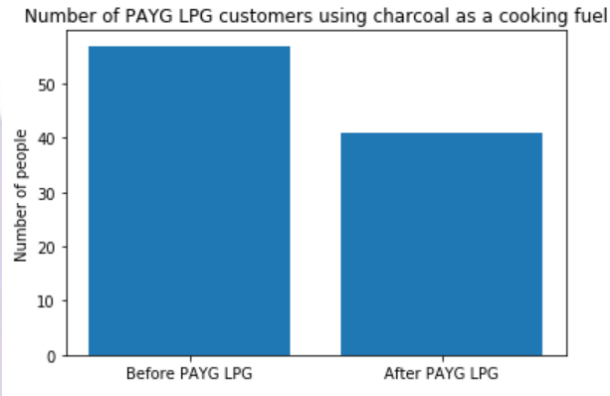

Figure 47

3.4.2 Frequency of use

In the household interviews, customers said they used their charcoal stove 4.3 times per week on average and their LPG stove 19.2 times per week. This was similar to the cooking event frequencies measured by the SUMs and the SMART data, which found the charcoal stove was used 4.9 times per week and the PAYG LPG stove 18.2 times per week. This breakdown is also shown in Table 8 below.

Method	INT	SUMs + SMART data
Avg weekly LPG cooking events	19.2 (82%)	18.2 (79%)
Avg weekly charcoal cooking events	4.3 (18%)	4.9 (21%)
Total weekly cooking events	23.5 (100%)	23.1 (100%)

Table 8: Average weekly use of cooking devices according to INT and sensor data

The ratio of LPG to charcoal cooking varied widely between customers, as is shown in the CD data displayed in Figure 48. The accuracy of individual reporting was low; only 61% of the SUMs customers, who all cooked regularly with their charcoal stoves, said they did so in TS1. Comparing the customer-level SUMs data to the INT data revealed large discrepancies in self-reported versus actual stove usage, with charcoal stoves being used 3.7x more than reported and LPG 1.5x more. Possible explanations for this include recall bias, the interview taking place with a person other than the main cook, and the impact of COVID-19 lockdown on cooking practices, as most of the SUMs data collection took place during this period. This echoes Wilson et al. (2018) in finding that self-reported user behaviour does not correlate well to measured stove use, and suggests that the methodological correlation shown in Table 8 arose through chance.

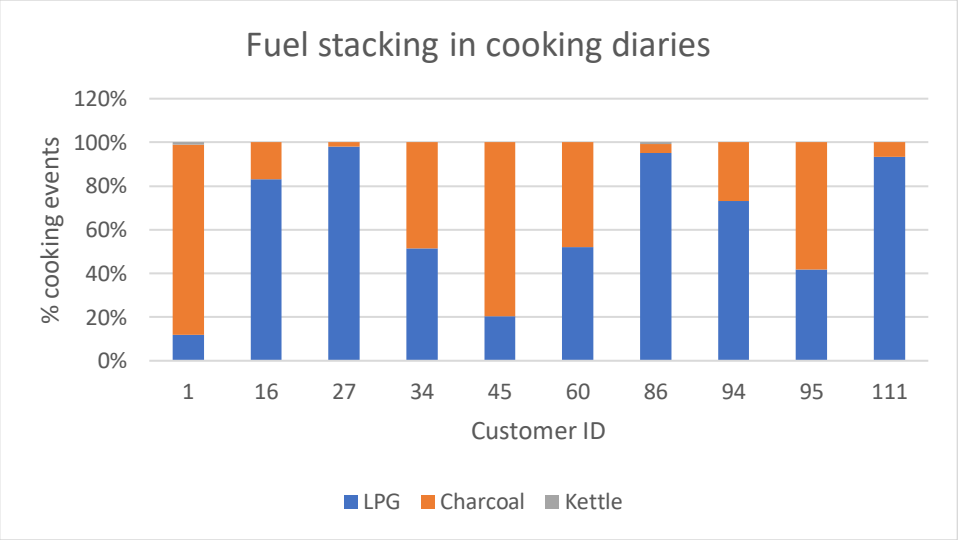

Figure 48

Of the days on which both LPG and charcoal usage data was recorded, LPG was used on 85% of available days, charcoal 41%, both fuels 34% of days and neither fuel on 8% of days (Figure 50). The high number of days on which both LPG and charcoal were used highlights the prevalence of stacking. The CD even showed instances of multiple fuel use within single meals. Meals consisted of dishes cooked only on LPG 55% of the time; only charcoal 34% of the time; and both fuels 13% of the time (Figure 49). This demonstrates that charcoal use was not driven solely by unavailability of LPG, as both fuels were clearly present in the home when stacked meals were being cooked.

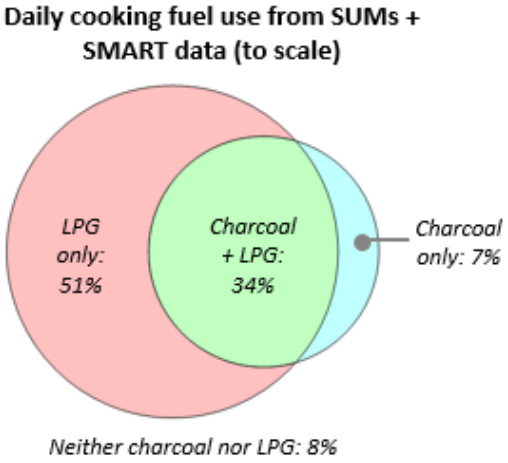

Figure 50

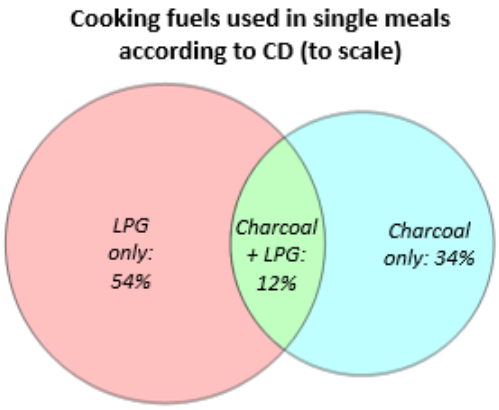

Figure 49

The reasons for stacking within meals are unknown, but it was interesting to note that the average number of dishes for meals involving a single cooking fuel was 2.12 versus 2.73 for meals involving multiple cooking fuels. The LPG stove provided by Bboxx had two burners. A driver of fuel stacking could have been the need to cook more than two dishes at once, and could be addressed with a four-burner stove. Eight out of ten (80%) of the CD participants recorded a stacked meal, suggesting that the majority of customers could benefit from a stove with more burners.

