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Promoting LPG usage during pregnancy: A pilot study in rural Maharashtra, India

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ABSTRACT

Household air pollution from the combustion of biomass and coal is estimated to cause approximately 780,000 premature deaths a year in India. The government has responded by promoting uptake of liquefied petroleum gas (LPG) by tens of millions of poor rural families. Many poor households with new LPG stoves, however, continue to partially use traditional smoky *chulhas*. Our primary objective was to evaluate three strategies to transition pregnant women in rural Maharashtra to exclusive use of LPG for cooking. We also measured reductions in kitchen concentrations of $PM_{2.5}$ before and after our interventions. Our core intervention was a free stove, 2 free LPG cylinders (one on loan until delivery), and repeated health messaging. We measured stove usage of both the traditional and intervention stoves until delivery. In households that received the core intervention, an average of 66% days had no indoor cooking on a *chulha*. In an adjacent area, we evaluated a conditional cash transfer (CCT) based on usage of LPG in addition to the core intervention. Results were less successful, due to challenges implementing the CCT. Pregnant women in a third nearby area received the core intervention plus a maximum of one 14.2 kg cylinder per month of free fuel. In their homes, 90% of days had no indoor cooking on a *chulha*. On average, exclusive LPG use decreased kitchen concentrations of $PM_{2.5}$ by approximately 85% (from 520 to 72 μg/m^3). 85% of participating households agreed to pay the deposit on the 2nd cylinder. This high purchase rate suggests they valued how the second cylinder permitted continuous LPG supply. A program to increase access to second cylinders may, thus, be a straightforward way to encourage use of clean fuels in rural areas.

1. Introduction

Exposure to household air pollution (HAP) from burning solid fuels is a leading cause of ill-health in India, leading to roughly 780,000 premature deaths in 2016 (Health Effects Institute, 2018). Since 2014, the Government of India has undertaken policies to increase the rural poor's access to clean liquefied petroleum gas (LPG) (Tripathi et al., 2015; Smith, 2017a; Smith, 2017b). The largest of these programs is Pradhan Mantri Ujjwala Yojana ("Prime Minister's Brightness Scheme," commonly referred to as PMUY). PMUY is targeted to provide LPG "connections" to 80 million disadvantaged households by 2019 (Press Information Bureau - Government of India - Cabinet Committee on Economic Affairs, 2018). It is one of the largest initiatives in history related to household energy.

In India, a LPG "connection" means that a household is authorized to order LPG from the national distribution network. All household users with an annual income of < 1 million INR (approximately 14,000 USD) may buy up to 12 cylinders a year at a subsidized price (Ministry of Petroleum and Natural Gas Orders, n.d.) (approximately 500 INR, 7 USD, per 14.2 kg canister of fuel in August 2018 (Indian Oil Corporation, n.d.)).[1] Unsubsidized fuel costs vary from 750 to 850 INR or more and are set monthly based on international prices (Indian Oil

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[1] Roughly 20 million users have given up access to subsidized fuel, largely as part of a separate "Give it Up" national program.

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Corporation, n.d.). The difference between the market and subsidized price is the national LPG subsidy paid for by the Indian taxpayer and the three Oil Marketing Companies (OMCs). The Government of India owns a majority share of stock in these three companies. India had approximately 220 million household LPG connections as of April 2018 (Petroleum Planning and Analysis, 2018), with the number rising monthly.

PMUY provides LPG access to poor households by covering the upfront cost of 1600 INR (23.4 USD) for the LPG cylinder deposit, the cost of the regulator and hoses, and small administrative fees. If needed, it also provides an interest-free loan for the 1000 INR (~14 USD) stove. Upfront costs are a well-known barrier for poor households to purchase any new clean cooking technology (Jeuland et al., 2015; *Petroleum Planning and Analysis Cell Assessment Report - Primary Survey on Household Cooking Fuel Usage and Willingness to Convert to LPG*, 2016; Gould and Urpelainen, 2018), although not the only one (Lewis and Pattanayak, 2012; Puzzolo et al., 2016). LPG is an aspirational fuel in India; it has not been difficult to persuade poor households to take up free connections as part of PMUY and pay for the cost of a first cylinder of fuel. Since its inception, about 71 million households have signed up for LPG connections through PMUY.

Unfortunately, in domains ranging from latrines and bednets to condoms and handwashing, access to health-promoting products does not produce large health benefits unless people stop using the old technology and shift to the new. The national database of all LPG customers indicates that after a year of being connected, the mean cylinder refill rate of PMUY households is ~4 cylinders per year, rather than the 7 or so that indicates full usage. Substantial evidence suggests that many health benefits accrue only when household air pollution goes down to low levels (Johnson and Chiang, 2015). This low rate of LPG usage by the poor suggests they continue to cook using biomass. Such “stacking” of fuels (Ruiz-Mercado et al., 2012; Ruiz-Mercado et al., 2013; Piedrahita et al., 2017) suggests that millions of people in PMUY homes continue to suffer the harm from smoky fires.

Our pilot study explores strategies to promote LPG usage among particularly vulnerable households – those with a pregnant woman. Several studies suggest that exposure to household air pollution leads to adverse pregnancy outcomes (Balakrishnan et al., 2018; Amegah et al., 2014; Siddika et al., 2016; Alexander et al., 2018). Additionally, pregnant women are experiencing major changes in their lives and may, thus, be open to other behavioural changes, making them a good target for focused programs to enhance their usage of clean fuels.

The primary aim of our study is to increase use of LPG and to reduce use of the indoor traditional stove during pregnancy. We provide incentives for LPG usage for the duration of pregnancy in three different ways. Our core intervention arm received a free stove and a free filled cylinder of LPG. The conditional cash transfer arm received the core intervention plus a subsidy covering part of the cost of fuel, conditioned on usage of LPG. A third arm received the core intervention plus free fuel. All arms received messaging on the potential benefits of clean cooking with LPG. We compare the number of days of pregnancy with no use of indoor chulhas for each strategy. Secondarily, we compare the number of fuel refills between arms. Finally, we also measured $PM_{2.5}$ concentrations in the kitchens of a subset of participants for 24 h before our interventions and for 24 h after intervention, when we asked that they only use their new stove.

2. Materials and methods

2.1. Study site

We worked in three adjacent areas of Junnar Block of Pune District, about 90 km north of the district capital, Pune, in the state of Maharashtra (Fig. 1). This tribal area lies adjacent to the Western Ghats and is largely agricultural, with rice, vegetable, and fruit production. It is dry much of the year, but blossoms in green during the monsoon with many small lakes and streams. Little space heating is used (except briefly during the monsoon rains), but most households heat bath water every day. Community characteristics are in Table 1. Two LPG distributors provide LPG in these areas. Both distributors work for Hindustan Petroleum Corporation Limited (HPCL), with whom we collaborated.

