earth

MDPI

Article

Characterizing Sustained Use of Cleaner Cooking Fuel in Rural Poor Households of South India

Praveen Kumar [1,*], Maritha Du [2] and Mingyue Ma [3]

[1] Boston College School of Social Work, Chestnut Hill, MA 02467, USA
[2] Boston Children's Hospital, Boston, MA 02115, USA; maritha.du@childrens.harvard.edu
[3] Boston College—Morrissey College of Arts & Sciences, Chestnut Hill, MA 02467, USA; mams@bc.edu
* Correspondence: praveen.kumar@bc.edu

Abstract: Approximately 40% of the global population (primarily rural poor) rely on traditional cookstoves, with pernicious social, economic, and health outcomes. The Government of India launched its massive Prime Ministers' Ujjwala scheme in 2016 to promote liquefied petroleum gas (LPG), a cleaner cooking system, in poor communities. While there has been a surge in adoption, consistent use of LPG has been tepid. We examined the trend of use of LPG for 18 months in 58 poor households of South India. In place of soliciting survey questions on stove usage, we deployed stove use monitoring technologies to accurately measure the use of LPG and traditional stoves. We also analyzed factors characterizing LPG use. None of the households used LPG for more than 55% of their cooking time. LPG refill transportation, perception of faster cooking, and caste were significant predictors of LPG use. The findings highlight that social workers must engage with these communities to improve their awareness and shape their perceptions of cleaner cooking.

Keywords: sustained use; LPG use; clean cooking; SUMS; community-based awareness

Citation: Kumar, P.; Du, M.; Ma, M. Characterizing Sustained Use of Cleaner Cooking Fuel in Rural Poor Households of South India. *Earth* **2022**, *3*, 313–323. https://doi.org/10.3390/earth3010019

Academic Editor: Samuel Asumadu-Sarkodie

Received: 21 January 2022
Accepted: 16 February 2022
Published: 19 February 2022

1. Introduction

Approximately three billion people (mostly poor), or 40% of the global population, primarily rely on traditional cooking stoves and fuels, a significant source of household air pollution [1,2]. While the estimates vary, there is a fair agreement that HAP accounts for approximately three million premature deaths annually [2–4]. Incomplete biomass combustion in traditional stoves emits high concentrations of gaseous and particulate pollutants, while poor ventilation exacerbates human exposure to these pollutants. Exposure to HAP has been significantly associated with pneumonia in children, low birth weight, cardiovascular disease, chronic lung disease, and lung cancer among adults [2,5,6]. Dirty fuels release harmful concentrations of $PM_{2.5}$ particles linked to cataracts and respiratory diseases like tuberculosis. They also pose risks for structural fires, and kerosene lamps adulterated with other fuels have the potential to explode, resulting in particularly lethal fires. Women and girls share the most significant implications from HAP. Women are more immediately and disproportionately affected by the implications of energy poverty and have less agency socially, politically, and economically to counter its impacts.

For most families in underdeveloped countries, the responsibility of fuel collection such as biomass (firewood, crop residues, twigs, or dung) and cooking usually falls on women. This leads to high exposure to HAP and an increased risk of gender-based violence when they have to walk long distances to unsafe and isolated areas to gather fuel [4]. In addition, young girls typically accompany their mothers in these activities, preventing them from pursuing education or income generation. The social situation of women and girls chronically exposes them to these household air pollutants. The disproportionate impact of HAP on women is evident, and the causal relationship between energy poverty, gender, educational, and health inequalities becomes increasingly apparent. These factors deepen the cycle of poverty as the time could instead be used to engage in economically

productive or skill-building activities. India bears a significant burden of disease from HAP. Estimates show that in India, HAP could be attributed to approximately 0.61 million premature deaths in 2019 alone [7]. Furthermore, new research has estimated that about 30% of outdoor air pollution is also due to the burning of household fuels [8].

1.1. Research Gap

Several countries, including India, have prioritized the issue of HAP. In 2016, the Indian Government introduced the Prime Minister's Ujjwala scheme to encourage the adoption of liquefied petroleum gas (LPG) as a cleaner cooking system in poor households [9–11]. There has been a surge in the adoption of LPG among rural poor households [7,10]. However, LPG stoves have not been consistently and sufficiently used in rural poor communities to displace traditional cookstoves as the primary means of cooking altogether. Stacking LPG with traditional cookstoves is routine in rural poor households of India, despite significant investment from the Ujjwala scheme [12]. Thus, it is critical to accurately determine the extent of LPG use when co-located with traditional stoves in households. The use of sophisticated stove use monitoring technologies in place of household surveys to examine stove stacking increases the accuracy of stove use estimation. Moreover, it is crucial to investigate the challenges that prevent the complete transition from traditional stove use to LPG use. A lot of research has focused on the initial adoption and uptake [12–14]. Merely adoption is insufficient to achieve social, economic, and health benefits by transitioning to cleaner cooking. We need to understand and characterize the factors that promote or hinder the sustained use of LPG in these households.