3.4.3 Fuel expenditure

Self-reported data from INT showed that each household purchased charcoal three times a month on average, spending 3,280 RWF (£2.60) each time, giving an average monthly charcoal expenditure of 8,350 RWF (£6.60), or 3.3% of average household income. Charcoal could either be bought in a small bucket of roughly 500g or in a large 25-50kg sack, although purchases of the latter were rare. The CD showed that the amount spent per purchase ranged from 200 RWF –11,000 RWF (£0.20 - £8.70), with the mean value of a bucket being 450 RWF (0.40). There was only one recorded sack purchase at 11,000 RWF (£8.70).

Similar purchasing patterns were observed for PAYG LPG. Bboxx's analysis of the SMART data found that the average payment size for credit was 2,530 RWF (£2.00) and that payments were typically made four times per month, spending an average of 10,500 RWF per month (£8.30), or 4.2% of average household income. Adding this to the charcoal equivalent yields that cooking fuel expenditure accounted for 7.5% of average household income.

These results show that charcoal cooking was demanding a disproportionate amount of cooking fuel spend. Although 79% of cooking events took place on LPG (Section 3.4.2), it only commanded 57% of total cooking fuel spend (Figure 52). If 21% more cooking events took place on LPG then the average customer's total monthly cooking fuel expenditure would decrease by 27% from 18,500 RWF to 13,420 RWF (£14.60 - £10.70), and Bboxx's monthly revenue per customer would increase by 28% from 10,500 RWF to 13,420 RWF (£8.30 - £10.70), as is shown in Figure 51. This rough calculation assumes that charcoal and LPG cooking events are similar; the preference to use charcoal for longer-cooking foods such as beans means that it is likely to underestimate the cost of transitioning solely to LPG (see Section 3.4.4). However, the findings suggest that significant commercial gains for providers and savings for customers could be yielded from eliminating charcoal cooking.

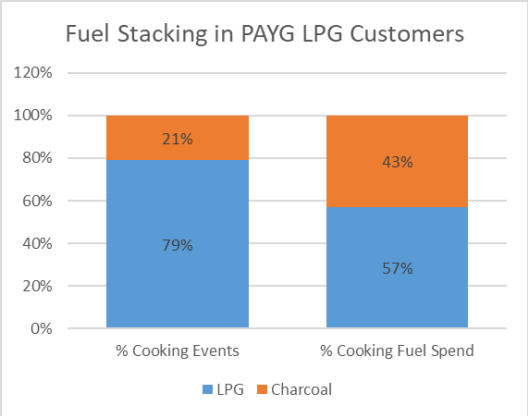

Figure 52

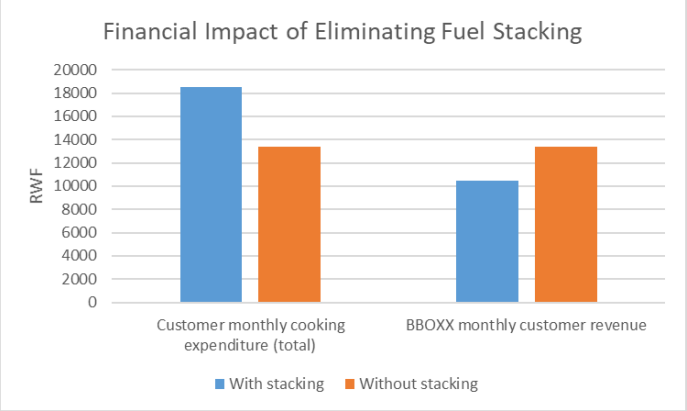

Figure 51

3.4.4 Dish-level cooking fuel preferences

Figure 54 and Figure 55 show cooking fuel choice for the top six dishes according to the CD. The data shows a strong preference for cooking green vegetables, rice and bananas on LPG. Potato and ugali were cooked on LPG more often than on charcoal, but the breakdown between fuels was more evenly distributed. The only food that was cooked more often on charcoal was beans. Section 3.3.3 found that ugali, potatoes and beans are the dishes that take the most time to cook and Figure 55 below shows there is strong correlation between cooking time and choice of cooking fuel. It is unclear whether this is because cooking with charcoal takes more time, or because charcoal was the preferred fuel for longer-cooking dishes. This preference echoes other cooking diaries studies, which found that traditional stoves were favoured for 'heavy' foods that take over an hour to cook such as beans, tripe and beans & maize stew (Leary, Scott, Serenje, et al. 2019; Scott et al. 2019b, 2019a). People also tended to see these foods as too expensive to cook on LPG because they use more fuel than other foods, even if the cost of that LPG was actually lower than the cost of the charcoal required to cook the same dish. This perception could have been reinforced by the fact that people could physically see how much charcoal was being used per dish, whereas until PAYG LPG, gas consumption was a mystery.

