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Use of liquefied petroleum gas in Puno, Peru: Fuel needs under conditions of free fuel and near-exclusive use

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Abstract

Reducing the burden of household air pollution could be achieved with exclusive adoption of cleaner fuels such as liquefied petroleum gas (LPG). However, we lack understanding of how much LPG is required to support exclusive use and how household characteristics affect this quantity. This paper used data from 90 participants in the Cardiopulmonary outcomes and Household Air Pollution (CHAP) trial in Puno, Peru who received free LPG deliveries for one year. Households with a mean of four members that cooked nearly exclusively (>98%) with LPG used an average of 19.1 kg (95% CI 18.5 to 19.6) of LPG per month for tasks similar to those done

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with the traditional biomass stove. LPG use per month was 0.5 kg higher for each additional pig or dog owned ($p=0.003$), 0.7 kg higher for each additional household member ($p<0.001$), 0.3 kg higher for households in the second-lowest compared to the lowest wealth quintile ($p=0.01$), and 1.1 kg higher if the household had previously received subsidized LPG ($p=0.05$). LPG use per month was 1.1 kg lower during the rainy season ($p<0.001$) and 1.7 kg lower during the planting season ($p<0.001$) compared to the cold and harvest seasons, despite the fact that LPG was not typically used for space heating. LPG use decreased by 0.05 kg per month over the course of one year after receiving the LPG stove ($p=0.02$). These results suggest that achieving exclusive LPG use in Puno, Peru requires that rural residents have affordable access to an average of two 10 kg LPG tanks per month. Conducting similar investigations in other countries could help policymakers set and target LPG subsidies to ensure that households have access to enough LPG to achieve exclusive LPG use and the potential health benefits.

Keywords

liquefied petroleum gas (LPG); clean energy; clean fuel; mixed methods; Peru; household air pollution

1. Introduction

Household air pollution (HAP) is one of the leading causes of death and disability in low- and middle-income countries (LMICs).¹ HAP is linked to many adverse health outcomes including low birth weight and pneumonia in children, and chronic obstructive pulmonary disease, lung cancer, and cardiovascular disease in adults.² Many LMICs have attempted to roll out improved biomass stoves and clean fuel technologies to reduce the burden of HAP through large-scale governmental efforts as well as smaller-scale programs.³ However, improved biomass stoves have not been shown to reduce exposure to fine particulate matter ($PM_{2.5}$) to the targets set by the World Health Organization (WHO).⁴ Thus most recent efforts focus on clean-burning fuels such as liquefied petroleum gas (LPG), electricity, ethanol, and biogas.⁴ Still, even these cleaner technologies have not achieved the WHO interim target for exposure to HAP in most field settings.⁴

A main contributor to the inability of most programs to achieve desired exposure reductions is stove stacking, in which households continue to use biomass-burning stoves in tandem with clean cooking technologies.⁵ Nearly all documented efforts to promote clean cooking have seen high levels of stove stacking.^{6–9} One of the most commonly cited reasons for stove stacking is the high cost of clean-burning fuel.⁹ Due to an inability to pay for the quantity of fuel necessary for exclusive use, many households continue to use biomass fuels that are often collected for free. Cleaner fuels such as LPG may be reserved for specific tasks such as tea, snacks, or emergency situations that require fast cooking.^{8,10}

Because exclusive LPG use has rarely been observed, there is a lack of knowledge about exactly how much LPG is required to support exclusive LPG cooking. Some governmental programs have attempted to estimate this quantity to design nationwide subsidy programs that will increase LPG access for rural and poor populations. In average families, for example, a one-month supply of LPG is estimated to be 14.5 kilograms (kg) by the Rural

LPG Program in Ghana,⁶ 10 kg by the *Fondo de Inclusión Social Energético* (Social Energy Inclusion Fund, FISE) program in Peru,⁷ and 15 kg by the national LPG program in Ecuador.¹¹ However, these averages may not fully capture the actual amount of LPG required for exclusive use if based on mixed fuel-using households, or may not capture variation in LPG needs across households with different characteristics or across time.

In Peru, access to LPG has increased through two governmental initiatives: 1) *Cocinas Peru* (Peru Stoves), which provided a free two-burner LPG stove, LPG tank, and accessories to poor families from 2013 through 2016, and 2) FISE, which provides vouchers that cover approximately half the cost of one 10 kg LPG tank per month for poor families.⁷ However, a recent analysis of the FISE program found that stacking of LPG with biomass fuel stoves was nearly universal among FISE beneficiaries surveyed in Puno, Peru.⁷ The authors posited that one potential explanation was the 10 kg of LPG provided per month by the FISE program was not sufficient to cover all cooking needs, thus leading to mixed use of LPG and biomass.⁷

By situating our analysis within a research study with intensive reinforcement of exclusive LPG use, this paper aims to characterize exclusive LPG use in Puno, Peru through the following objectives: 1) quantify the amount of LPG required to support exclusive use, 2) identify factors influencing the rate of LPG use when used exclusively, and 3) qualitatively explore household-level reasons for the observed rates of LPG use.

