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Exploring the impact of a liquefied petroleum gas intervention on time use in rural Peru: A mixed methods study on perceptions, use, and implications of time savings

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Abstract

Background—Efforts to promote clean cooking through adoption of clean-burning fuels such as liquefied petroleum gas (LPG) are often based on the idea that near-exclusive use of LPG could

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lead to health improvements. However, benefits beyond health, such as time savings, could be more tangible and meaningful to LPG users.

Objectives—This study investigated the effect of an LPG intervention on time spent cooking and collecting fuel, using objective measures of stove temperatures combined with self-reports under conditions of near-exclusive LPG use. We also investigated the perceived value of any time savings and potential economic and quality of life implications.

Methods—We analyzed data from the Cardiopulmonary outcomes and Household Air Pollution trial in Puno, Peru, a randomized controlled trial with 180 participants assessing exposure and health impacts of an LPG stove, fuel, and behavioral intervention. Surveys conducted with 90 intervention women receiving free LPG and 90 control women cooking primarily with biomass assessed time spent cooking and collecting biomass fuel and use of time savings. Cooking time was objectively measured with temperature sensors on all stoves. Qualitative interviews explored perceptions and use of time savings in more depth.

Results—Intervention women spent 3.2 fewer hours cooking and 1.9 fewer hours collecting fuel per week compared to control women, but cooked on average 1.0 more meals per day. Participants perceived time saved from LPG positively, reporting more time for household chores, leisure activities, and activities with income-generating potential such as caring for animals and working in fields.

Discussion—This paper suggests that the benefits of LPG extend beyond health and the environment. LPG use could also lead to economic and quality of life gains, through increased time for work, rest, and consumption of hot meals, and reduced arduous biomass fuel collection.

Keywords

household air pollution; liquefied petroleum gas (LPG); clean cookstoves; time savings; fuel collection; mixed methods

1. Introduction

Nearly three billion people worldwide use biomass fuels, such as wood, dung, charcoal, and crop residues, for their household cooking needs (World Health Organization, 2016). The burning of biomass fuel leads to high levels of household air pollution (HAP), which has been associated with negative health, environmental, and social outcomes (Gakidou et al., 2017). Using biomass fuel often requires a significant time investment to collect it from sometimes distant fields and forests, prepare the fuel by cutting, drying, or shaping it, assemble the fuel to start the fire, and cook with inefficient combustion and heat transfer. Many studies across a range of settings have found that the time required to cook with biomass is perceived as one of the main disadvantages of biomass cooking (Asante et al., 2018; Gould & Urpelainen, 2018; Hollada et al., 2017).

The burden of fuel collection and cooking tends to fall primarily on women and children, limiting the time they have available for income generation, education, and leisure activities (Shankar et al., 2014). In addition, fuel collection exposes women and children to environmental hazards (animal attacks and dangerous terrain), physical pain from carrying heavy loads, and violence or sexual assaults when collecting fuel alone (Martin, Glass, Balbus, & Collins, 2011; Shankar et al., 2014).

A few studies have investigated whether switching to cleaner stoves can reduce time spent cooking and collecting fuel. The majority of these studies have focused on improved biomass stoves, which intend to reduce biomass fuel consumption through improved heat transfer efficiency (Rehfuess, Puzzolo, Stanistreet, Pope, & Bruce, 2014). Although improved stoves still require collection or purchase and preparation of biomass fuel, studies have found evidence of reported time savings with improved compared to traditional biomass stoves, ranging from 11.3 to 17.3 hours per week (Bensch & Peters, 2015; Cundale et al., 2017; Jagoe et al., 2020).

Cleaner fuels such as electricity, liquefied petroleum gas (LPG), biogas, and ethanol have the potential for even greater time savings, given that they eliminate or drastically reduce the need for biomass fuel collection and have strong, concentrated heat that increases cooking efficiency. Only a few studies have investigated time savings in relation to cleaner fuels. Studies in India (biogas), Kenya (LPG and improved biomass stoves), and Sudan (LPG) found significant reductions in time spent cooking among participants who used cleaner technologies compared to traditional stoves, ranging from 2.3 to 18.4 hours per week (Anderman et al., 2015; Malla, Bruce, Bates, & Rehfuess, 2011). In terms of time spent collecting fuel, biogas users in India and a combination of LPG and improved biomass stove users in Kenya spent significantly less time collecting biomass fuel than traditional stove users, ranging from 1.2 to 10.5 hours per week (Anderman et al., 2015; Lewis et al., 2017; Malla et al., 2011). In contrast, Malla et al. (2011) found that in their Sudan site, LPG use did not reduce time spent collecting biomass fuel.

Most studies that have investigated time use related to both improved biomass and cleaner fuel stoves have not achieved exclusive use of the improved technology, thus limiting their ability to assess the full time savings potentially achievable with exclusive use (Jagoe et al., 2020; Kelly et al., 2018; Lewis et al., 2017). Additionally, most evidence on time savings has been selfreported, which may be inaccurate due to social desirability or recall bias (Gebreegziabher et al., 2018; Lewis et al., 2017; Malla et al., 2011).