1.2. Study Objectives

This study is a part of a parent NIH-funded project that explores the determinants of adoption and sustained use of LPG in rural poor communities in India [15]. In this study, we primarily focus on two specific research objectives. They are: (1) to explore stacking by examining the trend of LPG and traditional stove use in sample households; and (2) to explore the correlates of the proportion of LPG use with affordability, accessibility, and awareness (3As) related factors.

2. Methods

For this study, we recruited a random sample of 62 households. These households were a part of our larger parent project. The inclusion criteria for the selection were: (1) received LPG stove (either through the state level Deepam scheme or national level PM Ujjwala program) within a year; (2) household not planning to move in at least two years; (3) woman respondent (>18 years of age) was able to provide consent for the study; and (4) woman respondent was the primary cook of the household. Consents were obtained from the 65 households to continue using the stoves routinely, and data collection lasted for 18 months. This was an exploratory study to form a preliminary understanding of the level of stacking in these communities of rural India. Thus, it did not justify a formal sample size estimation. A random selection of 65 households from our larger parent project was mainly dictated by our resources to undertake this study for 18 months.

To collect data for research objective 1 on stacking, we deployed ibuttons or stove use monitoring systems (SUMS) iSUMS model DS1922L [16] on both LPG stoves and traditional stoves in the sample households. SUMS are thermocouple devices that are installed on the stoves near the burners. They log the temperature data (every 8 min) of the stoves. Using a field-tested application [one wire software], the temperature data is used to calculate the stove usage data for analyses. We followed the SUMS installation and stove use data collection protocols developed by Ruiz-Mercado, Canuz, Walker, and Smith (2013) [17]. The stove usage data provides the duration of use of the traditional and LPG cookstoves. A trained field person recorded and downloaded the SUMS data every two weeks from each household for 18 months. Data were downloaded using a probe connected to a laptop computer via a USB port. The files were then uploaded to our database system. To collect

data for research objective 2 on correlates of the proportion of LPG use, we conducted baseline, midline (after 9 months), and endline (after 18 months) household surveys. The follow-up surveys were conducted at the end of 9 and 18 months of monitoring. These field-tested surveys [13,15] included questions on the 3As.

2.1. Operationalization of Variables

2.1.1. Outcome Variable

Using the SUMS data, we received the actual duration of stove use per day of LPG and traditional stoves for 18 months. Our outcome variable was the proportion of LPG use at the baseline, midline (9 months), and endline (18 months).

2.1.2. Predictors

We collected data for the following key variables. These variables were selected after an exhaustive review of current literature on clean cooking use [9,12,14,18–23]. These predictors pertain to affordability, accessibility, and awareness (3As), widely regarded as three key constructs that determine stove uptake and use in rural India.

1. Refill cost: Recent literature indicates that LPG refill cost impacts the extent of LPG use in rural poor households of India. Households that could afford higher refills might be more likely to use LPG, other factors remaining constant. We collected data on average refill cost from each sample household at the baseline, midline, and endline.
2. Fuel contributing to less choking: We explored the perception of women (primary respondent) on LPG relative to traditional biomass use in terms of which fuel, they felt, contributes to less choking during cooking.
3. Fuel releasing less smoke: We explored the perception of women (primary respondent) on LPG relative to traditional biomass use in terms of which fuel, they felt, releases less smoke during cooking.
4. Fuel helping in faster cooking: We explored the perception of women (primary respondent) on LPG relative to traditional biomass use in terms of which fuel, they felt, helped in faster cooking of food.
5. LPG refill tank transportation: A filled LPG tank weighs approximately 29.5 KGs (65 pounds). Transportation of such heavy LPG tanks could be an essential accessibility factor determining consistent use. We explored the LPG tank delivery logistics to sample households with three options: (1) delivered to households by the LPG distribution agency; (2) self-delivery arranged by households in owned vehicle; and (3) self-delivery arranged by households in a hired vehicle.

2.1.3. Control Variables

We adjusted for monthly income, regularity of income, and the caste of the respondent in our model.

2.2. Data Analyses

We started data collection in 62 households. However, four households dropped out during 18 months of monitoring. To realize objective 1 on stacking, we conducted a trend analysis on 58 households, which completed the study. We collected SUMS data on stove use for each day of the 18 months monitoring period. We aggregated the data to develop monthly LPG use and traditional stove use for each of the households. Subsequently, we developed average values of LPG versus traditional stove use and percent of LPG versus traditional stove use of all the sample households for each month of the monitoring period. To realize objective 2 on correlates of LPG use, we developed a random-effects linear regression model for our panel data with three waves: baseline, midline, and endline. Our outcome variable was the proportion of LPG use. We adjusted for monthly income, regularity of income, and caste of the respondent. Before running the model for three-wave panel data, intraclass correlations (ICC) were calculated for the unconditional model to examine the proportion of variance accounted for at the individual level. The ICC for

the unconditional model was 0.26, indicating that 26% of the variance in outcome was accounted for by the grouping structure of the data and was explained at the primary unit of our analysis (households). Hence, we clustered our random effect model at the household level. Stata version 15 was used for bivariate and regression analyses. We used a 95% confidence interval for statistical significance.