2. Methods

2.1. Study Setting

This study was carried out in the rural communities surrounding the city of Puno, Peru, located 3,825 meters above sea level. Puno is characterized by a large Aymara and Quechua indigenous population, many of whom also speak Spanish. Puno experiences a rainy season from December to March with an average monthly rainfall of 142.3 mm (5.6 inches).¹² The cold season occurs from June to August with average low temperatures around -8°C (18°F). However, because of the high altitude, temperatures remain cool year-round, with high temperatures ranging between $14\text{--}16^{\circ}\text{C}$ ($57\text{--}61^{\circ}\text{F}$) and low temperatures between $-8\text{--}2^{\circ}\text{C}$ ($18\text{--}36^{\circ}\text{F}$).¹²

The majority of rural residents in Puno cook primarily with a biomass-burning stove (known as a *fogón* in Spanish), although many also own a secondary LPG stove.⁷ LPG distribution in Peru operates on a recirculation model: Households pay an initial deposit of 60 soles (US \$18) for an LPG tank and 36 soles (US \$11) for 10 kg of LPG. When empty, the tank is exchanged for a different full tank at a cost of 36 soles (US \$11).⁷ Most cooking is done indoors in kitchens that are separate from other rooms in the house. Common biomass fuels used in Puno include dung, wood, and crop residues, which are generally collected for free from livestock and hills surrounding rural homes.

2.2. Data collection

This study was conducted as part of the Cardiopulmonary outcomes and Household Air Pollution (CHAP) trial, a randomized controlled trial testing an LPG stove and fuel

distribution intervention to reduce HAP exposures and improve health outcomes.¹³ Details of the CHAP trial are described elsewhere.¹⁴ The CHAP trial enrolled 180 non-pregnant adult women aged 25–64 years who were the primary cook in their household, cooked daily with a traditional biomass stove (*fogón*), and cooked indoors in a kitchen separate from their sleeping space.

Enrollment was completed on a rolling basis between January 2017 and February 2018. Approximately 15 women were enrolled per month and randomly assigned to either the intervention or control group after completing baseline measurements. On the day of randomization, participants assigned to the intervention group received a cooking demonstration highlighting the benefits of LPG and strategies for preparing local dishes with LPG, a training session on proper use and maintenance of the LPG stove, one three-burner LPG stove, and one 10 kg tank of LPG. We provided a three-burner LPG stove manufactured locally specifically for the trial by Surges Industries (Juliaca, Peru) (Figure 1). At the time of our study, most LPG stoves on the market had only two burners (Figure 2).¹⁵ However, our formative research demonstrated that people typically cook with and prefer three burners given that the traditional biomass stoves in the region also have three burners.¹⁰ Our LPG stove was also designed to have an adjustable flame strength given formative research findings that the flames of typical LPG stoves on the market were perceived to be weak.

Participants received free unlimited deliveries of LPG refills for 12 months starting from their date of randomization. Across all intervention participants, LPG deliveries occurred between March 2017 and February 2019. Participants called the fieldworkers when their tank was low, and in response fieldworkers visited the household to remove the empty tank and install a full tank in its place. Fieldworkers additionally made frequent unrequested visits to households to check their LPG supply. Fieldworkers monitored the average number of days that an LPG tank lasted for each household. When participants used a tank faster than their average, fieldworkers asked standard questions to confirm that the participant had used the LPG tank only for their household's needs (i.e. not shared with or sold to others). When exchanging the LPG tanks, fieldworkers also reinforced exclusive LPG use and addressed any questions or concerns participants had about the LPG stove.

At each visit, fieldworkers completed a questionnaire to record the date and time of delivery, and the weight of both the empty and replacement LPG tanks. Tanks were weighed using a hanging scale (2-in-1 Travel Scale, Swisste, Portland, ME), which has a capacity of up to 50 kg.¹⁶ Weights were recorded to 2 decimal places.

2.2.1. Socio-demographic and behavioral data—Household demographic data was collected through a questionnaire administered once at baseline (prior to randomization) and again 12-months after randomization. A survey on cooking behavior was also administered 1, 3, 6, 9, and 12 months after delivery of the LPG stove. This survey included questions about the number of cooking sessions and stove use tasks completed during each session (allowing participants to select one or more reasons for using the stove) on the day prior to the survey. This paper relies primarily on data collected from the 90 intervention

participants, but also makes comparisons to quantitative data from the behavioral surveys with the 90 control participants.