While cooking with and collecting biomass fuel may be time intensive, primary cooks may not always view these activities negatively. A study in Peru reported that women enjoyed time spent cooking as a normal part of their daily routine (Hollada et al., 2017) and a study in Guatemala found women enjoyed the social time that biomass fuel collection afforded (Thompson, Hengstermann, Weinstein, & Diaz-Artiga, 2018). These findings indicate the necessity to understand not only time savings from a clean cooking device, but also whether users value the times savings. Many efforts to promote LPG adoption tout improved stoves and cleaner fuels as a way for women and children to improve their education and economic situation by attending school or engaging in business opportunities (Martin et al., 2011). However, there is a lack of evidence and disagreement in the literature on whether time savings are indeed dedicated to these activities and what benefits they bring to the individual (Abdulai et al., 2018; Cundale et al., 2017; Kelly et al., 2018; Pillarisetti, Jamison, & Smith, 2017; Thompson et al., 2018).

To our knowledge, no study has measured time savings with temperature-based stove use data among exclusive LPG users. Using stove temperature monitoring, self-report, and qualitative data, we sought to explore differences in time spent cooking and collecting fuel between primary biomass users and near-exclusive LPG users, understand how near-exclusive LPG users perceived changes in time use, and explore how near-exclusive LPG users spent any time saved.

2. Methods

2.1. Study Setting

This study was conducted in the high-altitude region of Puno, Peru. The area is populated by poor, indigenous people from Aymara and Quechua cultures, who typically earn a living through small-scale farming and raising livestock. Given Puno's nearly 4,000-meter altitude, trees are relatively scarce. Thus, most cooking is done with dung, which is usually collected (not purchased), shaped into patties, and dried. The traditional biomass stove in Puno is a three-burner clay stove called a *fogón.* LPG access in rural Puno has increased in recent years due to government programs such as *Cocinas Peru* (Peru Stoves), which distributed free LPG stoves to poor families from 2013–2016, and the *Fondo de Inclusión Social Energético* (Energy Social Inclusion Fund, FISE), which subsidizes approximately 50% of one 10-kilogram LPG tank per month for poor families who apply and qualify (Pollard et al., 2018).

2.2. Overall Study Design

This analysis was carried out as part of the Cardiopulmonary outcomes and Household Air Pollution (CHAP) randomized controlled trial, which aimed to test the impact of an LPG intervention on air quality and health outcomes (Fandino-Del-Rio et al., 2017). CHAP enrolled and randomized 180 adult, non-pregnant women between the ages of 25–64 in groups of 15 participants approximately every month from January 2017 to February 2018. Although many participants owned and occasionally used an LPG stove when enrolled, all reported cooking daily with biomass given the unaffordability of using LPG, even when subsidized, to meet all their cooking needs. Control households were free to purchase their own LPG stove and/or fuel throughout the trial. Intervention participants received a three-burner, locally-produced LPG stove, free continuous LPG refills delivered directly to their home for one year, and behavioral training and reinforcement for LPG use; control participants continued their baseline cooking practices. Details of the trial are described elsewhere (Fandino-Del-Rio et al., 2017).

2.3. Data Collection Methods

We used data from quantitative surveys and continuous temperature monitoring conducted as part of CHAP during the first year of the trial, in addition to supplemental qualitative interviews.

2.3.1. Quantitative Surveys—All participants completed a baseline survey prior to randomization assessing socio-demographic characteristics, types of fuels and stoves used, time spent cooking and collecting fuel, and money spent on fuel. A follow-up survey was conducted 1, 3, 6, 9, and 12 months post-randomization including unprompted questions on biomass fuel collection, stove use practices, and use of any time saved from LPG (Table 1). All survey data was collected by field workers who spoke both Spanish and Aymara, using the REDCap© data collection application on tablets (Harris et al., 2009).

2.3.2. Continuous Stove Use Monitoring—Stove temperature was measured by LabJack© Digit-TL temperature loggers, which were enclosed in aluminum cases (LabJack, 2017). At the point of enrollment (2–4 weeks prior to randomization), these devices were installed as stove use monitors (SUMs) on all traditional stoves in the household, as well as on previously owned LPG stoves in a subset of 24 control households (out of 68 control households with LPG stoves). SUMs were also affixed to all LPG stoves delivered by the study, which were installed in place of any previously owned LPG stoves. The SUMs were installed within the smoke stream a maximum of 1 meter above the traditional stove (Figure 1), and directly under the middle burner of the LPG stove (Figure 2). Biomass and LPG stove temperatures were recorded every minute throughout the duration of the 12-month intervention period. Field workers downloaded the SUMs data approximately every two weeks, and replaced batteries as needed.

2.3.3. Qualitative Interviews—A local field worker trained in qualitative methods performed in-depth interviews with 22 participants in the intervention group (12 non-exclusive and 10 exclusive LPG users). Our intention was to gain in-depth information from participants receiving free LPG fuel delivered directly to their homes on how these ideal conditions affected perceptions of time use, valuation of perceived changes in time, and activities performed with any time savings. All interviews were audio recorded and transcribed. Details on our qualitative methods are published separately (Williams et al., 2020).