2.2. Recruitment and intervention

Each arm was assigned to a single geographic area to prevent contamination between arms. Within each arm, we trained and provided a small incentive (150 INR, ~2.20 USD) to local ASHA workers to identify pregnant women who might be eligible for our program. ASHAs already maintain a register of women in their area as they become pregnant; we asked ASHAs to approach non-smoking women who were currently using biomass for cooking and were < 4 months pregnant. We thus recruited newly pregnant women as a convenience sample into three groups:

1) The Core Intervention group: a free LPG connection (as with PMUY), a free stove (instead of a loan for a stove, as is common under PMUY), a table (for safety), and health messaging.
2) The Conditional Cash Transfer arm received, in addition, a conditional cash transfer during pregnancy. We set the transfer at 2 rupees per meal (0.03 USD), about half the cost of the fuel used during preparation of a typical meal. We based payments on a specialized stove use monitor (SUM) we placed on the LPG stove (Pillarisetti et al., 2018). We called these special SUMs “Pink Keys.”
3) The Free Fuel group received the same package as the Core Intervention plus free fuel during pregnancy (until delivery, when the benefit ceased; up to 1 cylinder per month).

Health messages (shown in the Supporting Information) were delivered to all participants orally with the aid of a spiral-bound flipbook. Messages were developed and tested with local study staff and focused on the health-damaging impacts of biomass smoke and the aspirational nature of clean cooking with LPG. During the recruitment visit, fieldworkers administered the consent form and placed thermocouple-based SUMs on the traditional biomass stove, or *chulha*. Typically, the local ASHA worker who identified the participant was present during this visit. Fieldworkers administered a baseline questionnaire on the second visit. During this visit, in a subset of 30 households per arm, a pre-intervention measurement of kitchen $PM_{2.5}$ concentrations occurred for 24 h, while the households were still using only their *chulhas* for cooking. The third interaction occurred when the distributors' mechanics delivered and installed the LPG stove and cylinder and trained the women on its use. Our fieldworkers attended the installation and delivered health messages for the first time. Our team had previously equipped each LPG stove with a thermocouple SUM on each burner. Field staff revisited the same subset of households for a second air pollution monitoring visit 2–4 weeks after intervention. Staff requested households to use only LPG for the 24 h of post-intervention measurement. Fieldworkers also visited each household at regular intervals to deliver health messages and to download SUMs data and, in the CCT arm, to provide the cash transfer. The timeline in Fig. 2 show interactions between study staff and participants. Characteristics of study participants at recruitment are in Table 2.

Our intervention package differed from the typical PMUY offering. We provided each household a sturdier 2-burner stove than the stove currently offered in the PMUY program. National safety standards require the burners of the stove be placed above the top of the cylinder. Thus, we also provided a table to hold the stove.

2.3. Protocol modifications

Between three and four weeks after the start of the study, we

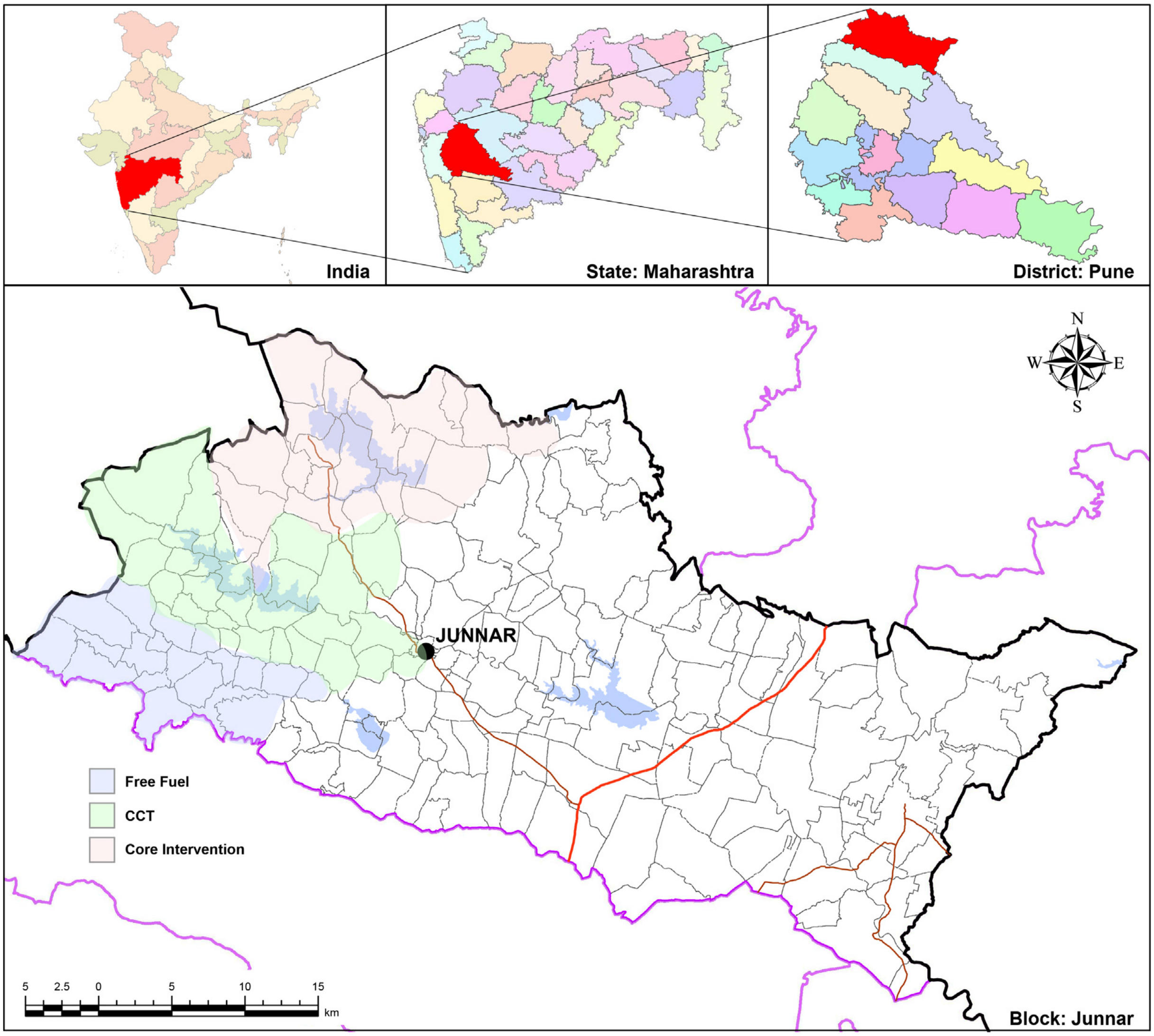

Fig. 1. Map of the study site. The state of Maharashtra is located in the center of Western India. Junnar block is located in the District of Pune, approximately 90 km north of the city of Pune and 150 km east of the city of Mumbai. The filled in black circle indicates the location of the study's field headquarters; the shaded areas correspond to the areas from which participants in each study arm were recruited. Map adapted from Maharashtra Remote Sensing Applications Centre (mrsac.gov.in).