3. Results

Figures 1–3 summarize the results of trend analyses on stacking (research objective 1) over the 18 months of monitoring. Figure 1 shows that the average use of LPG was approximately 615.5 h (45.2%) in 18 months for all households in the study. During that same period, the average use of the traditional cookstove was 747.8 h (54.8%).

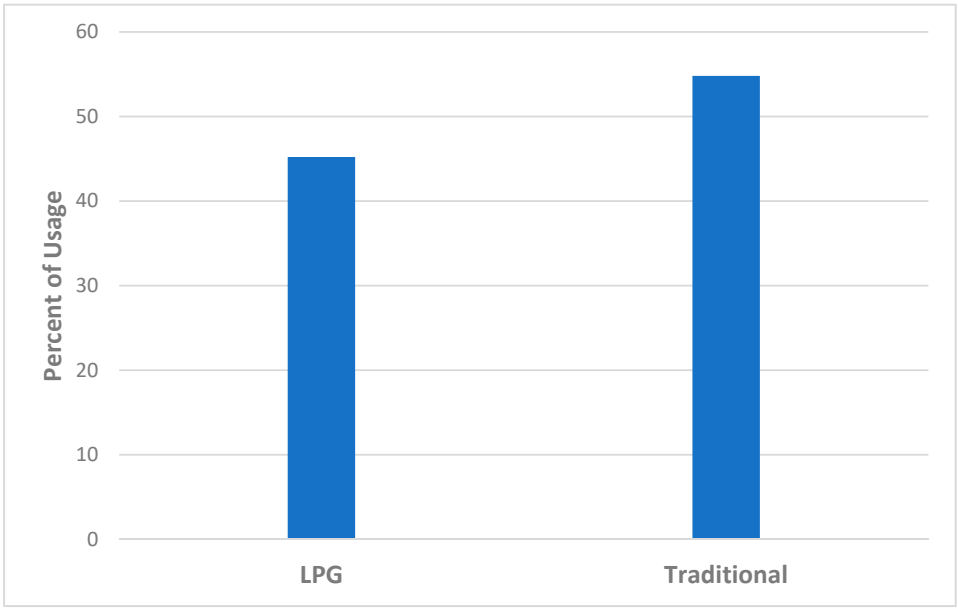

Figure 1. Percent average LPG and traditional stove use for all study households over 18 months of monitoring.

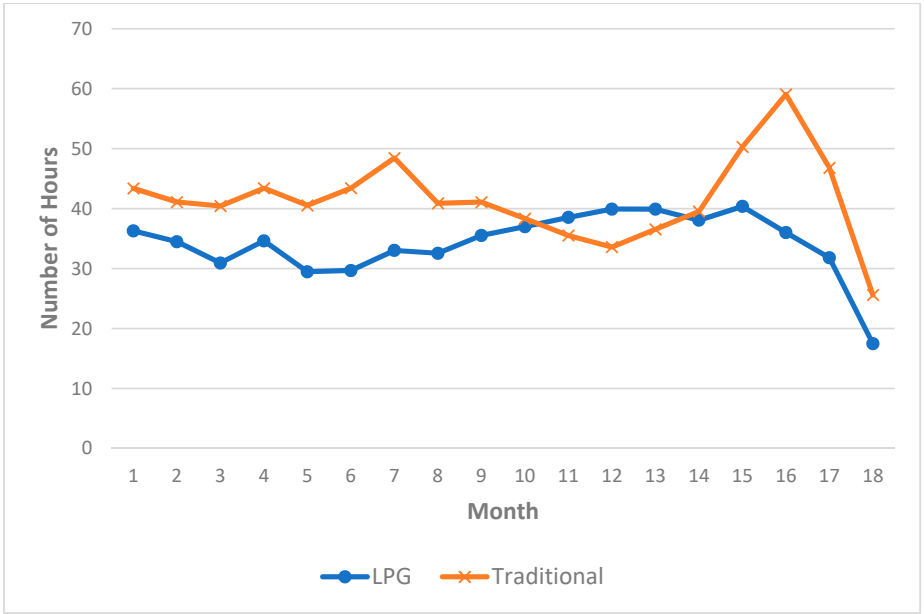

Figure 2. Average number of hours of LPG and Traditional Stove use per month for all study households over 18 months of monitoring.