2.4. Statistical methods

2.4.1. Stove Use Monitoring Data—Temperature data from the SUMs were processed using R version 3.6.2 (R Core Team, 2018). Separate algorithms were developed for temperature data from traditional and LPG stoves. In traditional stoves, a cooking event was defined as beginning at time t when the 30-minute rolling mean at ($t + 30$ *minutes)* was 2°C greater than at time t. Cooking events were considered to have ended once the 30-minute rolling mean temperature fell 2°C below the maximum 30-minute rolling mean reached within the cooking event.

For LPG stoves, a cooking event was defined to begin at time t if the 20-minute rolling mean at ($t + 5$ *minutes)* was more than 10% greater than the 20-minute rolling mean at *(*$t - 5$ *minutes)*. Cooking events were estimated to end once the temperature fell 3°C below the maximum 20-minute rolling mean during the event.

For both types of stoves, if multiple cooking events occurred within one hour of each other, they were classified as the same event. To be classified as an event, the rolling mean temperature had to exceed 20°C at some point during the cooking event. Additionally, the maximum duration for a cooking event was set at six hours for the *fogón* and four hours for LPG stoves. We set events to end shortly after temperatures started decreasing, as the decrease indicated that the participants had turned off the stove or stopped actively feeding the fire and were thus no longer spending time in front of the stove. We defined cooking time as the number of minutes between the start and end of a cooking event.

Using these algorithms, we estimated total minutes and total cooking events daily for each participant by summing across daily minutes and events on the *fogón* and LPG stoves. Any day with zero cooking events from either stove was considered missing data and dropped from the analysis. We considered *fogón* use to be zero for five participants who removed their *fogón* at LPG installation and did not re-install it, and for three participants who installed their LPG stove on top of their *fogón*. For 16 participants who removed their *fogón* after LPG installation and did not re-install it, we set *fogón* use equal to zero after the point of removal.

2.4.1. Yearly Average of Daily Cooking Minutes and Events—Our primary outcomes were yearly averages of the number of minutes spent cooking and number of cooking events per day. Using the SUMs data, we calculated a 12-month average for each participant by taking the mean of all available daily data. Using the survey data, we also calculated a 12-month average for each participant by taking the mean of daily data available from surveys conducted 1, 3, 6, 9, and 12 months after randomization. Separately for SUMs and survey data, we then averaged across participant means in each group to obtain intervention and control group means.

We then performed an intention to treat analysis in which we used two-tailed t-tests to compare the average number of minutes spent cooking and the average number of cooking events between intervention and control groups, separately analyzing survey and SUMs data. We also used two-tailed t-tests to compare cooking minutes and events between baseline and the post-randomization period within the intervention and control groups. Additionally, we conducted two-tailed t-tests and a Bland-Altman analysis to compare the yearly average of minutes spent cooking per day as estimated by SUMs data collected continuously over the 12-month intervention period and survey data collected at five time points throughout the year.

2.4.2. Sensitivity Analysis—To understand the impact of potential concurrent use of LPG and *fogón* stoves and unmonitored stove use, we conducted two sensitivity analyses with the SUMs data. First, we subtracted stacking minutes in which both the *fogón* and LPG stoves were used simultaneously; we recalculated yearly averages of minutes spent cooking per day and ran two-tailed t-tests to compare intervention to control groups. Second, we eliminated control households with evidence of unmonitored LPG stove use and re-ran the t-tests using the recalculated yearly averages that also accounted for stacking. This allowed us to quantify cooking minutes without potential over-counting due to concurrent use of the *fogón* and LPG stoves or potential undercounting due to missed cooking events in control households using unmonitored LPG stoves.

2.4.3. Fuel Collection Time—Total minutes spent collecting fuel per week as reported in surveys conducted 1, 3, 6, 9, and 12 months after randomization were calculated across participants in the intervention and control groups. We averaged the monthly data points to create an overall estimate of post-randomization fuel collection time. We ran two-tailed t-tests to compare differences in time spent collecting fuel between intervention and control participants, as well as between baseline and the post-randomization average.

All statistical analyses were performed in Stata SE, version 15 (StataCorp, 2017). Results were considered statistically significant if p-values were less than 0.05.

2.4.4. Qualitative Analysis—After audio recordings were transcribed and translated to English, the first author reviewed the interview transcripts to identify themes related to use and perceptions of time. She then made a codebook containing these themes and coded all transcripts using Atlas.ti version 8 to assist with data management (ATLAS.ti 8, 2018). Coded quotes were reviewed and confirmed by SAH. The first author extracted coded quotes to identify important points related to each theme, which were reviewed and agreed upon by all authors.

2.5. Ethical Approval

This study received ethical approval from the Institutional Review Board of Johns Hopkins University Bloomberg School of Public Health (00007128), as well as local approval in Peru from Asociación Benéfica PRISMA (CE2402.16) and Universidad Peruana Cayetano Heredia (66780). The trial is registered in ClinicalTrials.gov (identifier NCT02994680).

3. Results

3.1. Demographic characteristics

Demographic characteristics between intervention and control groups were similar (Table 2). Almost all participants spoke both Spanish and an Indigenous language (Quechua or Aymara), were married or cohabitating, worked as farmers, and owned a cell phone. On average, participants were 48 years old, had four household members, and had six years of education. Nearly all households had electricity. Most participants were classified into the lowest two national wealth quintiles, with an average monthly income of less than 250 soles (US $76). The majority of participants (73%) owned an LPG stove at baseline, although all participants reported using a traditional stove daily before enrollment. Participants in both groups commonly owned pigs, dogs, cattle, and sheep, and less commonly owned donkeys, horses, llamas, and alpacas.