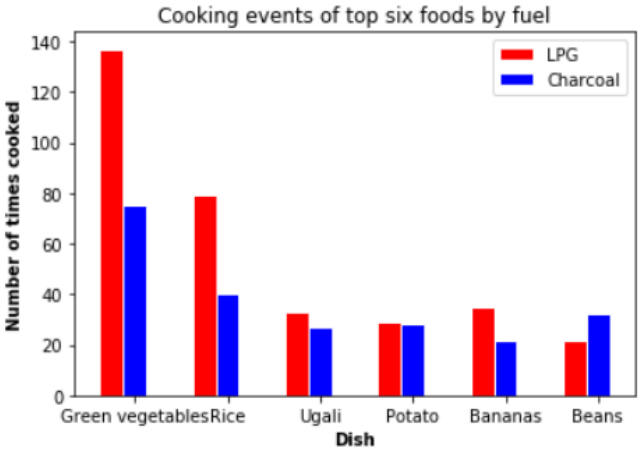

Figure 54

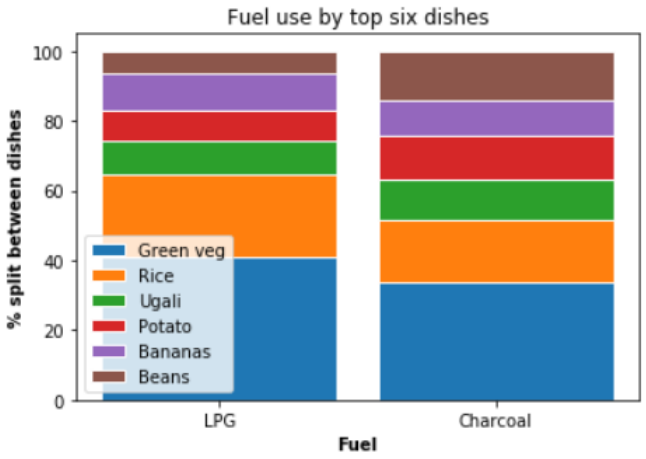

Figure 53

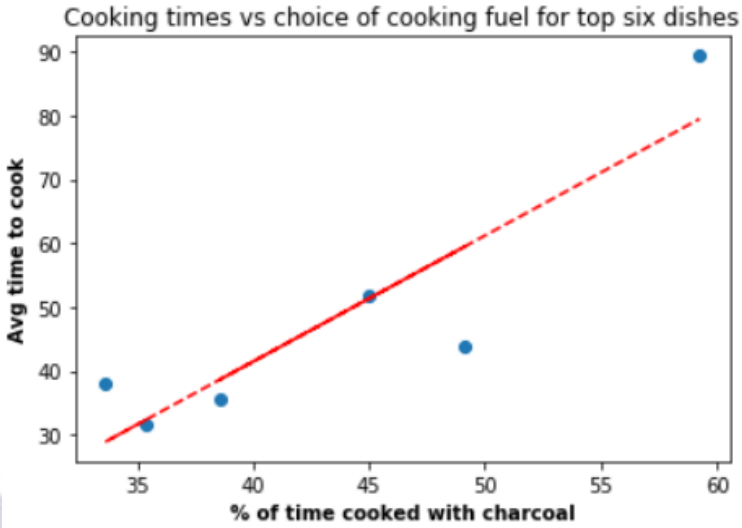

Figure 55

These results agree with TS1, where customers were asked what foods were best cooked on LPG (Figure 56) and what foods were best not cooked on LPG (Figure 57). A variety of foods fell into the former category, whereas there was a strong consensus (84%) that beans should not be cooked on LPG.