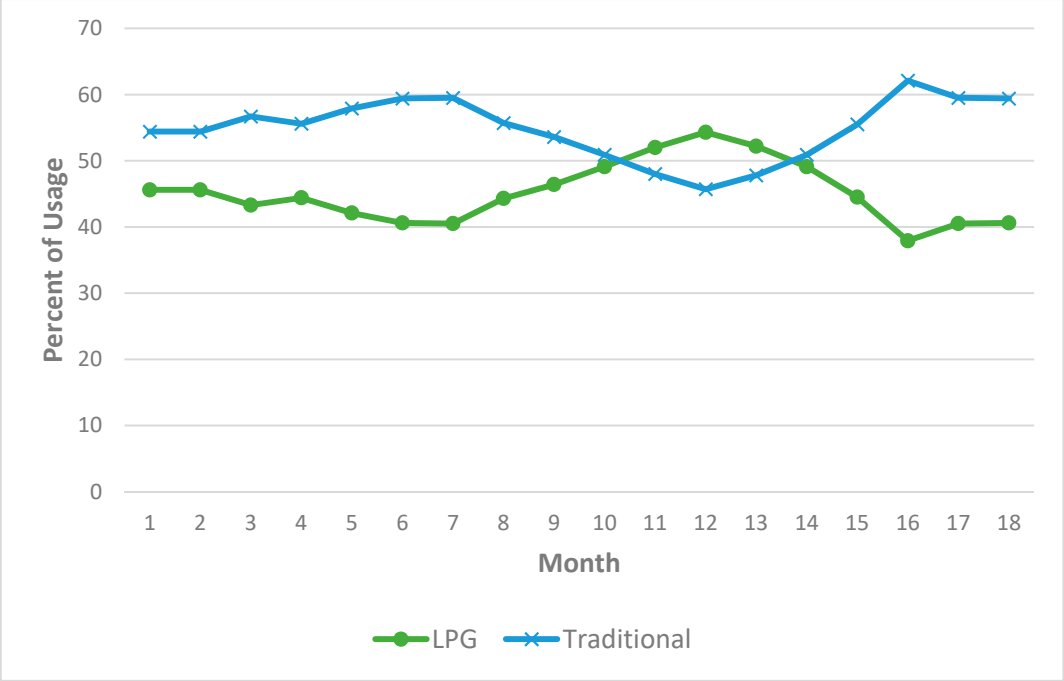

Figure 3. Percent of average LPG and traditional stove use per month for all study households over 18 months of monitoring.

Figure 2 (no. of hours) and Figure 3 (in percentage) show that the LPG use never surpasses traditional stove use except for three months. None of the months of the monitoring period saw the LPG use for more than even 55%.

Tables 1 and 2 summarize results on exploring correlates of the proportion of LPG use (research objective 2). As depicted in Table 1, the proportion of LPG use varied little in the 18-months monitoring period of the study. Compared to the baseline average (Mean = 0.46, SD = 0.28), the midline LPG use almost remained the same (mean = 0.46, SD = 0.28). There was a further reduction in LPG use at the endline by nearly five percentage points (mean = 0.41, SD = 0.33). In terms of income, most households' income fluctuated with each season—96.72% at baseline, 81.67% at midline, and 100% at endline. Interestingly, the refill cost increased throughout the 18 months—from 612.76 Indian National Rupee (INR) to 798.04 INR in the 18 months. In addition, during the 18 months, most households stated that the fuel that resulted in less choking, less emissions, and faster cooking was LPG. The primary refill method of these LPG cylinders was LPG agency home delivery—over 85% at all-time points. This means of transportation increased over the 18 months—from 85.48% of households at baseline to 96.36% of households at endline. Finally, most respondents belonged to the other backward caste (OBC)(67.74%), followed by the general caste (25.81%). Scheduled caste (SC) and scheduled tribe (ST) constituted 4.84% of the sample. As depicted in Table 2, refill cost, which fuel results in faster cooking, refill transportation, and the caste of the respondent were significant predictors. Regular income, which fuel results in less choking, and which fuel emits less smoke, were marginally significant. Even if refill cost was significant ($p < 0.05$), its effect was not substantial (coefficient = 0.0). On the other hand, the perception that biomass fuel use, compared to LPG, resulted in faster cooking decreased the proportion of LPG use by 0.12 points ($p < 0.01$, 95% CI = [−0.21, −0.04]) while controlling for all other variables. Households transporting the LPG by themselves in a hired vehicle, compared to LPG agency delivery, contributed an increase by 0.22 points in the proportion of LPG use ($p < 0.05$, 95% CI = [0.01, 0.43]) while controlling for all other variables. The impact of monthly income was not substantial. However, having an irregular income compared to having a regular income leads to a decrease of 0.17 points in the proportion of LPG use ($p < 0.10$, 95% CI = [−0.37, 0.04]) when controlling for all

other variables. Additionally, thinking that biomass fuel, compared to LPG, results in less choking decreased LPG use by 0.10 points the percentage of LPG use ($p < 0.10$, 95% CI = [−0.23, 0.03]) while controlling for all other variables. Thinking that biomass fuel, compared to LPG, results in less smoke decreased LPG use by 0.21 points ($p < 0.10$, 95% CI = [−0.21, −0.04]) while controlling for all other variables. Finally, belonging to the OBC caste or SC/ST caste, compared to the general caste, resulted in a decrease of 0.19 points ($p < 0.05$, 95% CI = [−0.21, −0.04] or a reduction of 0.17 percentage points ($p < 0.05$, 95% CI = [−0.32, −0.02]) in the proportion of LPG use, respectively.

Table 1. Descriptive statistics.