2.2.2. Qualitative data—We conducted qualitative interviews with 22 intervention participants to provide additional insight into the quantitative findings. Qualitative methods have been published separately.¹⁷ This paper drew on qualitative information related to reasons for LPG use, perceptions about cooking for animals, and opinions on the quantities of LPG used.

2.3. Analysis

2.3.1. Quantitative analysis—The primary objective of the quantitative analysis was to estimate the average amount of LPG used by intervention participants during their first year in the CHAP trial, when they were receiving free, unlimited LPG deliveries. LPG usage in kilograms was calculated in three ways:

1. Overall monthly average LPG use: We summed the total kilograms of LPG used across all tanks delivered to the household (based on the difference in weight between installation and replacement of each tank), and dividing by the total number of days between all deliveries. We then multiplied this daily rate by 30.4375 (average number of days in a month accounting for leap years) to obtain an overall monthly average for each participant.
2. LPG use per calendar month: For each calendar month, we summed the total number of kilograms used in the month, divided by the number of days in the month, then multiplied by 30.4375 to standardize rates across months of differing lengths.
3. LPG use by number of months since LPG installation: We used the dates of LPG tank deliveries to determine in which follow-up month each tank was used. For each tank, we calculated the total number of kilograms used divided by the total number of days over which the tank was used and multiplied by 30.4375 to estimate the monthly average. We averaged monthly rates across all tanks used in the same month.

We ran unadjusted and adjusted linear regressions to determine the impact of potential influencing variables on overall monthly average LPG usage, including number of dogs and pigs owned, number of household members, wealth quintile, years of education, age, percent of cooking done with LPG, and participation in FISE (Peruvian LPG subsidization program). We ran a multilevel mixed-effects linear regression to quantify changes in LPG use based on months since LPG installation, controlling for month of study enrollment, participation in FISE, and changes from baseline to 12-months post-randomization in percent of cooking done with LPG, number of pigs and dogs owned, wealth quintile, and number of household members. We calculated average LPG usage for each month after LPG installation by averaging monthly rates for all 90 intervention participants. We plotted this average as well as individual usage by month for 20 randomly selected participants.

We fit linear mixed effects models to estimate the impact of calendar month on the overall monthly average use of LPG, accounting for the fact that each participant had multiple measures of LPG consumption across 12 calendar months. We conducted a likelihood ratio test (LRT) to compare the log likelihoods from the models with and without calendar month, all containing significant covariates from the linear regressions. A one-way repeated-measures analysis of variance (ANOVA) was also performed to determine the impact of seasonality on LPG use, followed by pairwise comparisons of predictive margins to understand specific relationships between seasons. Seasons were defined as the cold season (June, July, August), harvest season (April, May), rainy season (December, January, February, March), and planting season (September, October, November).

We used data from the cooking behavior surveys conducted 1, 3, 6, 9, and 12 months post-randomization to quantify the average number of meals cooked across the surveyed days, separately for intervention and control participants. We calculated the percent of surveys in which participants reported each reason for lighting their stove at each meal. We included only reasons for meals cooked on the *fogón* by control participants and meals cooked with LPG by intervention participants to ensure comparisons were between the same stove types.

Household characteristics were summarized with descriptive statistics, including mean and standard deviation for continuous variables and percentages for categorical variables. Wealth status was calculated based on nationally representative wealth quintiles.¹⁸

We analyzed quantitative data using STATA SE version 15 (Stata Corp., College Station, Texas, USA) and R (www.r-project.org).^{19,20}

2.3.2. Qualitative analysis—The first author reviewed transcriptions from the interviews to identify emergent themes related to LPG use. She then reviewed identified themes with the last authors to create a codebook. The first author then used ATLAS.ti version 8 (Scientific Software Development GmbH, Berlin, Germany) to code transcripts by assigning the themes to relevant quotations.²¹ The last authors reviewed the coding and discussed and resolved any discrepancies with the first author. All authors reviewed the coded quotes to identify the key information related to each theme.

2.4. Ethical Approval

The trial received ethical approval from the Institutional Review Boards of Johns Hopkins University Bloomberg School of Public Health (00007128), Asociación Benéfica PRISMA in Peru (CE2402.16), and the University of Peru Cayetano Heredia (66780). The trial is registered in ClinicalTrials.gov (identifier [NCT02994680](https://clinicaltrials.gov/ct2/show/study?term=NCT02994680)). All participants provided informed consent.