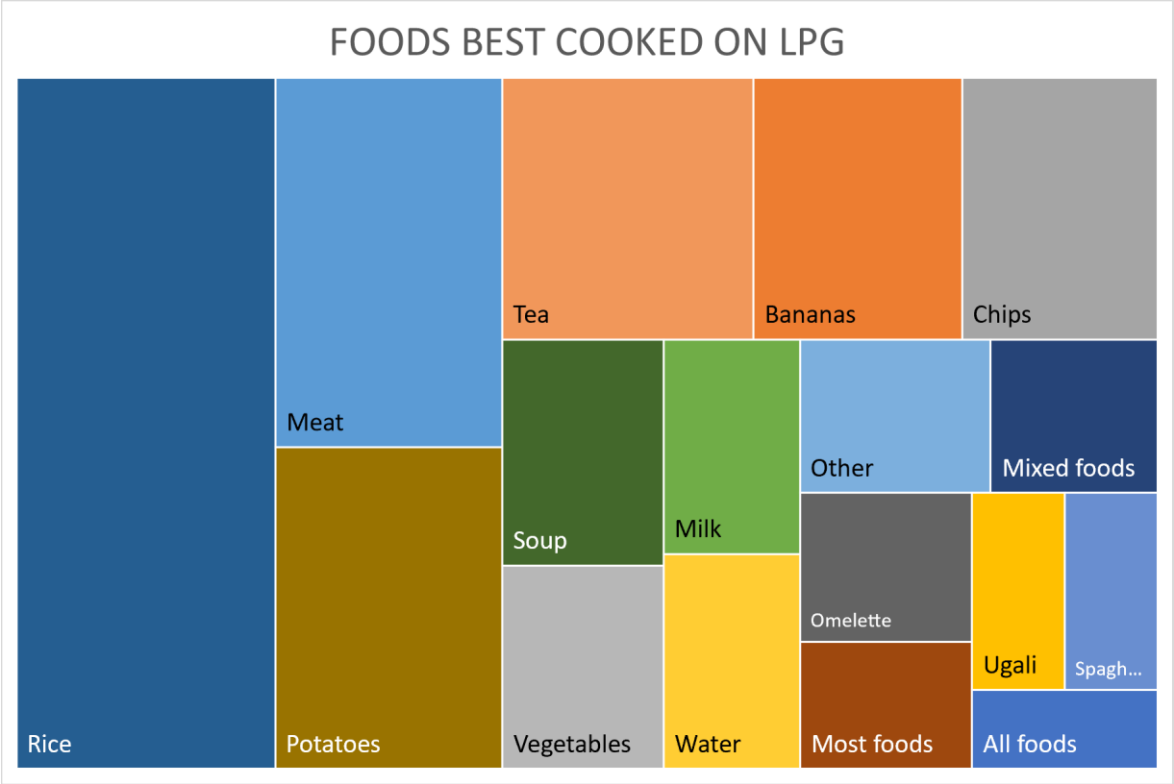

Figure 56

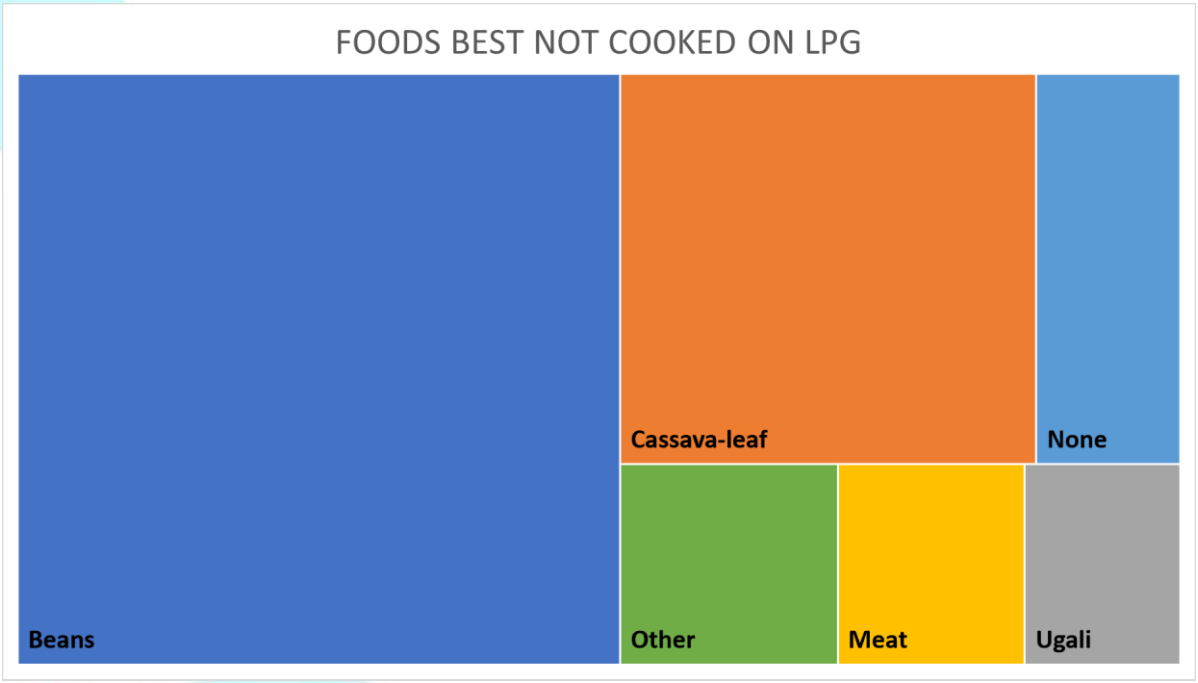

Figure 57

3.5 What interventions could reduce fuel stacking?

3.5.1 Changes to bean cooking practices

Section 3.4.4 described how beans tended to be cooked on charcoal, which pointed towards this dish being a driver of fuel stacking. 25% of the INT respondents (N = 6) said they had tried cooking beans on LPG. Of these, two said it took more time than charcoal, three observed that it was quick but consumed more fuel, and one said that it was quick with no difficulties. The perception that beans should be cooked from a dried state with charcoal was explored in the tests described in Section **Error! Reference source not found.**.

The results of the tests are shown in Figure 58 and Table 9. The costs of cooking each type of bean were calculated by adding the cost of beans to the mean cost of the fuel from the three experimental repeats. LPG was found to be most cost-effective fuel for pre-cooked (PC) and soaked beans, but not for dried beans. Soaking beans reduced costs regardless of cooking fuel used. The pre-cooked beans decreased the cost on LPG but counterintuitively increased it on charcoal. This could be an anomalous result; it is possible that the same amount of charcoal that is needed for dried beans was put on the stove and was left to burn out once the beans were cooked, meaning the results do not reflect the reduction in cooking energy needed.

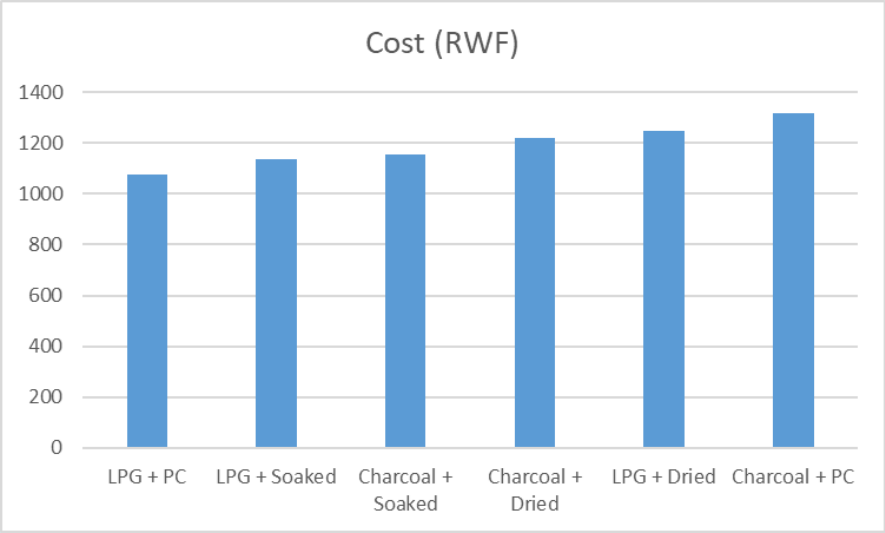

Figure 58

Table 9 below shows the results of the taste tests. People could not consistently identify either the fuel or the bean. The traditional method of cooking beans (charcoal + dried) had the best mean ranking but the pre-cooked (PC) beans received the most top votes.

Actual Fuel / Bean Combo	Av. Ranking (1 = favourite)	# Top Votes	% Guessed Correct Fuel	% Guessed Correct Bean
CHARCOAL DRIED	2.8	2	46.2%	76.9%
CHARCOAL PC	3.1	3	38.5%	61.5%
LPG PC	3.5	3	53.8%	76.9%
LPG SOAKED	3.7	2	84.6%	53.8%
CHARCOAL SOAKED	3.8	2	53.8%	53.8%
LPG DRIED	4.2	1	84.6%	38.5%

Table 9: BT taste test results

10 people participated in the interviews, five of whom said they were the main cooks for their households. All of them said that they normally cooked dried beans on charcoal. Eight of them (80%) said they would change the way they cooked beans after participating in the experiments, showing that using cooking demonstrations as a behaviour change tool is extremely effective. After participating in the tests, six customers (60%) said they would start soaking beans, three customers (30%) said they would switch fuel to LPG and one customer said they would start using pre-cooked beans. The two participants who were not planning to change their bean practices said that they did not like to cook beans at all (N = 1) and that soaking was too time consuming (N = 1).