Variable	Baseline		Midline (9 Months)		Endline (18 Months)	
	Mean (SD)	**% (n)**	**Mean (SD)**	**% (n)**	**Mean (SD)**	**% (n)**
Proportion of LPG use	0.46 (0.28)		0.46 (0.28)		0.41 (0.33)	
Refill cost (INR)	612.76 (89.38)		749.5 (85.62)		798.04 (58.82)	
Fuel results in less choking						
LPG		100.00 (62)		70.00 (42)		98.28 (57)
Biomass		0.00 (0)		30.00 (18)		1.72 (1)
Fuel emits less smoke						
LPG				96.67 (58)		100.00 (57)
Biomass				3.33 (2)		0.00 (0)
Fuel results in faster cooking						
LPG		98.39 (61)		95 (57)		96.55 (56)
Biomass		1.61 (1)		5.00 (3)		3.45 (2)
Way LPG refill tank transportation						
LPG agency home delivery		85.48 (53)		96.67 (58)		96.36 (53)
Self-delivery in owned vehicle		1.61 (1)		0.00 (0)		1.82 (1)
Households arrange self-delivery		12.90 (8)		3.33 (20		1.82 (1)
Monthly income (INR)	1162.30 (1018.89)					
Regularity of income during the past nine months						
Regular across all season		3.28 (2)		18.33 (11)		0.00 (0)
Fluctuated with each season		96.72 (59)		81.67 (49)		100.00 (53)
Caste of the respondent						
General		25.81 (16)				
OBC		67.74 (42)				
SC/ST		4.84 (3)				
Other religious minorities		1.61 (1)				

Table 2. Linear random effect model predicting proportion of LPG use.

Variables	Coefficient (SE)	95% CI
Affordability		
Refill cost (INR)	0.00 * (0.00)	[0.00, 0.00]
Awareness		
Less choking *(LPG is reference category)*	−0.10 ^{t} (0.06)	[−0.23, 0.03]
Less emissions *(LPG is reference category)*	−0.21 ^{t} (0.11)	[−0.43, 0.02]
Faster cooking *(LPG is reference category)*	−0.12 ** (0.04)	[−0.21, −0.04]
Accessibility		
Refill transportation *(LPG agency home delivery and self-delivery in owned car combined are reference category)*	0.22 * (0.11)	[0.01, 0.43]
Control variables		
Regularity of income *(regular is reference category)*	−0.17 ^{t} (0.10)	[−0.37, 0.04]
Monthly income (INR)	0.00 (0.00)	[−0.00, 0.00]
Caste *(general is reference category)*		
OBC	−0.19 * (0.08)	[−0.35, −0.03]
SC/ ST	−0.17 * (0.08)	[−0.32, −0.02]
Other religious minorities	−0.12 (0.08)	[−0.28, 0.04]
Intercept	0.32 (0.24)	[−0.14, 0.78]
ICC	0.26	
N time-person	91	
N respondents	58	

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; ^{t} $p < 0.10$.

4. Discussion

4.1. Research Objective 1: Stacking

Based on Figures 1–3, it is clear that traditional cookstove use is relatively higher than LPG use. The proportion of traditional cookstove use each month was consistently higher than that of LPG use except for the three months of monsoon season. Collection and use of biomass during the monsoon season were relatively difficult. After the conclusion of the monsoon, the proportion of use of biomass in traditional stoves again surpassed the LPG use. The findings show a high degree of fuel stacking. LPG was consistently a secondary stove for the households throughout the monitoring period. This phenomenon was observed in other regions of India and countries that similarly promote LPG or other cleaner stove use [20]. Stacking traditional stoves and LPG poses significant challenges to fully achieving the desired health benefits of clean cooking. Although LPG use reduces HAP, just more than one hour of use of solid fuel (such as biomass) in traditional stoves lead to HAP levels vastly exceeding the World Health Organization's (WHO) indoor air quality guidelines of annual concentration interim of particulate matter (35 $\mu g/m^3$) [24]. HAP exposure-response curve is non-linear, which means that there has to be a substantial reduction in traditional stove use and near-exclusive use of cleaner stoves like LPG to realize health benefits from clean cooking. LPG as a strategy to reduce HAP must be elevated to ensure that households use it almost exclusively to eliminate risk. It must be noted that we do not deny the likelihood of the Hawthorne Effect, that is, study participants altering their behavior when they have the knowledge of being observed. However, we think that we minimized the Hawthorne effect by two measures: (1) encouraging the study participants to use the stoves routinely by adequate and candid elaboration and discussion on any concerns the study participants might have before participating in the study; (2) a relatively long monitoring period of 18 months is a natural deterrent for the data to be influenced by any Hawthorne effect.

4.2. Research Objective 2: Correlates of Proportion of LPG Use

Understanding the factors that influence a household's fuel choice is crucial for enhancing the sustained use of LPG for HAP mitigation. This study presented evidence on the practice of stacking among LPG adopter households in rural India and provides further understanding on how affordability, accessibility, and awareness (3As) related factors affect LPG use. As previously shown in Table 2, faster cooking, refill transportation, the caste of the respondent, and refill cost were all significantly associated with the proportion of LPG use over a traditional stove.