Table 1
Study arm characteristics in Junnar Block, Pune District, Maharashtra, India.

Primary healthcare center (PHC) name	Madh	Aaptale	Inglun
Study arm	Core	Conditional Cash Transfer	Free Fuel
Number of villages	26	29	20
Type of area	Tribal	Tribal	Tribal
Population	25,807	30,862	16,048
Annual births	503	602	477
LPG distributors in study area	1	1	1
Households with LPG connection		44.2% (Census of India 2011)	

modified the study protocol to limit free fuel to one refill per month, as some households were overusing this benefit. Many of our households were 45 min or more from the distributor's showroom and warehouse. We also found that distributors were often not providing replacement cylinders quickly, leading some households to revert to biomass. To facilitate continuous access to LPG, we lent each household a second cylinder until the end of pregnancy. Households recruited after this protocol modification received the loan of the second cylinder as part of their intervention package. After the delivery of their baby, households could either return the second cylinder or could pay the deposit (1500 INR, 21 USD) to keep it.

This modification is consistent with behaviors in Indian cities. To avoid gaps in fuel supply, approximately 43% of LPG users in India have two cylinders (primarily in urban areas). For example, if a cook runs out of LPG one evening, she simply shifts to her second cylinder and does not care exactly when in the next weeks the empty cylinder is refilled. This second cylinder also provides the distributor the flexibility of visiting each neighbourhood on a weekly basis while maintaining continuous LPG access. However, a second cylinder is not currently part of the PMUY program and few rural households have two cylinders.

As we were distributing second cylinders, we also realized we could be more proactive about discouraging the use of *chulhas*. We began to ask households, in recognition of the now reliable LPG supply we had provided them, whether they would disable their *chulha* by dismantling it, moving it outdoors, or filling it with rocks. This request clarified that the main purpose of promoting LPG is stopping use of the smoke-producing *chulha*. Although *chulhas* are easily re-enabled (rebuilt, removing rocks, etc.), it was a symbolic act that directly linked our goals with concrete actions of the households. We kept the SUMs in use on

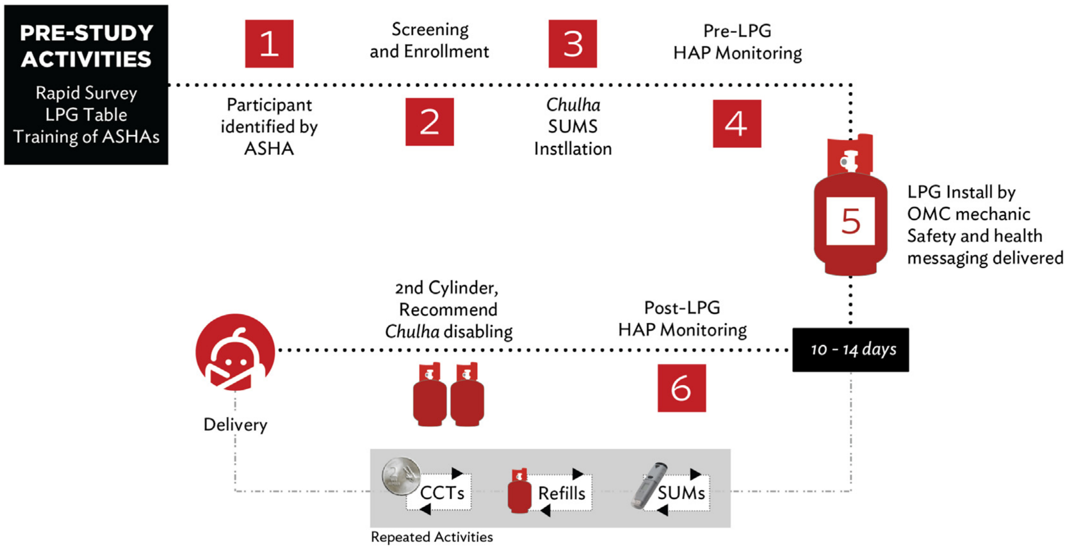

Fig. 2. Study timeline, noting major interactions with households. ASHA = Accredited Social Health Activist; SUMS = stove use monitoring system; HAP = household air pollution; OMC = oil marketing company; CCT = conditional cash transfer.

Table 2
Characteristics of the study population, by study arm.

Baseline characteristics	Core (N = 52)	CCT (N = 52)	Free Fuel (N = 51)
Mean age (SD)	24 (2.3)	22 (2.2)	24 (3.2)
Mean education in years (SD)	7 (3.0)	9 (3.0)	9 (2.9)
First time pregnancy (%)	35%	42%	50%
Non-nuclear homes[a] (%)	62%	81%	75%
Religion (%)			
Hindu	98	90	100
Buddhist	1.9	0	0
Others	0	9.6	0
Median annual income INR (USD)	25,000 (350)	35,000 (490)	30,000 (420)
Income Source (%)			
Work in own farm	0	3.9	43
Work in others' farms	98	92	51
Others	1.9	5.9	5.9
Mean meals cooked per day	2.0	2.0	2.0
Mean household size (SD)	5.1 (1.8)	5.5 (1.9)	5.1 (1.3)
Fuel used for cooking (%)			
Firewood only	5.7	18	5.8
Firewood and dung	92	83	92
% that heat bath-water daily	51	52	50

[a] Nuclear households are households comprised of a married couple or a man or a woman living alone or with unmarried children (biological, adopted, or fostered) with or without unrelated individuals. Any other household arrangement is defined as non-nuclear family.

disabled *chulhas* to check whether cooks used the *chulhas* when we were not present.

We encountered implementation issues with our new conditional cash transfer sensor (the Pink Key) and with transferring funds to households, which we originally planned to do through direct deposit into bank accounts. We switched to paying the pregnant participant directly every month and finalized implementation details in early 2018 with better functioning hardware.

2.4. Air pollution monitoring

Gravimetric kitchen measurements were made using battery-operated pumps (SKC PCXR8 and XR5000, Eight-Four, PA, USA) coupled to cyclones (BGI Triplex, SCC 1.062, Mesa, USA). 9 individual pumps and 11 cyclones were used in the study. We collected samples on 37 mm PTFE filters at a flow-rate of 1.5 l per minute. Flow rates were checked in the laboratory with a primary flow meter (Mesa Bios Defender 510, Mesa, USA) and verified at the time of deployment with calibrated rotameters (Aalborg, USA). We also collected 25 field blanks and 4 lab blanks. We used average field blank mass changes to correct field samples by adjusting for this difference.

Fieldworkers placed instruments in the kitchen (1) approximately 100 cm from the stove, (2) at a height of 145 cm above the floor, and (3) at least 150 cm away (horizontally) from doors and windows, where possible. Pumps were programmed to run for 24 h and then turn off. We administered a detailed post-monitoring questionnaire at the end of each measurement session. Households were asked not to use biomass during the post-intervention monitoring period. The survey asked about biomass use activities, locations of use, cooking duration, and the number and type of meals prepared.