3. Results

3.1. Participant Characteristics

Table 1 shows baseline characteristics of intervention participants. The majority of participants spoke both Aymara and Spanish (99%), were married or cohabitating (87%), and worked as farmers growing crops and/or raising livestock (87%). Over 70% of

participants reported that they owned an LPG stove prior to receiving one from the trial, although Month 1 survey data from control participants indicated that only 40% of participants with LPG stoves at baseline were likely using LPG regularly. Of the participants who owned an LPG stove at baseline, 64% (41) currently or previously received LPG vouchers through the FISE subsidy program (one participant had received FISE vouchers previously but no longer owned an LPG stove). Over 90% of households had electricity and access to a cell phone. The average household had approximately four members. Participants were mostly classified in the poorest (57%) and second poorest (36%) wealth quintiles. Nearly 60% of participants reported earning less than 250 soles (US \$76) per month, meaning an annual income of less than 3,000 soles (US \$909).

However, this reported income could be supplemented with products obtained through subsistence agriculture or in-kind bartering.

3.2. Reasons for LPG Use

Both intervention and control participants reported using the morning cooking session to cook food for their family, heat water for tea, and prepare animal fodder on the majority of surveyed days (Figure 3). Many participants in both groups (49% of control participants and 48% of intervention participants) also reported heating water for cleaning or bathing in the morning. The evening cooking session was most commonly used across both groups to cook food for the family and heat water for tea, with many participants also preparing animal fodder (42% of control participants and 40% of intervention participants). Re-heating leftovers was more commonly done in the evening than in the morning in both groups ($p<0.001$).

Most participants reported cooking once in the morning and once in the evening. Additionally, intervention participants reported cooking a mid-day meal on 32% of days, compared to only 13% of days for control participants. A larger number of intervention participants ($n=69$) reported ever cooking a mid-day meal than control participants ($n=20$) ($p<0.001$).

At the mid-day meal, in addition to cooking food for their families, intervention participants were more likely to report reheating leftovers and preparing tea, while control participants were more likely to report heating water for cleaning and preparing animal fodder. Only the difference in reheating leftovers ($p=0.004$) and preparing animal fodder ($p=0.04$) were significant, likely given the small number of control participants who cooked a mid-day meal ($n=20$).

Across all meals, intervention participants were more likely to reheat leftovers ($p<0.001$) and to light their stove solely to prepare tea than control participants ($p=0.005$). Using the stove for space heating or cooking food to sell was very rare for both intervention and control participants. Only one control participant and three intervention participants reported ever cooking food to sell, and each of these four participants only cooked food to sell on 20% of surveyed days. Among both intervention and control participants, space heating was only reported as an additional reason for lighting the stove for 0.7% of cooking events; no participants reported lighting their stove solely for space heating.

According to qualitative interviews, women commonly cooked for their pigs and dogs, noting that the animals would not eat raw food. However, some participants acknowledged that animals could eat raw food if they were raised that way.

“Leftovers, potato peels, chuño [freeze-dried potatoes], we grind it and cook it. [The pig] gets fat quickly. Other ladies buy... injections... to make them get fat. But not me, just natural.” (Woman, 58, 98.2% LPG use, 19.7 kg LPG per month, 2 HH members)

“Some people don’t cook [for the pig]. In cold water they stir ground barley or anything, and the pigs eat without any problem. We do it cooked it’s also normal... I have made it accustomed to cooked food.. I haven’t given it raw food... That could give it diarrhea” (Woman, 62, 92.0% LPG use, 14.9 kg LPG per month, 2 HH members)

People also described that some cooking tasks require more time to cook and thus use more LPG, such as boiling fava beans, cooking food for many animals or people, and cooking in clay pots.

“[The clay pot] takes a long time to heat the water, it’s slow. But the food cooked in the clay pot is delicious.” (Woman, 61, 98.8% LPG use, 19.0 kg LPG per month, 2 HH members)

“[The flame] has to be strong to boil the fava beans. They’re raw, they’re hard. It cooks... for three hours, but it uses a lot of gas.” (Woman, 48, 99.8% LPG use, 24.6 kg LPG per month, 2 HH members)

3.3. Average rates of LPG usage

Participants used on average 19.1 kg of LPG (SD 2.5) per household per month, and 5.9 kg of LPG (SD 2.4) per person per month (Table 2). Deliveries to replace empty tanks with full tanks were made on average every 16.1 days (SD 2.2), excluding three deliveries made early due to tank problems (i.e. malfunctioning valves and gas leaks). Table 2 shows that households with more members and more pigs or dogs used larger quantities of LPG per month, which aligns with qualitative findings.