3.2. Overall rate of LPG adoption

Intervention participants used LPG for 98.2% (SD 3.0, median 99.5%, range 86–100%) of cooking minutes according to SUMs data and 99.3% (SD 3.1, median 100%, range 83–100%) of reported cooking minutes according to survey data. Excluding 46 control participants with observed or reported LPG use in surveys and no SUM installed on their LPG stove, SUMs data indicates control participants (n=44) used LPG for 29.2% of cooking minutes (SD 29.7, median 29.3%, range 0–86%). In surveys, control participants (n=90) reported using LPG for 18.5% of cooking minutes (SD 21.3, median 10.6%, range 0–87%) and 25.7% of cooking events (SD 24.7, median 20.0%, range 0–91%).

3.3. Effects of LPG on cooking events and time

At baseline, participants reported cooking on average 195 minutes (3.3 hours) per day (SD 54), with no difference between intervention and control groups (Table 3). In surveys across the 12 months post-randomization, intervention participants reported cooking on average 177 minutes (SD 52, median 173 minutes) per day compared to 203 minutes (SD 51, median 192 minutes) per day by controls, a savings of 26 minutes per day or 3 hours per week.

Based on SUMs data post-randomization, intervention participants cooked an average of 27 fewer minutes per day than controls, or 3.2 fewer hours per week (Table 3). Among intervention households with baseline SUMs data (n=86), average time spent cooking per day after receiving the LPG stove (189 minutes, SD 31) was significantly lower than average daily time spent cooking by the same households at baseline (209 minutes, SD 62; p=0.006). Average daily time spent cooking by controls with baseline SUMs data (n=80) was not significantly different at baseline (214 minutes, SD 66) compared to after randomization (218 minutes, SD 60; p=0.43). Figure 3 displays time spent cooking from baseline throughout the post-intervention year among intervention and control participants, according to both survey and SUMs data.

Although intervention households spent less time cooking per day, the average number of reported daily cooking events by intervention participants (2.3 events, SD 0.3) was significantly higher than controls (2.1 events, SD 0.2; p<0.001). The SUMs data indicated an even greater difference in daily cooking events, with intervention households cooking on average 2.8 meals a day (SD 0.4) compared to 1.8 meals per day (SD 0.8) in control households (Table 3). Behavioral survey data confirms this finding, with 72.2% of intervention participants reporting cooking on average more than 2 meals per day, compared to only 33.3% of control participants.

Among intervention participants, there was no significant difference between average daily cooking minutes estimated from surveys (mean 177, SD 52) and SUMs (mean 189, SD 32; p=0.06). Similarly among control participants, average daily cooking minutes estimated from surveys (mean 203, SD 51) and SUMs (mean 215, SD 59; p=0.07) were not significantly different. Although not statistically significant, cooking time reported in surveys tended to be lower than SUMs estimates. Additionally, a Bland-Altman analysis showed good agreement between yearly averages of daily cooking time as estimated by SUMs and survey data, with Pitman's test of difference in variance indicating an r of −0.083 and p-value of 0.27.

3.1. Sensitivity Analyses for Stove Stacking and Unmonitored Stove Use

Concurrent use of LPG and *fogón* stoves during the same cooking event was rare. Only 6 participants reported using the LPG and *fogón* stoves simultaneously for a total of 7 cooking events over the intervention year, out of a total of 1,957 reported cooking events (0.4%). According to SUMs data, participants used more than one type of stove at the same time for an average of 2.0% of cooking minutes (SD 0.05) in the control group and 1.8% of cooking minutes (SD 0.06) in the intervention group (p=0.81). Qualitative interviews confirmed that when multiple stoves were used in the same day, the *fogón* was most commonly used in the morning and the LPG stove in the afternoon or evening.

> "Before the project, if we used gas, we only used it occasionally because there wasn't enough money… We only used it in the afternoons or when it rained." (Age 41, 96.6% LPG use, 17.7 kg LPG per month, 3 household members)

> "Before [the trial], I cooked with gas at midday and in the evening. In the morning I always used the fogón." (Age 46, 100% LPG use, 20.1 kg LPG per month, 4 household members)

Subtracting stacking minutes from the yearly average calculations based on SUMs data did not change our conclusions, given that there was no significant difference in the average daily number of stacking minutes by intervention (3.1 minutes, SD 9.5) and control (5.0 minutes, SD 14.4) participants (p=0.29). After accounting for stacking minutes, intervention participants spent on average 26 fewer minutes cooking per day than control participants (Table 4). After additionally removing control households with evidence of unmonitored LPG use (n=46), intervention participants spent on average 33.3 fewer minutes cooking per day than controls, amounting to 3.9 hours of time saved per week (Table 4).