Log forms detailing pre-and post-sample flow rates for gravimetric devices and placement and removal times for all devices were maintained on paper and double-entered upon return to the field headquarters. Lab staff weighed filters in triplicate using a Cahn C-34 Microbalance (Thermo Scientific, Waltham, MA, USA) in a temperature and humidity-controlled room at Sri Ramachandra Institute of Higher Education and Research. Additional details on filter handling and weighing are available in the Supporting Information.

2.5. Stove usage monitoring

Usage of both the *chulha* and the LPG stove were monitored using battery-powered, thermocouple temperature data loggers (Wellzion SSN-61, Xiamen, Fujian, China). Thermocouple probes varied in design. For the LPG stoves, we used K-type wire thermocouples. For traditional stoves, we used a K-type thermocouple with a temperature-resistant screw. Trained fieldworkers placed probes on LPG burners in a standard location underneath each burner. Loggers were placed behind stoves in PVC pipes with rubber caps. Probes for *chulhas* were placed 1–2 cm from the edge of the combustion zone and cemented into place using the same mud that the stove is made from.

We programmed loggers to record an instantaneous temperature in degrees Celsius every 5 min. Loggers were downloaded every 2–4 weeks to a Windows laptop using the logger's built-in USB port. After downloading, field workers used Wellzion's software to generate a quick plot and manually review it. They noted approximate minimum and maximum temperatures over the sampling period and visually inspected the data for any anomalies, including negative values (indicating that the thermocouple was either unplugged or damaged) and missing data. Field staff replaced probes and/or loggers when they detected non-resolvable issues.

We translated temperature data into days of use by examining daily temperature ranges and the daily maximum temperature measured by each sensor on each day. We interpreted a stove as used on any day with a temperature range greater than or equal to 30 degrees Celsius and a maximum temperature above 60 degrees Celsius. Because we made measurements on two LPG burners in all households and on multiple *chulha* burners in some households, use-day calculations were aggregated across stove types. For example, use of the left burner, the right burner, or both would constitute a day of LPG use.

After the intervention, fieldworkers also observed the status of the primary traditional stove during every visit. They noted if it had signs of use, including if it was warm or in active use; whether or not it was filled in or dismantled; or if it had been moved outside. When possible, we used these manual log files to fill in missing SUMs data (due to either equipment failure or removal of thermocouples from dismantled or filled in *chulhas*).

Logs and stove usage files were transferred to a central computer at the field office, where filenames – which included metadata like an alphanumeric household id, a code for study arm, and a code for SUMs placement – were inspected, corrected (if needed), and uploaded to a server in the School of Public Health at University of California, Berkeley. At approximately 6a India Standard Time, the server checked the previous day's files for common errors and archived and stored them locally and remotely. The automated system sent an email to study managers with a summary of the data analysed each night and a note about any files and/or sensors that warrant manual review.

2.6. LPG refill information

We measured the frequency of LPG refills in two ways. First, in collaboration with the local LPG distributors, we maintained logs of request dates for cylinder refills. Second, we followed up with households to ensure that they had indeed made a refill request and that the distributor had fulfilled the request. Field staff recorded information for each household in a separate binder or paper file. Data entry staff entered data into a Microsoft Excel spreadsheet weekly, where it was verified by the field manager and a data entry specialist.

2.7. Data analyses

Air pollution data were cleaned, blank-corrected, and summarized. *t*-Tests and non-parametric Kruskal-Wallis and Wilcoxon tests were used to compare distributions of stove usage and of log-transformed $PM_{2.5}$ concentrations before and after measurement and between arms during baseline and post-intervention periods.

We merged the SUMs data with fieldworker observations on stove usage by matching on calendar date, stove type, and household id. We used the observational data only where SUMs data were not available. All analyses were performed in R 3.5 (R Foundation for Statistical Computing, Vienna, Austria).

2.8. Ethical review

Institutional Review Boards of University of California, Berkeley; KEM Hospital Research Centre, and Sri Ramachandra Institute of Higher Education and Research approved this research and amendments to the initial protocol.

3. Results

We report two primary outcomes: the number of recorded LPG refills and the days using LPG and traditional stoves. Both outcomes estimate changes in the "dose of the therapy" in the form of equivalent periods of pregnancy protected from biomass smoke due to use of LPG. We also report kitchen air pollution results based on the 24-h pre- and post-intervention measurements and study-wide measures of usage across individual arms and the entire study.

Table 3
Average refill patterns by study arm through delivery. Note, these are refills after the first cylinder provided at distribution of the LPG intervention is depleted. The time to first refill is longer for households that received both the first and second cylinder on the same day. For households that received the 2nd cylinder on the same day as the first, the mean time to first refill was 75 days in the core arm and 52 days in the CCT arm, versus 46 and 35, respectively, in those that received their loan of a second cylinder after they had exhausted their first cylinder.

	Number of Refills				Days Until First Refill		Average Days Between Subsequent Refills	
Arm	Avg	SD	Min	Max	Avg	SD	Avg	SD
Core	1.4	1	0	3	63	22	32	24
CCT	3	1.6	0	6	45	32	33	27
Free fuel	3.6	1.8	1	7	43	18	31	19

Based on both Poisson (GLM) models and Wilcoxon tests for the refills, and *t*-tests for the days until first refill, there is a significant difference ($p < 0.05$) between the Core group and the other two groups, but not between the CCT and Free Fuel groups. There is no statistically significant difference for days between subsequent refills among the three groups.

3.1. Refill rates

We collected records of refills between February 2017 and mid-August 2018. For the current analysis, we analyse the period from receipt of intervention through child delivery (the last delivery occurred in mid-April 2018). The average time between introduction of the intervention and child delivery was 16 weeks (SD 6.4) in the core intervention arm, 22 weeks (SD 6.5) in the free fuel arm, and 20 weeks (SD 5.6) in the CCT arm. First refills happened most rapidly in the free fuel arm, followed by the CCT and core intervention arms.

The average number of days between refills after the first was similar across study arms, 31–33 days (Table 3). These rates of fuel usage are consistent with households using LPG for most of their cooking; as noted above, other poor households often have only about half as much LPG consumption as revealed in the oil companies' national refill databases. The refill rate in Table 3 is complicated by the differences in timing for introduction of the second cylinder. Additional details on the number and distribution of refills – and statistical tests comparing the mean time to refill by study arm – are described in Supporting Information Figs. S2, S3, and S4.

3.2. Stove usage monitors

We collected approximately 50 million data points, representing nearly 165,000 stove-days of data. SUMs were on *chulhas* prior to intervention for, on average, 35 days (SD 30); monitoring continued for an average of 200 days (SD 125) post-intervention.