The co-distribution of pre-cooked beans with LPG cylinders could promote the cooking of beans on LPG, especially as pre-cooked beans are not yet widely available in Rwanda. Similar approaches could be adopted for other heavy foods that tended to be cooked on charcoal, such as cassava leaf.

3.5.2 Changes to the business model

Table 1 shows that most of Bboxx's customers were on the tiered tariff, but in the household interviews customers favoured the flat option (Figure 59). This could be because this tariff mimics the charcoal purchasing that customers were accustomed to. It is possible that moving to a flat tariff would increase transparency and decrease customer dissatisfaction with affordability.

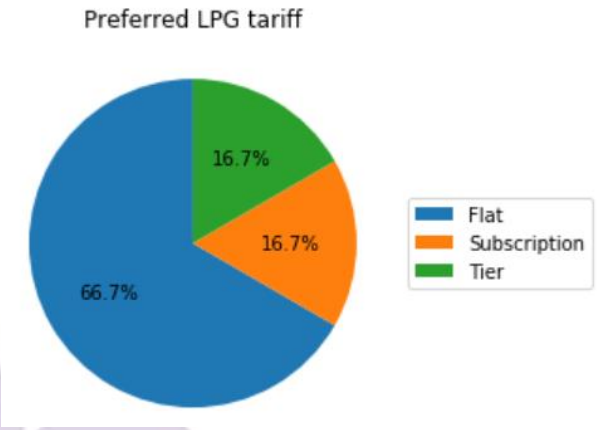

Figure 59

The average per kg price of LPG in Kigali during the pilot was 1,160 RWF (£0.90), (Ndegeya 2019) whereas PAYG LPG cost 1,280 RWF to 1,900 RWF (£1.00 - £1.50), which most customers paying at the higher end of the range. This was due to Bboxx amortising some of the equipment costs, servicing and delivery into the fuel price. Therefore separating out the loan repayment from the cost of fuel may also help improve perceptions of affordability.

Operational issues with the pilot meant that customers were not always able to use PAYG LPG, forcing them to revert to charcoal.
Table 10 explores the reasons for this in more detail and how they could be addressed.

Operational limitation	Impact on customer	Potential solutions
Bboxx closed during evenings and weekends	If customer runs out of fuel during these times then	Extend Bboxx opening hours Bboxx to use SMART data to monitor consumption and proactively replace cylinders

	they were unable to access replenishment	Spare cylinder to be kept in customers' home
Credit top ups were performed manually	Delays in adding credit to accounts left customers unable to access LPG	Extend Bboxx opening hours Automate top up process
Quality issues with the stove	Issues with rust on the burner and the knobs that controlled the gas flow meant people could not use the stove	Switch to a different, higher quality stove supplier

Table 10: Operation limitations and solutions

3.5.3 Changes to hardware

It can be unrealistic to expect a modern stove to completely displace a traditional one because of the wide array of end uses fulfilled by open fires such as space heating (Ruiz-Mercado and Masera 2015). The preference for using charcoal for long-cooking foods (such as beans, ugali and potatoes) suggests that pressure cookers could facilitate a complete transition away from charcoal.

Section 3.4.4 discusses how stacking within a meal was associated with cooking more dishes; a four-burner LPG stove could address this problem. These devices could be offered as part of the original hardware package or as upgrade options to mimic Bboxx's solar home system model.

3.5.4 Messaging as a behaviour change technique

TS2 was used to investigate the resonance of different ways of communicating the impacts of cooking beans on charcoal with customers. Respondents were presented with a number of different statements and were asked a) whether they believed them, and b) how likely they would be to change their behaviour if the scenario was demonstrably true. The statements are shown in Table 11 below and were based on rough calculations using the results of the beans tests and data found in the academic literature.

Scenario	Description
Money savings scenario	Through testing, we have found that there is a saving of 100 RWF (£0.08) each time a household cooks 1kg of beans on LPG with soaking, compared to cooking on charcoal without soaking. There was no difference in taste. If a household cooks 1kg of beans twice a week, then switching to cooking soaked beans on LPG will lead to savings of 10,000 RWF (£7.90) each year
Forest scenario	If everybody in Kigali cooked beans on LPG instead of charcoal, a forest twice the size of Kigali City, or 1/6th the size of Nyungwe Forest, would be saved each year
Cigarette scenario	If a household cooks beans on charcoal inside the home twice each week, then the air pollution that each present in the home breathes is the same as smoking 20 cigarettes per week

Children scenario	Air pollution affects children much more than adults. Therefore if a family cooks beans on charcoal inside the home twice each week, then the air pollution breathed by each child present is the same as smoking 40 cigarettes per week

Table 11: TS2 scenarios

The results are shown in Figure 60 and Figure 61below. Most people believed each of the scenarios, with the minimum rate being 80% for the money saving scenario, although this may reflect response bias more than true beliefs. The money saving scenario was the least effective, whereas the children scenario had both the highest belief rate and the highest likelihood of resulting in behaviour change. This indicates that messaging about the benefits of LPG or the harmful effects of biomass cooking may be more resonant when are framed in terms of child health, and therefore more likely to change cooking practices.