3.2. Overall Time Spent Collecting Fuel

Average reported time spent collecting fuel at baseline across all participants was approximately 167 minutes (2.8 hours) per week (SD 152), with no significant difference between intervention and control groups (Table 5). Over the 12 months post-randomization, intervention participants spent significantly less time collecting fuel compared to baseline (158 fewer minutes, p<0.001) while there was no significant change for control participants (p=0.41). On average, intervention participants spent 113 fewer minutes (1.9 fewer hours) collecting fuel per week compared to control participants after randomization.

3.3. Perceptions of time changes

In qualitative interviews, intervention participants confirmed that the LPG stove saved them time. They described that they were better able to control the speed at which they cooked with LPG, using a small flame when they wanted to cook more slowly and a larger one when they wanted to cook more quickly.

Additionally, women said the *fogón* required other preparation tasks over and above cooking, such as removing the ashes, retrieving the dung patties from storage, and breaking up the patties to fit in the *fogón*. They appreciated that they no longer needed to spend time on these tasks when cooking with LPG. Many women also said the LPG stove could be left cooking unattended while they completed other household chores, while the *fogón* required more constant feeding and tending of the fire.

> "[With gas] I take out the pigs, I milk the cow, I return and it's still cooking, the food is already cooked. When you leave the fogón, the dung runs out and it turns off, without having boiled the water." (Age 53, 97.9% LPG use, 19.1 kg LPG per month, 4 household members)

Women reported that their adolescent sons and daughters were more likely to cook for themselves with the LPG stove than with the *fogón*. They also said male household members commonly helped with tasks such as changing tanks and addressing gas leaks or other problems.

> "[My sons] did not cook with the fogón… They say, 'It will make me dirty.' Now with gas they cook. They arrive at noon, they fry themselves an egg, they reheat food." (Age 46, 100% LPG use, 20.1 kg LPG per month, 4 household members)

Most women said they did not cook with the *fogón* at mid-day because it was difficult, time-consuming, and there was social pressure against smoke coming from the chimney at noon. With LPG, in contrast, more women reported cooking at mid-day. This allowed them to enjoy a hot lunch, which they preferred over cold leftovers.

> "[With the fogón], I did not cook at noon. The smoke was very bad… and the fire took a long time to light… People look at you badly when smoke comes from your house at noon. They say, 'She is cooking so late!'… With gas it is easy and there is no smoke." (Age 61, 98.4% LPG use, 19.0 kg LPG per month, 3 household members)

Participants described biomass fuel collection as a solitary activity that was uncomfortable given the cold conditions. Collecting biomass fuel was often viewed negatively because it required a substantial time investment, long travel distances, and dangerous situations. Because of this, intervention participants were happy that they no longer needed to collect biomass fuel.

> "There is not a lot of dung because I only have a few cows… Sometimes I collect sticks and wood and we finish with wounds in our hands… Sometimes I go up the hill alone and I am afraid of those places… To go there takes an hour and time to collect it is another hour." (Age 55, 96.4% LPG use, 22 kg LPG per month, 4 household members)

3.4. Activities performed with time saved

According to the quantitative survey data, many women reported spending their free time on household chores such as washing clothes, cleaning the house, caring for children, and bathing (Table 6). Some also spent time on leisure activities such as visiting family, playing sports, attending community meetings, or walking around the community. Only one participant reported spending her free time relaxing with her spouse or friends. In qualitative interviews, many women said they were able to rest more because the LPG stove cooked quickly.

> "Now I wake up at 5am. Before [with fogón] I had to wake up at 4am, or 3am in the harvest season. With the fogón, it always took a long time." (Age 58, 98.3% LPG use, 19.7 kg LPG per month, 4 household members)

Quantitative surveys indicated that some women earned extra income by selling dung, weavings, and milk, which the LPG stove gave them more time and opportunity to produce. Across the surveys conducted 1, 3, 6, 9, and 12 months after receiving the LPG stove, 32 participants (35.6%) reported spending a portion of their extra time specifically on business or knitting. However, 100% of participants reported using time saved to care for their animals and/or work in their fields (Table 6).

> "[With the gas stove] I can take care of my animals first, and then I cook. First, I give them barley, gather the dung, and afterwards I cook. I couldn't do that before. I had to start cooking as soon as I woke up. And it didn't cook quickly. Now it's not like that." (Age 62, 99.7% LPG use, 19.9 kg LPG per month, 3 household members)

4. Discussion

This study provides quantitative evidence, supported by self-reported survey data, that cooking with LPG can save significant time compared to cooking with biomass fuels. Our results suggest that exclusive use of LPG results in between 3.2 to 3.9 fewer hours cooking and 1.9 fewer hours collecting biomass fuel per week, for a total of up to 5.8 hours saved per week. Participants perceived this time savings as a positive change.

Our estimates of time savings from clean fuel use are slightly higher than a previous study in Sudan, which found LPG users saved 2.3 hours per week compared to traditional stove users (Malla et al., 2011). However, a study in India found much greater time savings, with biogas users saving nearly 13 hours per week compared to traditional stove users (Anderman et al., 2015). The time savings from LPG use that we estimated in our study may be underestimated for several reasons. Control households used LPG for approximately one third of their cooking tasks, suggesting that they may spend more time cooking if they used biomass exclusively. Also, our measures of time did not account for the qualitatively-reported behaviors of cooks.