“As we are only two people, sometimes we cook very little. Sometimes [a gas tank] lasts 20 days... Those that have families... sometimes it only lasts 12 days.” (Woman, 62, 92.0% LPG use, 14.9 kg LPG per month, 2 HH members)

According to unadjusted and adjusted linear regressions, participants used significantly more kilograms of LPG per month for each additional family member and each additional pig or dog (Table 3). Participants who had received vouchers through the governmental FISE program (indicating experience cooking with subsidized LPG) also used significantly more kilograms of LPG per month compared to non-FISE participants.

Households in the second poorest wealth quintile used significantly more LPG per month than those in the poorest quintile. However, the participant’s education and age did not significantly affect the amount of LPG used per month. The percent of cooking with LPG

did not significantly affect the amount of LPG used, likely due to the fact that participants used LPG for over 98% of all cooking.

3.4. Impact of seasonality and amount of time in study on LPG consumption

LPG use also varied by calendar month and season (Figure 4). Average LPG usage per month was highest during the winter months of June and July, which fell during the cold season. Although participants did not report using LPG for space heating, qualitative findings indicated that higher usage in these months could be related to other cooking tasks done more commonly on cold days, such as heating water or preparing tea.

“I put on hot water to bathe myself. It’s cold, now it’s freezing. So I put hot water to wash, sometimes to wash the vegetables... When it’s cold, I warm myself with tea.” (Woman, 42, 86.0% LPG use, 16.8 kg LPG per month, 8 HH members)

LPG use was also high during April and May, the harvest season, when produce for cooking was more abundant. LPG usage was lower on average across the months of December, January, February, and March (the rainy season) and in September, October, and November (the planting season). However, the mean amount of LPG used per month had a fairly narrow range, from 18.1 kg (November) to 20.2 kg (July). A less restrictive mixed effects model (with calendar month) fit the data significantly better than a more restrictive model (without calendar month) (LRT, 11 df, $p < 0.001$).

ANOVA results showed that the cold season was characterized by higher LPG usage than the rainy and planting seasons (1.1 kg, $p < 0.001$ and 1.7 kg, $p < 0.001$, respectively). LPG usage during the harvest season was also higher than that of the rainy and planting seasons (1.1 kg, $p < 0.001$ and 1.7 kg, $p < 0.001$ respectively).

Controlling for changes in percent of cooking done with LPG, number of pigs and dogs, number of household members, and wealth quintile between baseline and 12-months post-randomization, as well as for previous FISE participation and randomization month, participants used on average 0.05 kg less LPG each month over the course of the 12-month intervention period ($p = 0.02$). This means on average participants used 0.6 kg less LPG in month 12 than in month 1. Although statistically significant, this represents only 3% of the average amount of LPG used per month, and each participant’s usage fluctuated month by month (Figure 5).

Qualitative interviews indicated that fluctuations in animal ownership or family size could influence the rate of LPG consumption within a household at different points in time.

“When we had a pig, I had to cook more for the pig. Now I don’t have a pig... We ate the pig... Now I’m going to buy another one.” (Woman, 62, 98.8% LPG use, 15.9 kg LPG per month, 3 HH members)

“When we have a lot of family members [at home], the gas runs out in 12 days. Right now, when we are just two people, my granddaughter and me, the gas lasts 15 days. Soon my daughter is going to arrive and the gas will run out [more quickly].” (Woman, 54, 99.9% LPG use, 21.2 kg LPG per month, 3 HH members)

3.5. Perceptions of LPG consumption

When study staff asked participants about their LPG usage to confirm that they were not sharing it with others or using it for reasons other than household needs, some households reported that they felt they used their LPG tanks too quickly. This inadvertently caused some participants to try to ration their LPG, despite the fact that the study would provide as much LPG as needed.

Some participants said they cooked with their biomass stove when they thought their LPG tank was running out too quickly, while others avoided preparing long-cooking dishes so as not to use too much LPG.

“I’ve cooked fava beans [on LPG], but it uses the gas quickly. The fieldworkers said, „You finished in 13, 14 days.” They scared me. I won’t cook that, I say, because I finished quickly.” (Woman, 48, 99.8% LPG use, 24.6 kg LPG per month, 2 HH members)

“The fieldworker told me, „Ma’am, you’ve finished...why has [the gas] run out so fast?” It was 7, 8 days... I have to cook for my dog, for my pig, everyone, we’re a big family... Because they said that, I am rationing myself. I am cooking just a little, no more.” (Woman, 38, 100% LPG use, 23.1 kg LPG per month, 4 HH members)

Participants reported being conscious and careful with their LPG use. Close monitoring by fieldworkers and participants’ desires to comply with all perceived study rules to avoid the unfounded fear of being cut from the study or displeasing the fieldworkers suggests that wasteful LPG consumption was likely not occurring.