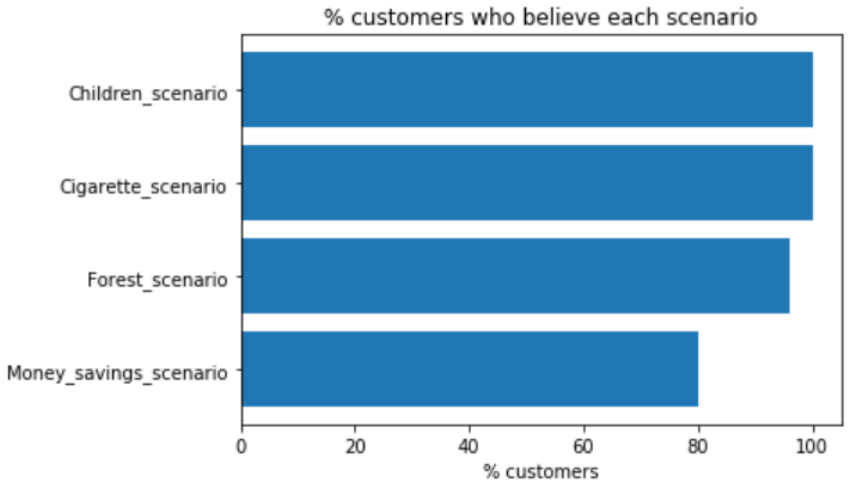

Figure 60

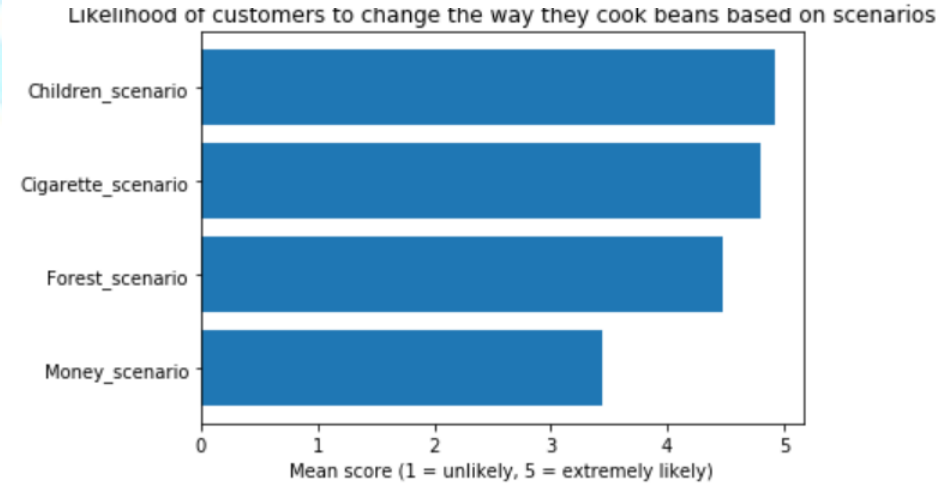

Figure 61

The contradictory perceptions of PAYG LPG's affordability suggest that another high potential intervention is educating customers about the savings that can arise from increased adoption of LPG.

3.6 What were the impacts of the pilot shut-down and COVID-19 lockdown on cooking practices?

3.6.1 Pilot shut-down

At the end of March 2020 Bboxx closed their Rwandan PAYG LPG pilot. Customers were gifted the equipment along with the remaining fuel in their cylinder. Due to COVID-19 Bboxx were unable to remove the gas monitoring components for some households, which meant that consumption data continued to be collected until the cylinder being monitored was emptied of LPG.

The SUMs data showed that running out of LPG resulted in a higher frequency of charcoal cooking events for most customers; the average number of charcoal cooking events per week rose from 3.9 during the pilot to 5.3 after losing access to Bboxx LPG. This change was not statistically significant (Wilcoxon p = 0.130). The utilisation rate of charcoal stoves (i.e. the % of days on which they were used) exhibited another insignificant increase, from 34% of days during the pilot to 42% of days after (Wilcoxon p = 0.227). There were a range of measurements for both metrics, as can be seen in Figure and Figure below, with some households experiencing a decrease in use of charcoal. These findings show that whilst cooking with charcoal stoves increased after the end of the Bboxx pilot, they did not displace PAYG LPG as the primary fuel.

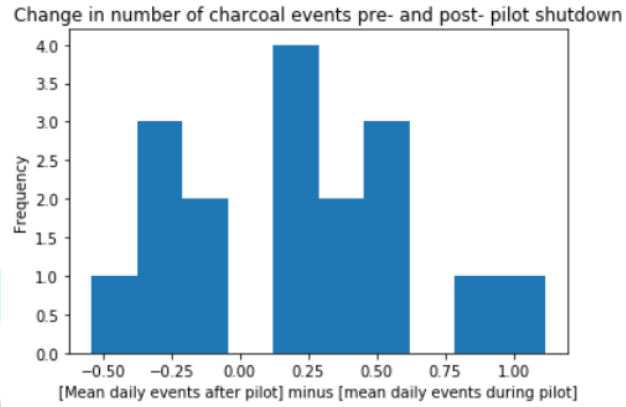

Figure 62

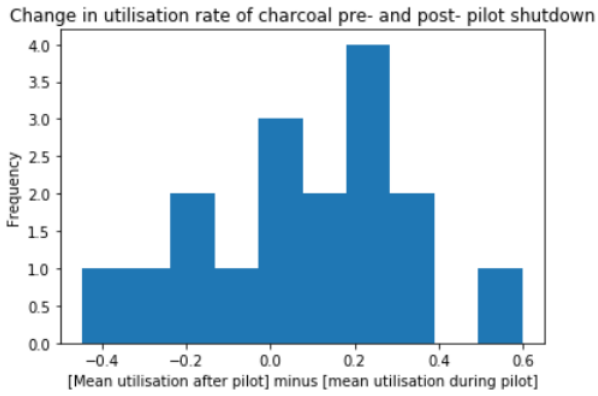

Figure 63

Bboxx LPG had run out for all customers by the time the bulk of the CD data collection occurred in May; the SUMs had also been removed from the charcoal stoves at this time. Eight customers (80%) were primarily cooking with LPG throughout the diaries. Of the other 20%, one customer did not record any LPG cooking and had reverted to using charcoal only. Another relied on charcoal only up until the 5th of June when they started using LPG. Cash flow issues preventing the purchase of a whole cylinder of gas may have caused this gap in LPG use.

Table 12 compares the primary fuel from before the start of the PAYG LPG pilot, taken from Bboxx's baseline survey, with the primary fuel after the pilot, which was calculated from the CD, for the 10 CD participants. Seven customers continued to use LPG as their main fuel (70%). Of these customers, six (60%) had transitioned 'up the energy ladder' by moving from a primary fuel of charcoal to LPG. Three customers continued to cook with the same fuel as they had before and one switched from LPG to charcoal. Hence even after the PAYG LPG service stopped, the combined effects of participating in the pilot and acquiring LPG equipment facilitated a transition to cleaner cooking.