We reduced stove usage data into two categories – days with exclusive LPG use and days with any *chulha* use. A visual depiction of time trends of usage in these categories by study arm is in Fig. 3. It shows in the post-intervention period the fraction of days with exclusive LPG use, with any LPG use, and with any chulha use.

The number of days with exclusive LPG use was significantly higher in the free fuel arm than in either the core intervention ($p < 0.05$) or CCT ($p < 0.05$) arms. The free fuel arm had the highest average number of days with exclusive LPG use (102 days, 90%), followed by the core intervention arm (62 days, 66%), and the conditional cash transfer arm (61 days, 49%, Table 4). Mixed use occurred, on average, on 27 days (28%) in the core intervention arm, 38 days (36%) in the

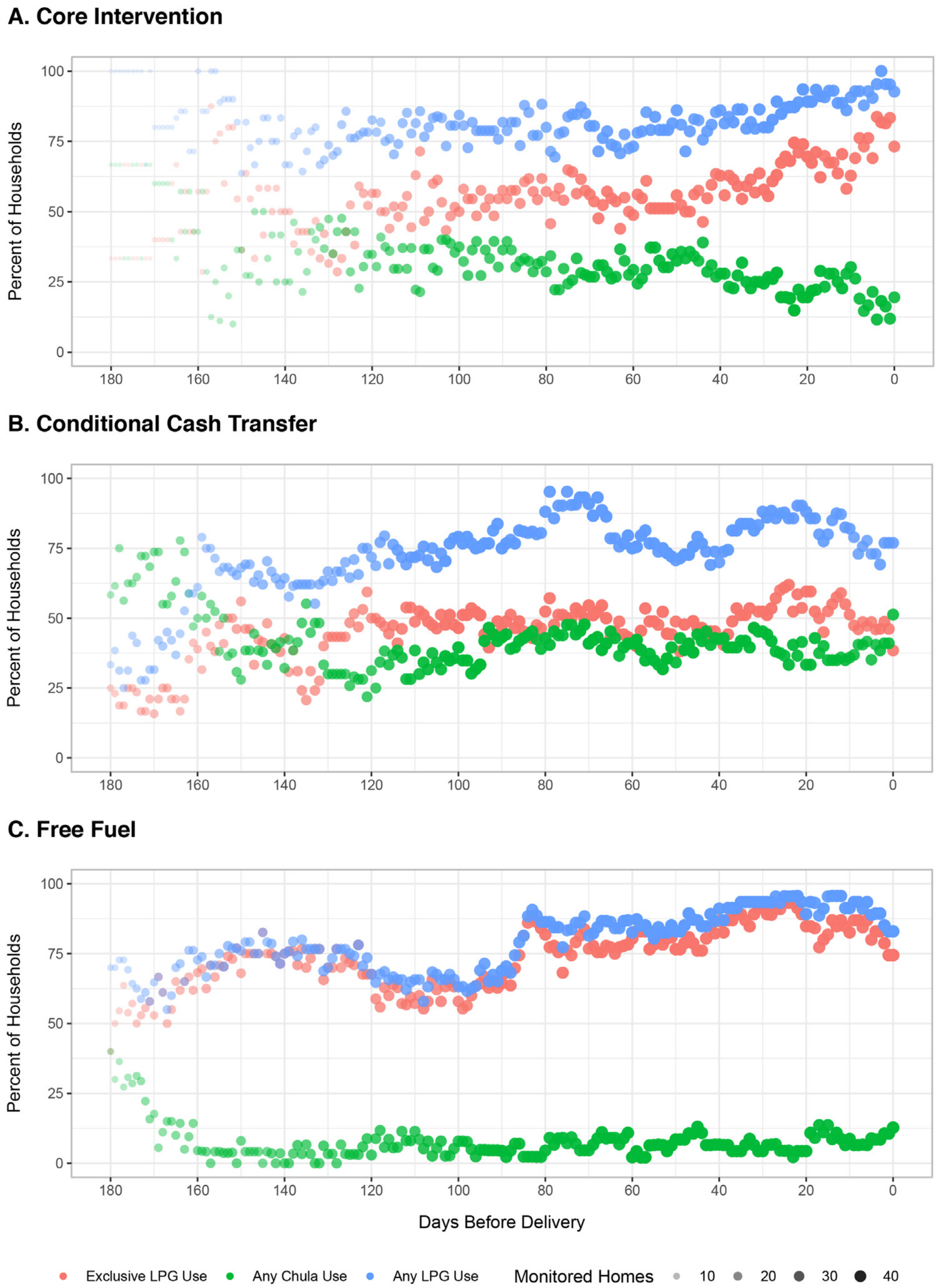

Fig. 3. Trends in exclusive LPG use, any LPG use, and any *chulha* use prior to delivery by study arm. Panel A is the Core Intervention arm, B is the CCT arm, and C is the Free Fuel arm. The x-axis is the number of days before delivery (day 0) after receipt of the intervention; the y-axis is the percent of total monitored use days. The size and opacity of the points indicates the number of households monitored on each day (larger and darker points are a larger number of homes).

Table 4
Days with intervention, with valid monitoring, and with exclusive use of LPG.

	Pregnancy Days													
	With intervention		With valid monitoring & recorded cooking[a]			With LPG only[b]			With chulha only[b]			With mixed use[b]		
	Mean	SD	Mean	SD	%	Mean	SD	%	Mean	SD	%	Mean	SD	%
Core[c]	120	42	94	43	82	62	43	66	5	8	6	27	33	28
CCT[c]	144	36	119	48	86	61	50	49	20	21	15	38	34	36
FF[c]	162	43	113	54	73	102	49	90	3	6	4	8	18	6

[a] Valid monitoring days are between LPG installation and delivery where data are present (not missing or indicative of no cooking).
[b] The percent in each category is 100 times the average number of days divided by the average number of days with valid monitoring & recorded cooking.
[c] No cooking was detected by stove use monitors in the Core arm on 13 days, in the CCT arm on 18 days, and in the Free Fuel arm on 22 days.

Table 5
Measured 24-h kitchen $PM_{2.5}$ (μg/m^3) by study phase.

Phase	Mean	SD	Median	Min	Max	N
Base	505	320	430	60	1900	91
Post	76	84	45	10	411	83
Reduction	85%		90%		$p < 2.2 \times 10^{-16}$*	

Note, post-measurements occurred in sessions when the households were asked to use the intervention LPG stove exclusively.
* *p*-value from Welch's two-sample *t*-test.

CCT arm, and 8 days (6%) in the free fuel arm. The percentage of days with mixed use in the free fuel arm was significantly lower than in the core intervention (Wilcoxon Rank Sum, $p < 0.001$) and CCT arms (Wilcoxon Rank Sum, $p < 0.001$). Mixed use was not significantly different between the CCT and core intervention arms (Wilcoxon Rank Sum, $p = 0.34$). In general, the free fuel arm achieved nearly full usage of LPG after a learning period at the start.