4. Discussion

To our knowledge, this paper is the first to investigate the rate of LPG use among rural households that transitioned from cooking with primarily biomass to near-exclusive use of a cleaner-burning LPG stove. Given that participants in previous LPG promotion efforts have not adopted LPG exclusively, the results of this study provide novel information about the quantity of LPG required to support exclusive LPG use in the rural, high-altitude setting of Puno, Peru. This information is essential to reduce the health burden of household air pollution from biomass stove use, which will not be possible unless households have affordable access to enough LPG to cover the majority of cooking tasks and enable near-complete abandonment of biomass stoves.²²

The findings of this study indicate that the average rural household in Puno, Peru requires approximately two 10 kg tanks of LPG per month for their cooking tasks. This amount is higher than the one tank per month previously estimated by the Peruvian government.⁷ Accounting for the unique characteristics influencing rural cooking behaviors is important to fully understand LPG consumption requirements. For example, households with more pigs, dogs, and household members have higher LPG consumption likely given the need to cook more food. Households in the poorest wealth quintile may use less LPG than those in the second poorest because they cannot afford as much food or may not have as much access to

different types of food as those in higher quintiles, thus leading to less cooking. Previous FISE participants may also consume more LPG given their previous familiarity and comfort with LPG or potential habits of using subsidized LPG more liberally. More research on how subsidization affects LPG usage behavior is needed.

Overall, the LPG stove is generally used for the same purposes as the biomass stove, likely given the fact that participants perceived the trial LPG stove to have an adequate number of burners, accommodate previously owned pots, and enable preparation of most traditional dishes.¹⁷ However, LPG users often cook a mid-day meal, which is less frequently done with the biomass stove. This could be another reason why LPG needs are higher than previously anticipated, because cooking tasks that were not originally done with the biomass stove are being added into the cooking repertoire once LPG is available. Similarly, Ruiz-Mercado et al. found that different cooking technologies fulfilled different cooking niches.⁵ Thus, we cannot assume that families will continue performing the same cooking tasks that were done with a biomass stove once they transition to LPG. Estimates of LPG consumption requirements will be lower than the actual amount needed if LPG-specific cooking tasks are not considered in usage estimates.

Based on our results, achieving exclusive LPG use in Puno requires either increasing the LPG subsidy for poor families, and/or identifying strategies to reduce the LPG needs of rural households. To obtain the needed two tanks of LPG per month assuming participation in the Peruvian FISE program, households would have to pay approximately 56 soles per month (US \$17), equating to more than 22% of monthly income for most families. The high cost of LPG is one of the most frequently cited reasons why households across a range of settings continue cooking with biomass even after adopting LPG.⁹ For example, a major reason why participants in the national LPG program in Ghana did not refill their LPG tanks was that refills cost more than double what households were paying for housing, water, and energy combined.⁶ Our results corroborate this finding, indicating that exclusive LPG use may be cost-prohibitive for most poor, rural families. Follow-up is underway to understand fuel use and purchase patterns among intervention households after the termination of their free LPG from the trial.

As the current FISE voucher only covers 5 kg of LPG per month, only about one quarter of participants' LPG needs are being met by the program. A targeted and graduated subsidy, adjusting the amount of LPG allotted based on family size as well as numbers of pigs and dogs owned, could help fill this deficit. Ecuador currently implements a sliding LPG subsidy, in which families with more people receive more subsidized LPG per month.¹¹ LPG programs such as FISE could also educate families on how to reduce household LPG consumption, such as cooking less for animals or using aluminum pots. Promoting conservation strategies concurrently with an increased subsidy could make exclusive LPG use more affordable. More research to design and evaluate potential LPG conservation strategies is currently underway.

In contrast to other studies that have found LPG use to be highest in the rainy season (when biomass fuel is wet and harder to light),⁷ our study demonstrated that when access to LPG was consistent and free, LPG use was lower in the rainy season compared to winter months.

This could have been due to warmer ambient temperatures, less availability of produce to cook, or more time spent in the fields instead of cooking during this growing season. Some studies have found that use of clean cooking technologies decreases over time after receipt of the technology, due largely to transition back to biomass stoves.^{6,23} Although our study found that the amount of LPG fuel used decreased slightly over the 12 months after LPG stove installation, this reduction represented only 3% of the average amount of LPG used per month. Individual fluctuations in fuel use across the year and qualitative data indicate that month-to-month variations in household structure (i.e. number of animals and people in the house) likely influence changes in the quantity of LPG used over time more so than time since receipt of the LPG stove under conditions of free LPG and near-exclusive LPG use.