Customer ID	Primary fuel before pilot *Source: Bboxx baseline survey*	Primary fuel after pilot. Source: CD
1	LPG	Charcoal
16	Charcoal	LPG
27	Charcoal	LPG
34	Charcoal	LPG
45	Charcoal	Charcoal
60	LPG	LPG
86	Charcoal	LPG
94	Charcoal	LPG
95	Charcoal	Charcoal
111	Charcoal	LPG

Table 12: Overall impact of PAYG LPG pilot on CD customers. Green = moved 'up' energy ladder, red = moved 'down'

This important finding alludes to the incremental role that PAYG LPG could fulfil in the wider clean cooking transition, as a way of introducing biomass users to LPG cooking with minimal financial risk.

3.6.2 COVID-19 Lockdown

In TS2, which took place mid-LD, customers were asked about the impact of COVID-19 on their cooking habits. 65% of respondents (N = 15) reported there was reduced availability of foods and increased prices, with potatoes and rice rising by 10-30%. This is despite the government freezing the prices of staple foods (Uwiringiyimana 2020a).

Customers were asked about changes in their fuel use due to the lockdown (Table 13). The majority reported an increase in LPG use but no change for charcoal. 10 out of 11 respondents (91%) said their increase in LPG use was due to the whole family being at home. One customer explained, "Some of us used to take breakfast and lunch at work, but now we are working at home. So, it is a requirement that we take both breakfast and lunch at home. That is why the LPG is used more than usual". It is interesting that the additional cooking energy need was met by LPG rather than charcoal; it implies that LPG was the primary fuel for these customers and that charcoal continued to be used as a backup.

	Charcoal	LPG
Customers using more fuel than before	2	11
Customer using the same as before	15	6
Customers using less fuel than before	3	3

Table 13: Changes in domestic customer fuel use due to COVID-19 lockdown

3.6.3 Easing of COVID-19 Lockdown

A comparison of the cooking diaries contents pre-LD and post-LD concluded that the bulk of the CD data (collected post-lockdown) was representative of cooking habits during Bboxx's pilot. The number of food cooking events per day was very similar, as is shown in Figure 64 and the proportion of cooking performed on each fuel was almost identical across the two periods (Figure 65). Most of the top six most common dishes were cooked a similar amount (Figure 66), apart from an increase in consumption of bananas (112% more post-LD compared to pre-LD) and fewer green vegetables (decrease of 26%). This is likely to have been due to the change of season from rainy pre-LD to dry post-LD. In dry season, green vegetables only grow in swampy areas so there tends to be restricted availability in the Kigali markets. In contrast bananas flourish at this time, resulting in plentiful supplies and lower prices. Participants recorded spending more time cooking post-LD (Figure 67).

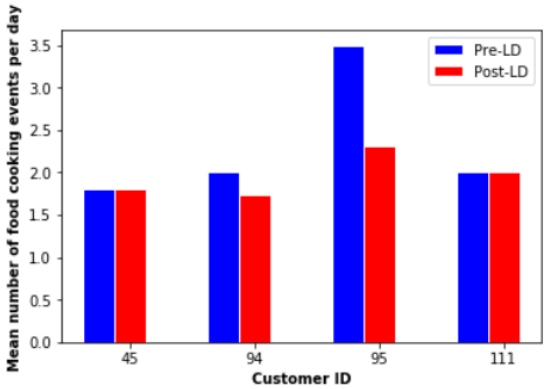

Figure 64: Mean no. food cooking events per day pre- and post-LD for CD customers

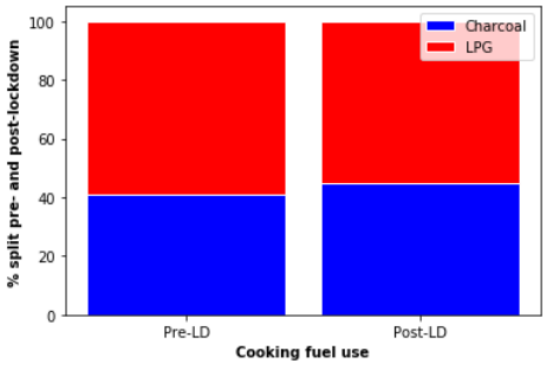

Figure 65: Proportion of cooking event using charcoal and LPG pre- and post-LD for CD customers

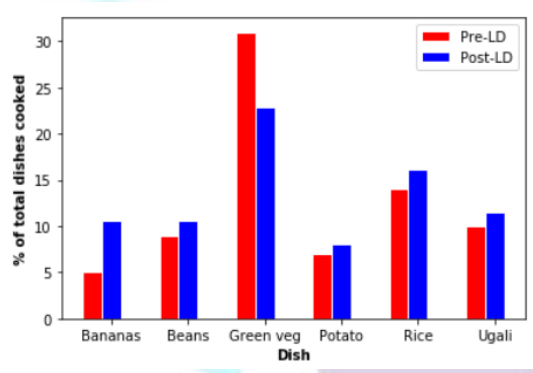

Figure 66: Frequency of cooking top six dishes pre- and post-LD for CD customers

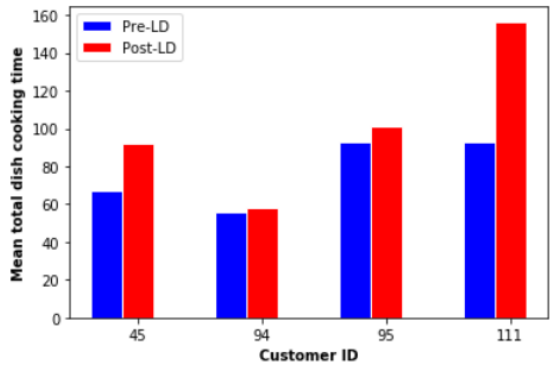

Figure 67: Mean total dish cooking time pre- and post-LD for CD customers

There was little shift in utilisation rates (Figure 68 and Figure 69), with LPG being used on 87% of recorded days pre-LD and 86% mid-LD, and charcoal changing from 41% to 39% correspondingly. The proportion of stacked cooking days on which both LPG and charcoal were used reduced from 34% to 30%, and days on which no cooking occurred halved from 8% to 4%; perhaps unsurprising given the imperative to stay home during lockdown (p =0.168). All of these changes were found to be insignificant (Wilcoxon test p = 0.878 for LPG; p = 0.239 for charcoal; p = 0.182 for stacked; p = 0.168 for no cooking).