Consideration of the fact that many participants left the LPG stove cooking unattended while doing other tasks or that other household members performed some of the recorded LPG cooking events could reduce our estimates of time spent cooking by intervention participants, as also found in Kenya (Jagoe et al., 2020). Lastly, women in our study knew that their free LPG deliveries would end after one year, thus they continued collecting small amounts of biomass fuel to have a stockpile for after the study. Biomass fuel collection could be reduced even further with a permanent switch to LPG.

In Puno, women appreciated the reduced need to collect biomass fuel given the cold climate and solitary nature of the task. This contrasts to a previous study in Guatemala, in which women enjoyed collecting biomass fuel (Thompson et al., 2018), and suggests that reductions in time spent collecting fuel may not be viewed as positively in more temperate climates or where fuel collection may be a more social activity.

Qualitative interviews indicated that adoption of LPG improved participants' quality of life. Women appreciated that they could sleep more and that they and their families could consume more hot meals. An improvement in general happiness could also have longer-term health benefits, which were not explored as part of this study.

Although we did not explore changes in household socio-economic status as part of these analyses, our results suggest that households could experience economic benefits from time savings with continued LPG use over time. For example, spending extra time knitting, milking cows, working in the fields, or caring for livestock could provide households with more products to sell or consume, e.g. (Jagoe et al., 2020). Furthermore, since women in the trial were receiving free LPG, they may not have felt as compelled to use their extra time to earn income as they would have if they were buying their own LPG. Future investigations could explore the amount of time spent working between women receiving free or subsidized LPG and those who pay, and whether households see any significant economic benefits from LPG use under those conditions.

Additionally, more research is needed to understand how dynamics around fuel collection and stove use change with different types of fuel. Although women and children are typically responsible for collecting biomass fuel (Shankar et al., 2014), men may take more responsibility for refilling LPG tanks and maintaining or repairing LPG stoves, as our qualitative results indicated. As also found in Ghana, our study indicated that men were more willing to cook with an LPG stove (Abdulai et al., 2018). These shifts in household responsibilities could also save women time.

4.1. Strengths

This study is the first to use temperature-based stove use monitors to objectively measure time savings in addition to self-reported time savings within an LPG intervention. It is also one of the first to achieve near-exclusive LPG adoption by intervention participants, allowing us to estimate time savings under a near-exclusive use scenario. Our use of mixed methods provided an in-depth understanding of not only the amount of time saved, but also the value of those time changes to participants and factors that must be considered when interpreting quantitative estimates of time savings (i.e. who is doing the cooking and time spent in front of the stove). Additionally, triangulation between self-reported and temperature monitoring of cooking time demonstrated that user estimates of time came fairly close to objective measurements by a data logger.

4.2. Limitations

Some cooking events on traditional stoves, especially on colder days, may not have been captured due to poor SUMs positioning. This was more common in control households and often resulted in zero daily cooking events, which were excluded from the analysis. Our SUMs estimates also did not account for potential use of unmonitored biomass or LPG stoves. However, observational and survey data suggest use of unmonitored biomass stoves was uncommon. Additionally, our estimates are based on use of a three-burner LPG stove; time savings from stoves with fewer burners or different burner sizes may be different.

Data was collected among an older adult female rural population where access to biomass fuel was relatively abundant. Time savings impacts of LPG interventions may be different among younger populations with more children in the household who may help with fuel collection and cooking tasks, or where people spend more time collecting scarcer biomass fuel. Lastly, LPG was delivered directly to participant households. Under real-world conditions, women or other household members may need to spend time obtaining LPG refills if delivery is not available or affordable. Pollard et al. found that participants in an LPG subsidization program in Peru spent an average of 67 minutes obtaining an LPG refill (Pollard et al., 2018), suggesting people would spend an average of 34 minutes per week to obtain two 10 kg LPG refills per month. Thus, even with this extra LPG refill time deducted, women could still save more than 5.2 hours per week by cooking with LPG.

5. Conclusion

Findings indicate that exclusive adoption of LPG resulted in between 5.1 and 5.8 h of time savings per week. Participants used this additional time on household chores, leisure activities, and work with the potential for income generation, which could lead to improved quality of life, better health, and improved economic conditions. Our study suggests that use of LPG has important benefits beyond potential improvements to air quality and health that can be integrated into LPG promotion efforts. By quantifying the impact of LPG on time, this study provides evidence for one of the most commonly promoted benefits of LPG. Increased promotion of the ability of LPG to save families time as one of the many benefits of LPG adoption could lead to more widespread LPG adoption and reduce the burden of household air pollution.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Acronyms

CHAP	Cardiopulmonary outcomes and Household Air Pollution trial
FISE	*Fondo de Inclusión Social Energético* (Energy Social Inclusion Fund)
GEE	General estimating equations
HAP	Household air pollution
Kg	Kilogram
LPG	Liquefied petroleum gas
$PM_{2.5}$	Fine particulate matter
SUMs	Stove use monitors

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Highlights

- Exclusive use of liquefied petroleum gas (LPG) saved participants 5.1 hours per week from reduced time spent cooking and collecting fuel.
- LPG allowed participants to cook more hot meals per day with less overall cooking time compared to traditional stoves, improving perceived quality of life.
- Time savings are highly valued by participants in Puno, Peru and are used for household chores, leisure, caring for animals, and working in the fields.
- This study provides quantitative evidence for the commonly mentioned benefit that LPG saves time compared to biomass stoves.