The LPG usage rates we observed in Puno are somewhat higher than estimates of LPG consumption in other countries. The RLP program in Ghana estimates that rural households need on average 14.5 kg of LPG per month,⁶ and the LPG subsidy program in Ecuador estimates that households in the lowest wealth quintiles require 15 kg of LPG per month.¹¹ However, because exclusive LPG use among the rural poor has been rare, it is possible that current estimates of LPG needs could change with further investigation of exclusive LPG usage among these populations. The difference may also be due to Puno's high altitude where water boils at a lower temperature and thus food requires more time to cook, or differences in the types of food cooked, cooking practices, and/or LPG stove designs. Nonetheless, this study provides an initial snapshot of LPG usage needs among the rural poor.

4.1. Strengths and Limitations

Our study was strengthened by the fact that we achieved near-exclusive LPG use among rural participants who previously used primarily biomass, allowing us to estimate the amount of LPG needed to use LPG at levels necessary for realizing potential air quality and health improvements. Our mixed methods approach also enabled us to interpret and understand quantitative outcomes more fully. We also collected data over the course of an entire year with very little missing data. However, several limitations are important to keep in mind. Our results may underestimate LPG needs if participants avoided certain cooking tasks or performed some tasks with other stoves for fear of using the LPG too quickly, which may have been unintentionally caused by fieldworker questioning to confirm the LPG was used only for household needs. Conversely, our results could overestimate LPG needs if participants cooked with overly strong flames, shared LPG tanks with others, or cooked more than they normally would have because LPG was free. However, given extensive training and reinforcement, close monitoring by field workers and stove use monitors, and participants' desire to comply with study rules, the possibility that participants misused or shared LPG is slim. Overall, potential over- and under-consumption likely balanced out in our LPG estimates.

5. Conclusion

The results of our paper provide an important starting point for the types of factors that should be investigated elsewhere as potential influencers of LPG use. Important factors to

consider when determining how much LPG to subsidize include: 1) practices of cooking for animals, 2) number of family members, 3) seasonal differences, 4) types and frequency of daily cooking tasks, 5) LPG stove design, 6) environmental conditions such as altitude or temperature, 7) types of pots used, and 8) frequency of parties or other infrequent cooking tasks.

Attaining exclusive adoption of cleaner-burning fuels, which is necessary to reduce household air pollution from biomass stoves and realize potential health improvements, requires a solid understanding of the amount of fuel needed to support exclusive use. Governments can use knowledge about the quantity of fuel required and important influencers of this quantity to design LPG promotion programs that will enable access to a sufficient amount of fuel for affordable exclusive use. Our results suggest that exclusive use in Puno requires more LPG than current government estimates, highlighting the importance of conducting investigations such as these among rural populations exclusively using LPG to accurately set targets and subsidy limits. Compiling and comparing LPG usage needs across countries would enable more detailed comprehension of LPG needs and bolster global efforts to reduce household air pollution by not only “making the clean available” but also ensuring that a sufficient amount is made available at an affordable cost.²⁴

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Abbreviations:

CHAP	Cardiopulmonary outcomes and Household Air Pollution trial
DHS	Demographic and Health Survey
FISE	<i>Fondo de Inclusión Social Energético</i> (LPG subsidization program in Peru)

HAP	Household air pollution
HH	Household
Kg	Kilograms
LMIC	Low- and middle-income countries
LPG	Liquefied petroleum gas
PM_{2.5}	Fine particulate matter
WHO	World Health Organization

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Highlights:

- Study participants in Puno used on average 19.1 kg of LPG per month.
- LPG use was greater with pig/dog ownership, wealth, family size, and LPG vouchers.
- Participants used LPG and biomass similarly, but more often prepared lunch with LPG.
- The current subsidy in Peru covers only 25% of rural residents' LPG needs.
- Programs must provide enough fuel for exclusive use to achieve potential benefits.

Figure 1.
Three-burner liquefied petroleum gas (LPG) stove provided by the trial.

Figure 2.
Example of a two-burner liquefied petroleum gas (LPG) stove more commonly available on the market at the beginning of the trial.

Figure 3. Percent of surveys in which participants reported each reason for stove use during morning, mid-day, and evening cooking sessions, stratified by biomass and LPG users. Biomass sample size is based on the number of control participants who reported ever cooking each meal with their biomass stove; LPG sample size is based on the number of intervention participants who reported ever cooking each meal with their LPG stove.