The majority of households stated that the fuel used in the LPG stove resulted in faster cooking. Yet, the proportion of use of the LPG decreased if households perceived that traditional stoves resulted in faster cooking. Anecdotal evidence highlights that reducing cooking time is an essential motivator for switching to clean cooking, more than other awareness-based factors like the stove emitting less smoke or the stove resulting in less choking [25,26]. Reduced cooking time could translate into time savings that can be used for other purposes, including leisure. Women, who are generally the primary cooks, can often have busy schedules. Therefore, cooking time is a critical determinant of the extent of stove use.

The proportion of LPG use increased when the households themselves arranged for the transportation of LPG to their respective homes instead of relying on the LPG agencies for the delivery. Our findings bolster the recent research in clean cooking literature on logistics and accessibility. People in rural communities often need to travel long distances to the closest LPG distribution center. Therefore, transportation costs and time in transit are often cited as factors that prevent high LPG use [12,25]. The time cost of refilling may be high for rural households. If a household lives far from the closest distribution center, they may have to spend considerable time in transit while paying for the refill and transportation costs. Therefore, unlike biomass, LPG tanks require a supply network outside of the control of households as the most common refill method is LPG agency home delivery. It requires a household to place their empty LPG tanks before the scheduled delivery date with a nearby agency owner who charges a specific amount for the handling and transportation. Because there are irregularities that remain in the delivery of refills, households may prefer the self-delivery method of refilling in a hired vehicle to save time. The households, which are more inclined to use LPG tend to rely less on LPG agencies for delivery.

The OBC caste or SC/ST caste groups have negative associations with LPG use compared to the general caste. OBC and SC/ST caste communities have been socio-historically less privileged. The Government claims that there has been an equitable effort to promote clean stove use across all socio-economic groups. However, the findings show that households' social status still dictates sustained use of technologies in poor communities. Recent literature has shown that LPG refill cost is a critical obstacle to sustained use of LPG [11,12,27]. Findings from this study suggest that refill cost, though a significant indicator, did not have a substantial effect on determining LPG use.

The correlates [faster cooking and refill transportation] demonstrate that attitudes and perception toward LPG stoves matter in influencing the level of use of such evidence-based health interventions. This is analogous to recent findings from clean cooking literature [27,28], where the authors argue the significance of mental models of consumers shaped by their degree of awareness on clean cooking. Sustained use of LPG is a function of affordability, accessibility, and awareness-related factors. However, there is a no-one-size-fits-all solution. There is a strong likelihood that specific rural communities (such as the communities studied here) are less impacted by refill cost and their monthly income but dwell more on their perceptions, attitudes, and social strata to decide on the extent of LPG use. These social and behavioral dynamics often lead households to switch back and forth between the use of different stoves over time rather than moving linearly up an "energy ladder" [28].

4.3. Implications for Future Research, Strategies, and Policy

The study has two significant implications for future research, strategies, and policy. They are:

1. Using technologies like SUMS provides accurate evidence on stove usage in the wake of significant investment in clean cooking policies. Improvement in user-behavior knowledge by deploying SUMS provides granularity in uncovering the efficacy of clean cooking social policies and programs. Social workers and policy makers should continue engaging with technologists to deepen their efforts to design and develop human-centered technology applications to improve understanding of the behavior of energy-poor communities in resource-constrained areas.
2. The study uncovers that attitudes and perceptions of poor communities toward LPG, and by extension toward cleaner cooking systems, matter. The findings highlight the need for further research to engage in targeted community-based awareness and educational campaigns regarding the benefits of clean cooking. Cooking is both a highly culturized and a personal activity influenced by internal and external factors. Adequate understanding and routine application of the person-in-environment perspective makes the social and policy researchers uniquely positioned in challenges on clean cooking. They can better understand the individual, relational, and environmental (both natural and built) factors that could expedite or impede the extent of clean cooking use in poor communities.
3. The study, though exploratory, provides a robust idea on the current usage levels of LPG and traditional stoves, and the significance of supporting infrastructure. The findings could be leveraged to inform policy makers to develop logistical support an infrastructure to ensure timely delivery of LPG tanks to these households.
4. The study uncovers the importance of attitudes and perceptions on clean cooking in poor communities. This calls for the policy makers to further empathize on targeted awareness campaigns to promote the utility and benefits of clean cooking in these communities.

5. Limitations of the Manuscript

There are a few limitations to our study, which are discussed below:

1. Regression analyses for this study were conducted on a small sample size (n = 58). Low statistical power prevented multilevel analyses by controlling for institutional level characteristics.

2. The study was carried out in the Thambalpalle and Peddamandyam mandals (blocks) in the Chittoor district of Andhra Pradesh state in India. Even though existing literature suggests that the 3As on the sustained use of LPG are shared in similar contexts, the findings are still specific to this region and thus have limited generalizability implications.

3. The deployment of sophisticated stove use monitoring sensors (SUMS) allows accurate and precise measurements on the duration of stove use, yet the data is prone to the Hawthorne effect. Participants might have behaved differently than usual because they knew they were being observed.