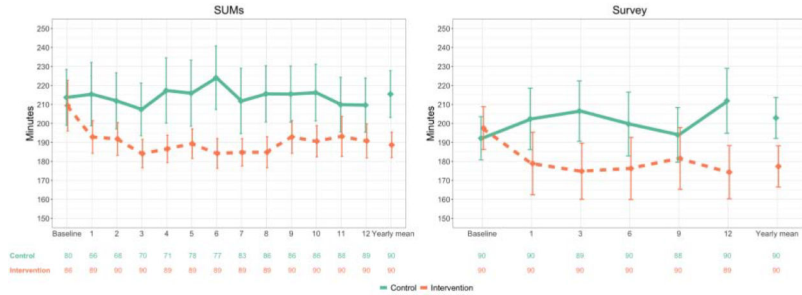

Figure 1.

Stove use monitor (SUM) on a traditional biomass stove (*fogón*).

Figure 2.
Stove use monitor (SUM) on a liquefied petroleum gas (LPG) stove.

Figure 3.

Average minutes spent cooking per day based on SUMs and survey data at baseline, at monthly time points over the intervention year, and averaged across monthly time points in a yearly mean among intervention and control participants.

Table 1.

Questions used to assess time use in the CHAP behavioral survey.

How many different periods of time did you spend cooking for any reason in this house yesterday?	________	
Repeat for each period of cooking:		
Approximately how much time did you cook in total?	_____ h _____ m	
What types of stove(s) did you use? (select all that apply)	☐ Gas stove ☐ *Fogón* ☐ Improved stove ☐ Don't know	
What were the reasons for lighting the stove? (do not read options; select all that apply)	☐ Cook food for the family ☐ Make tea ☐ Cook food for the animals ☐ Cook food or beverages to sell	☐Heat water for bathmg or cleaning ☐ Heat the house ☐ Re-heat leftovers ☐ Other, specify:
If the participant used more than one type of stove: Type of stove: Approximately how much time did you cook with	Type of stove: ________________ _____ h _____ m Type of stove: ________________ _____ h _____ m	
In the last week, how many hours did you spend collecting and preparing dung, wood, or crop residue for fuel?	_____ h _____ m	
When you cook with gas, do you spend more time, less time, or the same amount of time cooking in comparison to the *fogón?*	☐ Less time cooking with gas ☐ The same amount of time cooking with gas and the *fogón* ☐ More time cooking with gas ☐ Don't know	
If you spend less time cooking with gas, what activities do you do with your extra time? (do not read options; select all that apply)	☐ Play or watch sports ☐ Rest or sleep ☐ Care for children ☐ Talk with spouse ☐ Wash clothes ☐ Care for annuals (feed, take to pasture) ☐ Work m the field ☐ Visit family ☐ Go to community meetings	☐ Watch television ☐ Take a walk ☐ Spend time with friends ☐ Bathe or personal care ☐ Knit ☐ Clean the house ☐ Dance ☐ Do business in town ☐ Don't know ☐ Other, specify:

Table 2.

Demographic characteristics of CHAP participants, overall and by study arm.

	Intervention n (%) (n=90)	Control n (%) (n=90)	Total n (%) (n=180)
Language			
Only Aymara	1 (1.1%)	3 (3.3%)	4 (2.2%)
Aymara/Quechua + Spanish	89 (98.9%)	87 (96.7%)	176 (97.8%)
Married or Cohabitating	78 (86.7%)	74 (82.2%)	152 (84.4%)
Participant Occupation: Fanner	78 (86.7%)	77 (85.6%)	155 (86.1%)
Husband Occupation: Fanner *	63 (80.8%)	55 (74.3%)	118(77.6%)
Wealth Quintile			
Poorest	51 (56.7%)	50 (55.6%)	101 (56.1%)
Poor	32 (35.6%)	37(41.1%)	69 (38.3%)
Middle	7 (7.8%)	3 (3.3%)	10 (5.6%)
Monthly Income			
0-99 soles	20 (22.2%)	25 (27.8%)	45 (25%)
100–249 soles	33 (36.7%)	38 (42.2%)	71 (39.4%)
250-499 soles	34 (37.8%)	26 (28.9%)	60 (33.3%)
500 or more soles	3 (3.3%)	1 (1.1%)	4 (2.2%)
Owned LPG at baseline	64 (71.1%)	68 (75.6%)	132(73.3%)
Electricity in household	85 (94.4%)	90(100%)	175 (97.2%)
Previously participated in FISE	42 (46.7%)	46 (51.1%)	88 (48.9%)
Household owns a cell phone	81 (90.0%)	81 (90.0%)	162 (90.0%)
Owns pig(s)	52 (57.8%)	54 (60.0%)	107 (59.4%)
Ow ns dog(s)	66 (73.3%)	57 (63.3%)	123 (68.3%)
Owns cattle	84 (93.3%)	80 (88.9%)	164(91.1%)
Owns sheep	80 (88.9%)	85 (94.4%)	165 (91.7%)
Owns donkeys or horses	19(21.2%)	17 (18.9%)	36 (20.0%)
Owns llamas or alpacas	23 (25.6%)	21 (23.3%)	44 (24.4%)
Age **	48.7 ± 9.1. (25.0–64.4)	47.9 ± 11.1, (25.3–64.8)	48.3 ± 10.1. (25.0–64.8)
Years of Education **	6.1 ± 3.4, (0-11)	6.4 ± 3.3, (0-12)	6.2 ± 3.3, (0-12)
Number of Household Members **	3.8 ± 1.7, (1–9)	3.6 ± 1.5, (1–7)	3.7 ± 1.6. (1–9)