3.3. Household air pollution

We measured air quality in 110 households at baseline and 87 post-intervention. 19 samples from the baseline phase and 4 samples from the post-intervention phase were excluded due to pump or battery failures, leaving 91 pre-intervention and 83 post-intervention measurements. For the post-intervention measurement, we asked households to cook only on the LPG stove.

Table 5 summarizes the 24-h gravimetric kitchen $PM_{2.5}$ concentrations at baseline and after the intervention (see the SI for a breakdown by study arm and intervention phase). The average PM concentration was 505 μg/m^3 at baseline and 76 μg/m^3 after the intervention, an 85% reduction. Average reductions in kitchen concentrations ranged from 81 to 87% across study arms (Fig. 4). All arms had similar pollution levels both at baseline and after the intervention. The conditional cash transfer arm had slightly smaller baseline and slightly higher post-intervention levels, although differences are not statistically significant (distributions in Supporting Information Fig. S1). We additionally assessed the impact of compliance with our request to use exclusively LPG on kitchen PM concentrations. There was no significant difference between homes with chulha use or with missing chulha data and homes with no chulha use (SI Table S2).

3.4. Second cylinder purchases

As shown in Table 6, approximately 85% of households paid to keep the second cylinder after the end of the project. Most (82%) households paid a single lump sum directly, with the rest paying in 2 or 3 instalments over several weeks. The share paying a lump sum varied slightly across the three groups (79–92%).

About 65% of household disabled their *chulha* in one way or another (Table 6), but with considerable variation (35–88%) across arms.

4. Discussion

We report on efforts to encourage clean fuel usage among 155 biomass-using pregnant women living in rural Maharashtra, India. We provided each woman a core intervention of a free stove and cylinder. One arm received only the core intervention, one arm received additional cash transfers conditioned on LPG use, and one arm received free fuel. We measured air pollution concentrations in the kitchen before and after deployment of the intervention and tracked stove usage using a combination of sensors and field observations.

At the start of our study, our intervention package already went beyond the 1600 INR (22 USD) benefit provided by the Government of India in the PMUY program, which covers hoses, the deposit on the cylinder and regulator, and safety and usage training during household installation by the distributor, and a no-interest loan for the stove. Ours included, in addition, the first 14.2 kg of LPG, a free double-burner stove, a table to raise the cooking surface off the ground, and messaging related to the health benefits of cooking with clean fuels. After the start of the project, we further revised the intervention to include loan of a second full cylinder to increase the reliability of fuel supply at the households.

Given the rolling nature of the changes and the relatively short time before they were made, we did not distinguish effects before and after the changes in protocol. We acknowledge that these changes in protocol, which we made months into the study, were not part of the initial study design. As the results were fairly striking, however, we report them here and have since started further studies where the second cylinder is part of the initial protocol. We note that, in particular, our understanding of refill patterns was complicated by the delayed provision of a second cylinder in some homes.

Additionally, weeks of pregnancy protection and the number of refills used by households were impacted by a gap of, on average, 50 days (SD 31) between enrolment and distribution of the intervention. This period was due in large part to factors outside control of the

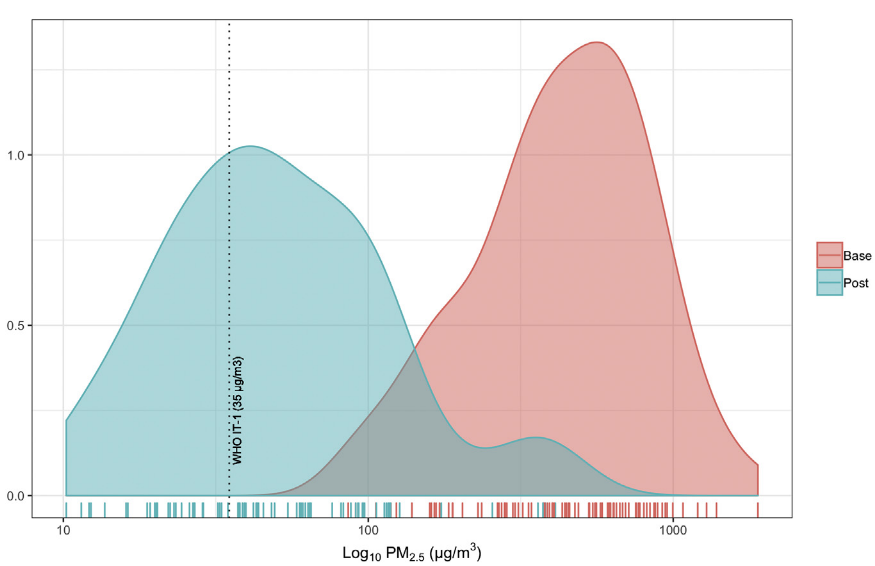

Fig. 4. Log-transformed kitchen $PM_{2.5}$ concentrations for baseline and post-intervention measurements across all three arms. Vertical lines at bottom show individual measurements. For reference, a vertical dotted line at WHO's Interim Target 1 (35 μg/m^3 annual average) has been included. Post-measurements occurred in sessions when the households were asked to use the intervention LPG stove exclusively.

Table 6
Payment for second cylinder and disabling of *chulha*.

Characteristics	Core (N = 52)	CCT (N = 52)	Free Fuel (N = 51)	Total (N = 155)
Purchased 2nd cylinder N (%)	44 (84.6)	41 (78.8)	47 (92.1)	132 (85.1)
Median duration of buying 2nd cylinder after receiving it in months	6.3	7.2	4.3	5.9
2nd cylinder purchased through single payment N (%)	34 (86.3)	27 (65.8)	47 (100)	108 (81.8)
Chulha filled w/stones/mud N (%)	0	7 (13.4)	8 (15.6)	15 (9.6)
Dismantled *chulha* N (%)	0	9 (17.3)	15 (29.4)	24 (15.4)
Moved *chulha* outdoors N (%)	17 (32.6)	15 (28.8)	12 (23.5)	44 (28.3)
Chulha reported not in use N (%)[b]	1 (1.9)	6 (11.5)	10 (19.6)	17 (10.9)
Total disabled *chulhas* through July 2018 N (%)	18 (34.6)	38 (73)[a]	45 (88.2)	101 (65.1)

[a] Status of *chulha* in one household unconfirmed.
[b] Based on fieldworker observations.

research team, including the following:

- an insufficient number of connections allocated to our district by the OMC, due in part to reallocation to other states that were holding elections;
- the time taken to receive permission from the national OMC administration for the study and for the dissemination of instructions through the bureaucratic structure to our local distributors;
- difficulty scheduling delivery of connections promptly after enrolment in the study and receipt of proper paperwork from participants.

A national program seeking to protect pregnant women would, presumably, work through these issues prior to commencing. As such, they would be able to cover a substantial number of additional pregnancy-weeks with clean fuel, providing more benefit to families participating in the program.