Figure 4. Line graph of average kilograms of liquefied petroleum gas (LPG) used by calendar month with 95% confidence interval bars. The grey lines indicate seasonal averages.

Figure 5.

Kilograms of liquefied petroleum gas (LPG) used per month based on the number of months since LPG installation. Light blue lines represent LPG use over time since LPG installation for 20 randomly selected participants. The dark blue line represents LPG use over time since LPG installation averaged by month across all 90 participants.

Table 1.

Demographic characteristics of CHAP intervention participants at baseline.

	Intervention Participants (n=90) % (n) or mean (SD), range
Language	
Only Aymara	1.1% (1)
Aymara + Spanish	98.9% (89)
Married or Cohabiting	86.7% (78)
Participant Occupation: Farmer	86.7% (78)
Wealth Quintile	
Poorest	56.7% (51)
Poor	35.6% (32)
Middle	7.8% (7)
Monthly Income *	
0–99 soles / 0–30 USD	22.2% (20)
100–249 soles / 31–75 USD	36.7% (33)
250–499 soles / 76–151 USD	37.8% (34)
500 or more soles / 152+ USD	3.3% (3)
Owned LPG stove before trial	71.1% (64)
Electricity in household	94.4% (85)
Previous or current FISE participant	46.7% (42)
Household owns cell phone	90.0% (81)
Owens pig(s)	57.8% (52)
Owens dog(s)	73.3% (66)
Age in years	48.7 (9.1), 25.0–64.4
Years of Education	6.1 (3.4), 0–11
Number of Household Members	3.8 (1.7), 1–9

*
1 USD = 3.3 soles (as of February 2020)

Table 2.

Average kilograms of LPG used per month and days between deliveries for intervention participants, overall and by family size and animal ownership

	N	Kg per month (mean $\pm$ SD, range)	Days between deliveries (mean $\pm$ SD, range)
Overall			
Per Household (HH)	90	19.1 $\pm$ 2.5, 13.3–25.1	16.1 $\pm$ 2.2, 12.1–22.8
Per person	90	5.9 $\pm$ 2.4, 2.1–16.7	---
By # of HH members			
1–2	24	17.4 $\pm$ 2.5, 13.3–24.6	17.6 $\pm$ 2.4, 12.4–22.8
3–4	42	19.2 $\pm$ 2.3, 14.2–23.1	15.9 $\pm$ 2.0, 13.0–21.2
5+	24	20.6 $\pm$ 1.8, 16.8–25.1	14.8 $\pm$ 1.3, 12.1–18.1
By # of pigs and dogs			
0	7	17.1 $\pm$ 2.5, 13.8–20.3	18.0 $\pm$ 2.6, 15.0–21.9
1	34	18.2 $\pm$ 2.6, 13.3–23.7	16.9 $\pm$ 2.4, 12.6–22.8
2–3	40	19.8 $\pm$ 2.1, 15.9–25.1	15.4 $\pm$ 1.6, 12.1–19.1
4+	9	20.7 $\pm$ 1.7, 17.4–23.1	14.7 $\pm$ 1.3, 13.0–17.2

Table 3.

Influence of household characteristics on average kilograms of LPG used per month, adjusted and unadjusted linear regressions.

Factor		Unadjusted**			Adjusted**		
		Change in kg used/ month*	95% CI	p-value	Change in kg used/ month*	95% CI	p-value
Number of pigs and dogs		0.5	(0.2, 0.8)	0.003	0.4	(0.1, 0.7)	0.004
Number of household members		0.7	(0.4, 1.0)	<0.001	0.7	(0.4, 1.0)	<0.001
Wealth Quintile	Poorest (n=51)	0 (Reference)			0 (Reference)		
	Poor (n=32)	1.4	(0.3, 2.5)	0.01	1.3	(0.4, 2.2)	0.006
	Middle (n=7)	0.3	(-1.7, 2.2)	0.79	0.3	(-1.5, 2.0)	0.76
Years of education		0.1	(-0.1, 0.2)	0.73	0.1	(-0.1, 0.2)	0.39
Age of participant		-0.03	(-0.1, 0.02)	0.25	0.1	(-0.02, 0.1)	0.13
% Cooking done with LPG		0.1	(-0.1, 0.3)	0.33	0.1	(-0.01, 0.3)	0.07
Previous FISE participant		1.1	(0.02, 2.1)	0.05	1.1	(0.3, 2.0)	0.01

* Coefficients represent the change in average kilograms of LPG used per month for each unit of continuous variables or between groups of categorical variables

** Unadjusted analyses refer to a regression of each variable separately against average kilograms of LPG per month; adjusted analyses include all variables from the table in the regression.