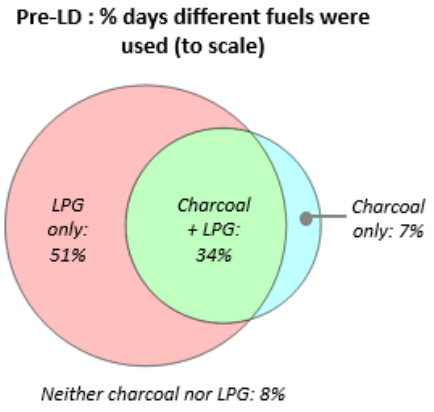

Figure 63

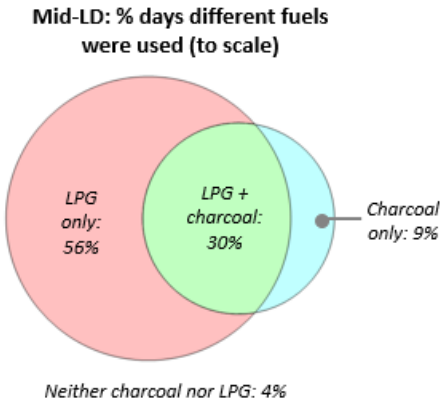

Figure 62

The validity of these findings to the rest of Bboxx's customers was checked by comparing the SMART data for the subset of customers used to the wider customer base. For the wider customer base, the average utilisation rate for LPG was also similar pre- and dur-LD (75% pre-LD and 72% dur-LD). The mean time spent cooking per day was almost identical (1:43 pre-LD and 1:44 dur-LD, and both groups spent more time cooking mid-LD. The broad similarity of the results between the two groups indicates that the impacts described in the paragraphs above are also representative of other Bboxx customers.

4 Limitations

Some elements of the study used small sample sizes, such as N = 10 for the cooking diaries, exposing a risk that findings were not representative of the wider population. Efforts were taken to increase the reliability of results by having purposeful overlaps between subsets of customers involved in each method and triangulating results wherever possible.

COVID-19 meant that the lead researcher had to return to the UK early, leading to a heavy reliance on enumerators, limited scope for face to face engagement and an inability to conduct monitoring and evaluation activities as planned. There was some data loss due to equipment memory limits and quality issues. Planned focus group discussions were cancelled, so a rich qualitative dimension was lost. Although every effort was taken to account for the impact of the pandemic on results, the social and economic implications of the pandemic were far-reaching and are likely to have diminished the study's validity to 'normal' times.

Instances of respondent and recall bias were unearthed through the study. To combat this, efforts were made to compare findings to objective SUMs and SMART data wherever possible.

5 Further work

This study demonstrated the extent and prevalence of fuel stacking in Bboxx's PAYG LPG customers. More research is needed to understand if these findings are representative of PAYG LPG customers elsewhere. Further work is also needed to understand the efficacy, scalability and financial viability of the suggested fuel stacking interventions.

The results from this study will also be published as a journal paper and disseminated at academic conferences. A MECS MECS field seminar are also planned. A follow-on study is being planned in Kenya, which will trial different interventions to reduce fuel stacking in Bboxx's PAYG LPG customers.

This research has sparked a collaboration between UCL and Farm Fresh, the Rwandan manufacturer or pre-cooked beans, and funding applications have been submitted to further explore how Farm Fresh's product could facilitate biomass-LPG cooking transitions.

6 Conclusions

In conclusion, this research has generated a detailed understanding of the demographics of Bboxx's PAYG LPG customers in Rwanda, their perceptions of the technology and their patterns of fuel stacking. Bboxx's customers were relatively wealthy compared to the Kigali average, and most used charcoal as their primary cooking fuel before signing up to Bboxx's product. They were attracted to the safety, delivery and affordability of the product, as well as the ability to buy fuel in small amounts. Operational issues led to negative perceptions of Bboxx's service. The average customer saved RWF 3,240 per month (£2.60) since starting to use PAYG LPG, although some experienced an increase in cooking fuel spend.

Green vegetables, rice, ugali, potatoes, bananas and beans accounted for 74% of dishes cooked. Of these, only beans were cooked on charcoal more often than on LPG; the telephone survey revealed a widely held perception that beans should be cooked on charcoal, but blind tests showed that in reality they could not tell the difference. LPG was preferred for frying and boiling. Most customers still had working charcoal stoves in their homes and used them frequently; consumption data showed that LPG was used 18 times per week on average and charcoal five times, although there was considerable variation in the amount of stacking between customers. Both fuels were used on 34% of days and in 12% of meals; it is possible that stacked meals were driven by the need to cook several dishes simultaneously. Although 79% of cooking events took place on LPG, it only accounted for 57% of total cooking fuel spend. Data suggested that a complete shift to LPG could result in a 27% decrease in customer cooking fuel expenditure and a 28% increase in revenues for Bboxx.

Thus reducing fuel stacking could provide health and financial benefits to customers and a pathway to business sustainability for Bboxx. A number of interventions were identified that could persuade customers to decrease their reliance on biomass cooking, including: 1) amending the PAYG LPG tariff to increase transparency of costs; 2) increasing operational coverage and automation to ensure that customers never run out of gas; 3) offering four-burner LPG stoves; 4) educating customers about the health benefits to children and economic benefits of increased LPG adoption; 5) behavioural interventions targeted at changing the way that people cooked foods regarded as incompatible with LPG such as beans.

COVID-19 lockdown had little impact on LPG and charcoal cooking practices, but when people lost access to PAYG LPG, charcoal cooking in the weeks immediately after increased. This effect died out over time; cooking diaries data collected at the ease of lockdown showed that most customers continued to use LPG as their main fuel. This shows that even after the PAYG LPG service stopped, the experience of participating in the pilot facilitated a transition to clean cooking. This highlights the important transitory role that PAYG LPG could play in the wider clean cooking transition.

This work has generated key insights particularly relevant to implementers of cooking-as-a-service business models and clean cooking practitioners in Rwanda. It highlights the pervasiveness and complex drivers of fuel stacking, and the opportunity that lies in understanding how to alter the balance.

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