4. Structure and composition of respondents' personal networks could be associated with the proportion of LPG use. An in-depth analysis of the personal social networks of the respondents was beyond the scope of the current study and should be a key topic in clean cooking for future research.

6. Conclusions

This study highlighted the association of affordability, accessibility, and awareness-related factors with the sustained use of LPG. Stacking was prevalent among households despite their initial adoption. Refill transportation methods, perception of faster cooking, and the caste of the respondent were significant predictors. Perception of which fuel results in less choking and less emissions were marginally significant predictors. Thus, accessibility and awareness factors could still influence the household choice in specific communities,

even after considerable attention by the Government to make LPG affordable to poor communities. This merits development of community-based intervention and underscores the need to focus on awareness. Educational and outreach campaigns that directly address these concerns have the potential that leads to a significant positive effect on promoting LPG use. More research is needed to test the impact of different intervention strategies to achieve a sustained and exclusive use of LPG in rural poor households of India.

Author Contributions: Conceptualization, P.K.; methodology, P.K.; software, P.K., M.D.; validation, P.K., M.D., M.M.; formal analysis, P.K., M.D., M.M.; investigation, P.K.; resources, P.K.; data curation, P.K., M.D., M.M.; writing—original draft preparation, P.K., M.D., M.M.; writing—review and editing, P.K., M.D., M.M.; visualization, M.D., M.M.; supervision, P.K.; project administration, P.K.; funding acquisition, P.K. All authors have read and agreed to the published version of the manuscript.

Funding: This study is funded under the Clean Cooking Implementation Science Network led by the Fogarty International Center of the National Institutes of Health (NIH) Common Fund. The content is solely the responsibility of the authors and does not necessarily represent the official view of the funders or the affiliate organizations of the authors.

Institutional Review Board Statement: The study was approved by the Boston College Institutional Review Board (IRB #18.271.01).

Informed Consent Statement: All participants provided verbal consent to participate in the study and to respond to the study instruments.

Data Availability Statement: The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Acknowledgments: We are most grateful to the community participants of this study and the Foundation for Ecological Security for enabling access to these communities. In particular, we thank Kaushal, Hemalatha, Noorjan, Shaheensha, Geetha, and Rahul.

Conflicts of Interest: The authors declare that they have no conflict of interest.

References

1. Bonjour, S.; Adair-Rohani, H.; Wolf, J.; Bruce, N.G.; Mehta, S.; Prüss-Ustün, A.; Lahiff, M.; Rehfuess, E.A.; Mishra, V.; Smith, K.R. Solid fuel use for household cooking: Country and regional estimates for 1980–2010. *Environ. Health Perspect.* **2013**, *121*, 784–790. [CrossRef] [PubMed]
2. Balmes, J.R. Household air pollution from domestic combustion of solid fuels and health. *J. Allergy Clin. Immunol.* **2019**, *143*, 1979–1987. [CrossRef] [PubMed]
3. Landrigan, P.J. Air pollution and health. *Lancet Public Health* **2017**, *2*, e4–e5. [CrossRef]
4. Simkovich, S.; Goodman, D.; Roa, C.; Crocker, M.E.; Gianella, G.E.; Kirenga, B.J.; Wise, R.; Checkley, W. The health and social implications of household air pollution and respiratory diseases. *NPJ Prim. Care Respir. Med.* **2019**, *29*, 1–17. [CrossRef]
5. Dionisio, K.L.; Howie, S.R.C.; Dominici, F.; Fornace, K.; Spengler, J.D.; Donkor, S.; Chimah, O.; Oluwalana, C.; Ideh, R.C.; Ebruke, B.; et al. The exposure of infants and children to carbon monoxide from biomass fuels in The Gambia: A measurement and modeling study. *J. Expo. Sci. Environ. Epidemiol.* **2012**, *22*, 173–181. [CrossRef]
6. Balakrishnan, K.; Dey, S.; Gupta, T.; Dhaliwal, R.S.; Brauer, M.; Cohen, A.J.; Stanaway, J.; Beig, G.; Joshi, T.K.; Aggarwal, A.N.; et al. The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: The Global Burden of Disease Study 2017. *Lancet Planet. Health* **2019**, *3*, e26–e39. [CrossRef]
7. Pandey, A.; Brauer, M.; Cropper, M.L.; Balakrishnan, K.; Mathur, P.; Dey, S.; Turkgulu, B.; Kumar, G.A.; Khare, M.; Beig, G.; et al. Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. *Lancet Planet. Health* **2021**, *5*, e25–e38. [CrossRef]
8. Ruiz-Mercado, I.; Masera, O. Patterns of stove use in the context of fuel–device stacking: Rationale and implications. *EcoHealth* **2015**, *12*, 42–56. [CrossRef]
9. Aggarwal, S.; Kumar, S.; Tiwari, M.K. Decision support system for Pradhan Mantri Ujjwala Yojana. *Energy Policy* **2018**, *118*, 455–461. [CrossRef]
10. Mhamia, A. Pradhan Mantri Ujjwala Yojana—A Giant Step Towards Better Life for All. 2016. Available online: http://pib.nic.in/newsite/printrelease.aspx?relid=148971 (accessed on 14 December 2021).
11. Sharma, A.; Parikh, J.; Singh, C. Transition to LPG for cooking: A case study from two states of India. *Energy Sustain. Dev.* **2019**, *51*, 63–72. [CrossRef]