* Denominator is the number of married or cohabitating participants

** Age, education, and number of household members are reported as mean ± SD, (range)

Table 3.

Daily average number of cooking events and time spent cooking (in minutes) by study arm assignment, based on yearly averages of survey and SUMs data.

	Intervention		Control			
	n	Mean ± SD	n	Mean ± SD	Difference	Two-tailed t-test p-value
Baseline						
Cooking Time-Survey	90	198 ±54	90	192 ±54	−5 (−21, 11)	0.51
Cooking Time- SUMs	86	209 ± 62	80	214 ±66	4 (−15, 24)	0.67
Yearly Average of 1, 3, 6. 9, and 12 Month Survey Data*						
Cooking Time	90	177 ±52	90	203 ±51	26 (10, 41)	0.001
Cooking Events	90	2.3 ±0.3	90	2.1 ±0.2	−0.3 (−0.3, – 0.2)	<0.0001
Meal 1	90	107 ±32	90	133 ±33	26 (17,35)	<0.0001
Meal 2 (of 2)	89	52 ±23	89	64 ±24	11 (4. 18)	0.001
Meal 2 (of 3)	69	54 ±34	34	70 ±37	16 (1-30)	0.04
Meal 3 (of 3)	69	54 ±30	34	62 ±35	8 (−6, 21)	0.26
Yearly Average of 12 Months of SUMs Data						
Cooking Time	90	188.7 ±32	90	215.4 ±59	27 (13,41)	<0.001
Cooking Events	90	2.8 ±0.4	90	1.8 ±0.8	−1 (−1.2,−0.8)	<0.0001

* Four instances in which participants cooked more than 3 meals per day are not included given the small sample size

Table 4.

Sensitivity analyses of daily average cooking minutes based on SUMs data by study group, according to all data, data excluding stacking minutes in which *fogón* and LPG stoves were used simultaneously, and data excluding both stacking minutes and control participants with evidence of unmonitored LPG use.

	All data		Excluding stacking minutes		Excluding stacking minutes and controls with unmonitored LPG use	
	n	**Mean ± SD**	**n**	**Mean ± SD**	**n**	**Mean ± SD**
Control	90	215.4 ± 59	90	211.4 ± 52	44	218.7 ±56
Intervention	90	188.7 ± 32	90	185.5 ±31	90	185.5 ±31
Difference		26.7		26.0		33.3
(95% CI)		(13,41)		(13,39)		(18. 48)
Two-tailed t-test p-value		<0.001		<0.001		<0.001

Table 5.

Weekly time spent collecting and preparing fuel in minutes, intervention vs. control participants at baseline, 1, 3, 6, 9, and 12 months after randomization, and averaged over the post-intervention data points.

	Intervention (n=90)		Control (n=90)			
	n	Mean ± SD	n	Mean ± SD	Difference (95% CI)	Two-tailed t-test p-value
Baseline	90	182±157	90	151±146	−31 (−76, 14)	0.17
Month 1	90	25 ± 64	90	194 ±247	169 (116, 222)	<0.0001
Month 3	90	39 ±71	90	147 ± 144	108 (75, 142)	<0.0001
Month 6	90	23 ±62	90	119 ± 142	95 (63, 128)	<0.0001
Month 9	90	18 ±40	89	107±156	89 (55, 122)	<0.0001
Month 12	89	14 ±32	90	115 ±144	101 (71, 132)	<0.0001
Average of Month 1, 3, 6, 9, and 12 Data	90	24 ± 34	90	136 ±86	113 (93, 132)	<0.0001

Table 6.

Perceptions and use of time by intervention participants across surveys conducted at 1-, 3-, 6-, 9-, and 12-months after receiving the LPG stove.

	Reported in any monthly survey (n=90), N (%)
Report LPG cooks faster than *fogón*	**90 (100%)**
Activities with time saved:	
Care for animals	90 (100%)
Wash clothes	75 (83.3%)
Work in the field	75 (83.3%)
Clean/household chores	62 (68.9%)
Knit/other crafts	30 (33.3%)
Care for children	18(20.0%)
Bathe	4 (4.4%)
Sleep	1 (1.1%)
Visit family	3 (3.3%)
Attend community meetings	1 (1.1%)
Take a walk	4 (4.4%)
Do business in town	2 (2.2%)
Spend time with spouse or friends	1 (1.1%)
Play sports	1 (1.1%)
Cleaned LPG stove in the last week	90 (100%)
Fixed a problem with LPG stove in the last week	1 (1.1%)