4.1. Explicitly discouraging chulha use

The relatively large number of households that disabled their chulha (65%) suggests that our health messages (see SI) may have been highly effective; however, we have no comparison group, so this result is suggestive. We suspect that the health messages were effective in the context of loan of a second cylinder, where fuel unreliability is essentially eliminated, as other studies have shown significant levels of stacking with cooking interventions (Thoday et al., 2018; Pollard et al., 2018; Gould et al., 2018; Pillarisetti et al., 2014). We have an ongoing project where we are evaluating the impact of a second cylinder and of messaging on chulha usage in communities neighboring the ones described here.

4.2. Free fuel as an unconditional transfer to poor, pregnant women

The approximate total cost of our support in the free fuel arm during pregnancy, including the stove (2150 INR), LPG, and table (1000 INR), was approximately 5400 INR (~80 USD). In some states this amount is equivalent to or less than what is already provided as pregnancy benefits (e.g., 12,000 INR in Tamil Nadu (Balasubramanian and Ravindran, 2012), 5000 INR in Odisha (Raghunathan et al., 2017)). For the fuel alone, the extra cost to a program designed to supplement households already set up with connections by the PMUY program would be ~2200 INR depending on usage (~4.6 refills @ 480 INR each) This cost is on top of the connection cost provided by the PMUY program and the fuel subsidy provided to all households in the country.

The program costs for protection from smoke can be determined in various ways. Using the number of days of exclusive LPG use as the metric, the extra program cost for the increase in free fuel arm usage over the core arm was ~50 INR per day. Using a relaxed metric of exclusive plus mixed LPG-*chulha* use, this cost was ~100 INR per day. It is important to note, however, that the core arm received many benefits over the national PMUY program (table, stove, second cylinder loan, health info) and already used LPG for 66% of the time in our study.

4.3. Limitations and challenges

This project faced significant implementation challenges, including procuring LPG connections; identifying, purchasing, and delivering tables to households to safely elevate the cooking surface; working with distributors to ensure timely refills; and procuring second cylinders, among others. We discuss these challenges briefly, with more details in the Supporting Information to aid others working on similar projects.

4.3.1. Procuring cylinders

We encountered logistical hurdles in cylinder and connection procurement (described in more detail in the Supporting Information). These challenges led to substantial differences in the time that households had access to the intervention prior to the pregnant woman's delivery. Issues included submission of complete paperwork documenting participant identity, residence, and bank account details and the sometimes long period between turning in paperwork and receiving the connection.

4.3.2. Identifying and procuring tables

The LPG stove should sit above the top of the regulator to reduce the risk of fire. Most kitchens in our study did not have a platform of adequate height from which the LPG stove could be safely operated. Thus, we provided a locally-made standard table – four feet long, three feet wide, and 2.5 ft tall, with metal legs and a stone top – to all households prior to delivery of our LPG intervention.

4.3.3. Fieldwork challenges

The burden on fieldworkers during this study was relatively high, with a small team visiting households regularly. Households were spread over an area of approximately 400 km^2, often separated by rough roads that became impassable during the monsoon. Many households were a significant distance from the roads, as well, decreasing the number of households that field staff could visit per day. Additional challenges included placement of thermocouple probes and implementation of the Pink Key for the CCT arm (Pillarisetti et al., 2018). More broadly, our SUMs strategy would have benefitted from sensors on secondary combustion sources, including outdoor *chulhas*.

4.3.4. Birthweight

As this project was a pilot with relatively small sample sizes per treatment arm, we were underpowered to detect a difference in the prevalence of low birthweight or in differences in distributions of birthweight between study arms. At the same time, we tested that we were able to collect birthweights shortly after delivery – even in this dispersed rural setting. We collected 151 birthweights for the 155 participants; the average birthweight was approximately 2.58 kg (SD 0.45 kg). 46 (30%) of collected birthweights were < 2.5 kg in the study population. For a national program, the mode of birthweight collection utilized here – relying on a combination of phone calls to households, birth certificates and cards, and communication with ASHA workers – may be feasible. A high-quality research study would need to provide health centers with high quality scales and special training on collecting birthweight.

4.3.5. Air pollution

Our air pollution sample size was small and short in duration. It shows significant reductions in kitchen concentrations of $PM_{2.5}$ with a transition to LPG, but more measurements – including personal exposure assessment – should be undertaken. Furthermore, we were unable to account for meteorological conditions or ambient air pollution on sampling days, though samples were obtained over a short period of time in each phase of the intervention. Finally, we note that some concentrations are much higher than expected, indicating the potential for use of unmonitored stoves or other biomass combustion devices in the home.

Our study had no true control group, partly due to the need to provide a table to all participants because of safety requirements and the need to cover as long in pregnancy as possible and thus to directly recruit participants early. We also compared 3 adjacent areas, so did not randomize at the household level. In the future, it may be possible to combine databases from the public health care system and from the LPG distributors to follow pregnant women who are just joining PMUY to see how much fuel they use without household visits.

5. Conclusions

Despite the small overall sample size and geographic bounds of this pilot study, our findings support a number of hypotheses that should be investigated further, as they have profound policy implications for programs seeking to expand access to and exclusive usage of LPG:

- Pregnant women seem to be a receptive population for an enhanced PMUY program, as *chulha* use in even the core intervention arm decreased for much of pregnancy.
- In the free fuel arm, *chulha* use was below 15% of monitored days throughout pregnancy, indicating an impact of this extra benefit.
- Loaning the second cylinder to households had major benefits in terms of enhanced ease of refill and reliability. Its popularity is shown by 85% of households being willing to pay the deposit after the birth of their baby in order to retain the second cylinder. Making second cylinders affordable and available in rural areas may help increase usage.
- Asking, but not requiring, households to disable their *chulha* was surprisingly successful, with 65% of households complying. Implementing such a request is relatively low cost and could benefit future programs to improve LPG access and utilization.
- $PM_{2.5}$ levels in the kitchen dropped by about 85% when using LPG compared to the *chulha*, indicating a substantial reduction in risk. Despite these reductions, mean levels ($76\,\mu g/m^3$) were still above the WHO Interim Target of $35\,\mu g/m^3$. Thus, there may have been unmeasured *chulha* use either indoors or outdoors or other sources of pollution (such as ambient air pollution) in the near home environment that elevated exposures for a subset of monitored homes.
- The percent reduction and the post-intervention kitchen $PM_{2.5}$ concentrations were lower and usage of LPG higher than what has been observed in any of the previous household cookstove intervention studies that used non-LPG technologies. The "acceptability" of LPG as a cook-fuel thus remains unequivocally high.
- The study provides a compelling argument to focus on policies that can cover the additional financial and administrative burden for the poorest communities to increase usage of LPG without which it may be impossible to reduce consequent health-risks in the near-term.