12. Gould, C.; Urpelainen, J. LPG as a clean cooking fuel: Adoption, use, and impact in rural India. *Energy Policy* **2018**, *122*, 395–408. [CrossRef] [PubMed]
13. Kumar, P.; Dover, R.E.; Iriarte, A.D.-V.; Rao, S.; Garakani, R.; Hadingham, S.; Dhand, A.; Tabak, R.G.; Brownson, R.C.; Yadama, G.N. Affordability, accessibility, and awareness in the adoption of liquefied petroleum gas: A case-control study in rural India. *Sustainability* **2020**, *12*, 4790. [CrossRef]
14. Srinivasan, S.; Carattini, S. Adding fuel to fire? Social spillovers in the adoption of LPG in India. *Ecol. Econ.* **2020**, *167*, 106398.
15. Kumar, P.; Dhand, A.; Tabak, R.G.; Brownson, R.C.; Yadama, G.N. Adoption and sustained use of cleaner cooking fuels in rural India: A case control study protocol to understand household, network, and organizational drivers. *Arch. Public Health* **2017**, *75*, 1–11. [CrossRef] [PubMed]
16. Berkeley Air Monitoring Group. *Stove Performance Inventory Report*; Berkeley Air Monitoring Group: Berkeley, CA, USA, 2012.
17. Ruiz-Mercado, I.; Canuz, E.; Walker, J.L.; Smith, K.R. Quantitative metrics of stove adoption using Stove Use Monitors (SUMs). *Biomass-Bioenergy* **2013**, *57*, 136–148. [CrossRef]
18. Lewis, J.J.; Pattanayak, S.K. Who adopts improved fuels and cookstoves? A systematic review. *Environ. Health Perspect.* **2012**, *120*, 637–645. [CrossRef]
19. Bhojvaid, V.; Jeuland, M.; Kar, A.; Lewis, J.J.; Pattanayak, S.K.; Ramanathan, N.; Ramanathan, V.; Rehman, I.H. How do people in rural India perceive improved stoves and clean fuel? Evidence from Uttar Pradesh and Uttarakhand. *Int. J. Environ. Res. Public Health* **2014**, *11*, 1341. [CrossRef]
20. Cheng, C.-Y.; Urpelainen, J. Fuel stacking in India: Changes in the cooking and lighting mix, 1987–2010. *Energy* **2014**, *76*, 306–317. [CrossRef]
21. Malakar, Y. Studying household decision-making context and cooking fuel transition in rural India. *Energy Sustain. Dev.* **2018**, *43*, 68–74. [CrossRef]
22. Pillarisetti, A.; Ghorpade, M.; Madhav, S.; Dhongade, A.; Roy, S.; Balakrishnan, K.; Sankar, S.; Patil, R.; Levine, D.I.; Juvekar, S.; et al. Promoting LPG usage during pregnancy: A pilot study in rural Maharashtra, India. *Environ. Int.* **2019**, *127*, 540–549. [CrossRef]
23. Tripathi, A.; Sagar, A.D.; Smith, K.R. Promoting clean and affordable cooking. *Econ. Political Wkly.* **2015**, *50*, 81.
24. Williams, K.N.; Kephart, J.L.; Del Rio, M.F.; Condori, L.; Koehler, K.; Moulton, L.H.; Checkley, W.; Harvey, S.A. Beyond cost: Exploring fuel choices and the socio-cultural dynamics of liquefied petroleum gas stove adoption in Peru. *Energy Res. Soc. Sci.* **2020**, *66*, 101591. [CrossRef] [PubMed]
25. Abdulai, M.A.; Afari-Asiedu, S.; Carrion, D.; Ae-Ngibise, K.A.; Gyaase, S.; Mohammed, M.; Agyei, O.; Boamah-Kaali, E.; Tawiah, T.; Dwommoh, R.; et al. Experiences with the mass distribution of LPG stoves in rural communities of Ghana. *EcoHealth* **2018**, *15*, 757–767. [CrossRef] [PubMed]
26. Rehman, I.H.; Malhotra, P.; Pal, R.C.; Singh, P.B. Availability of kerosene to rural households: A case study from India. *Energy Policy* **2005**, *33*, 2165–2174. [CrossRef]
27. Kar, A.; Pachauri, S.; Bailis, R.; Zerriffi, H. Using sales data to assess cooking gas adoption and the impact of India's Ujjwala programme in rural Karnataka. *Nat. Energy* **2019**, *4*, 806–814. [CrossRef]
28. Beltramo, T.; Blalock, G.; Levine, D.I.; Simons, A. Does peer use influence adoption of efficient cookstoves? Evidence from a randomized controlled trial in Uganda. *J. Health Commun.* **2015**, *20*, 55–66. [CrossRef]