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Appendix A. Supplementary data

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References

Alexander, D.A., Northcross, A., Karrison, T., Morhasson-Bello, O., Wilson, N., Atalabi, O.M., Dutta, A., Adu, D., Ibigbami, T., Olamijulo, J., Adepoju, D., Ojengbede, O., Olopade, C.O., 2018. Pregnancy outcomes and ethanol cook stove intervention: a randomized-controlled trial in Ibadan, Nigeria. Environ. Int. 111, 152–163.

Amegah, A.K., Quansah, R., Jaakkola, J.J., 2014. Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: a systematic review and meta-analysis of the empirical evidence. PLoS One 9 (12), e113920.

Balakrishnan, K., Ghosh, S., Thangavel, G., Sambandam, S., Mukhopadhyay, K., Puttaswamy, N., Sadasivam, A., Ramaswamy, P., Johnson, P., Kuppuswamy, R., Natesan, D., Maheshwari, U., Natarajan, A., Rajendran, G., Ramasami, R., Madhav, S., Manivannan, S., Nargunanadan, S., Natarajan, S., Saidam, S., Chakraborty, M., Balakrishnan, L., Thanasekaraan, V., 2018. Exposures to fine particulate matter (PM2.5) and birthweight in a rural-urban, mother-child cohort in Tamil Nadu, India. Environ. Res. 161, 524–531.

Balasubramanian, P., Ravindran, T.K.S., 2012. Pro-poor maternity benefit schemes and rural women: findings from Tamil Nadu. Econ. Polit. Wkly. 47 (25), 19–22.

Gould, C.F., Urpelainen, J., 2018. LPG as a clean cooking fuel: adoption, use, and impact in rural India. Energy Policy 122, 395–408.

Gould, C.F., Schlesinger, S., Toasa, A.O., Thurber, M., Waters, W.F., Graham, J.P., Jack, D.W., 2018. Government policy, clean fuel access, and persistent fuel stacking in Ecuador. Energy Sustain. Dev. 46, 111–122.

Health Effects Institute, 2018. State of Global Air 2018. Special Report. MA, Boston.

Indian Oil Corporation Limited indane cooking gas. https://www.iocl.com/Products/Indanegas.aspx, Accessed date: 8 August 2018.

Jeuland, M.A., Bhojvaid, V., Kar, A., Lewis, J.J., Patange, O., Pattanayak, S.K., Ramanathan, N., Rehman, I.H., Soo, J.S.T., Ramanathan, V., 2015. Preferences for improved cook stoves: evidence from rural villages in north India. Energy Econ. 52, 287–298.

Johnson, M.A., Chiang, R.A., 2015. Quantitative guidance for stove usage and performance to achieve health and environmental targets. Environ. Health Perspect. 123 (8), 820–826.

Lewis, J.J., Pattanayak, S.K., 2012. Who adopts improved fuels and cookstoves? A systematic review. Environ. Health Perspect. 120 (5), 637–645.

Ministry of Petroleum and Natural Gas Orders Notifications & amendments related to LPG. http://petroleum.nic.in/marketing/orders-notifications-amendment/lpg-orders-notification-amendments.

Petroleum Planning and Analysis, 2018. Cell LPG Profile - Data on LPG Marketing. New Delhi, India, April 1 2018. .

Petroleum Planning and Analysis Cell Assessment Report - Primary Survey on Household Cooking Fuel Usage and Willingness to Convert to LPG; New Delhi, India.

Piedrahita, R., Kanyomse, E., Coffey, E., Xie, M., Hagar, Y., Alirigia, R., Agyei, F., Wiedinmyer, C., Dickinson, K.L., Oduro, A., Hannigan, M., 2017. Exposures to and origins of carbonaceous PM2.5 in a cookstove intervention in Northern Ghana. Sci. Total Environ. 576, 178–192.

Pillarisetti, A., Vaswani, M., Jack, D., Balakrishnan, K., Bates, M.N., Arora, N.K., Smith, K.R., 2014. Patterns of stove usage after introduction of an advanced cookstove: the long-term application of household sensors. Environ. Sci. Technol. 48 (24), 14525–14533.

Pillarisetti, A., Gill, M., Allen, T., Madhavan, S., Dhongade, A., Ghorpade, M., Roy, S., Balakrishnan, K., Juvekar, S., Smith, K.R., 2018. A low-cost stove use monitor to enable conditional cash transfers. EcoHealth 15 (4), 768–776.

Pollard, S.L., Williams, K.N., O'Brien, C.J., Winiker, A., Puzzolo, E., Kephart, J.L., Fandiño-Del-Rio, M., Tarazona-Meza, C., Grigsby, M.R., Chiang, M., Checkley, W., 2018. An evaluation of the Fondo de Inclusión Social Energético program to promote

access to liquefied petroleum gas in Peru. Energy Sustain. Dev. 46, 82–93.
Press Information Bureau - Government of India - Cabinet Committee on Economic Affairs, 2018. Cabint Approves Enhancement of Target under Pradhan Mantria Ujjwala Yojana.
Puzzolo, E., Pope, D., Stanistreet, D., Rehfuess, E.A., Bruce, N.G., 2016. Clean fuels for resource-poor settings: a systematic review of barriers and enablers to adoption and sustained use. Environ. Res. 146, 218–234.
Raghunathan, K., Chakrabarti, S., Avula, R., Kim, S.S., 2017. Can conditional cash transfers improve the uptake of nutrition interventions and household food security? Evidence from Odisha's Mamata scheme. PLoS One 12 (12), e0188952.
Ruiz-Mercado, I., Canuz, E., Smith, K.R., 2012. Temperature dataloggers as stove use monitors (SUMs): field methods and signal analysis. Biomass Bioenergy 47, 459–468.
Ruiz-Mercado, I., Canuz, E., Walker, J.L., Smith, K.R., 2013. Quantitative metrics of stove adoption using stove use monitors (SUMs). Biomass Bioenergy 57, 136–148.
Siddika, N., Balogun, H.A., Amegah, A.K., Jaakkola, J.J., 2016. Prenatal ambient air pollution exposure and the risk of stillbirth: systematic review and meta-analysis of the empirical evidence. Occup. Environ. Med. 73 (9), 573–581.
Smith, K.R., 2017a. Why both gas and biomass are needed today to address the solid fuel cooking problem in India: a challenge to the biomass stove community. Energy Sustain. Dev. 38, 102–103.
Smith, K.R., 2017b. The Indian LPG Programmes: Globally pioneering initiatives. In: Debroy, B., Malik, A. (Eds.), India @ 70, Modi @ 3.5. Wisdom Tree, New Delhi, India.
Thoday, K., Benjamin, P., Gan, M., Puzzolo, E., 2018. The mega conversion program from kerosene to LPG in Indonesia: lessons learned and recommendations for future clean cooking energy expansion. Energy Sustain. Dev. 46, 71–81.
Tripathi, A., Sagar, A., Smith, K., 2015. Promoting clean and affordable cooking: smarter subsidies for LPG. Econ. Polit. Wkly. L (48), 81–84.