The Value of Community Technology Workers in LPG Adoption: A pilot in Shirati, Tanzania

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Original article

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Posted Date: September 2nd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-69387/v1

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Abstract:
Background: The issue of clean cooking lies at the nexus of environmental engineering, environmental health, pollution, energy access, gender and household dynamics, behavioral sciences and international development. In Tanzania, approximately 96% of the population relies on polluting or "unclean" fuels for cooking. Moving away from firewood and charcoal has proven challenging due to low adoption of clean stoves. Here we investigate the application of community health workers, an existing community engagement model for health systems, to clean cooking adoption. We implemented a pilot study with Community Technology Workers as a means to overcome maintenance, education, and behavioral barriers. We evaluated the training, work, and impact of a CTW on stove adoption on a sample of 30 households over a one-year period. Technically trained local CTWs educated thirty families on the Liquefied Petroleum Gas (LPG) stove and conducted weekly check-in surveys.

Results: The results from the mixed methodology approach show that families initially have very high rates (100%) of adoption, but as the issues of poverty, other obligations, and sickness arise, roughly 70% of families present sustained, regular refilling of LPG cylinders.

Conclusions: The findings imply the feasibility of this type of community infrastructure model to promote and facilitate adoption, but also supports the need to couple this local support with financial mechanisms (e.g. a savings bank). The support from these community trainers paired with these high rates of adoption have large implications for this model's use in rural, poor areas to increase LPG use and adoption.

Key Words: clean cooking, community infrastructure, sustainable development, LPG, Community Technology Worker

Background

Globally, 3 billion people rely on traditional or unimproved fuels such as firewood, charcoal, and other forms of biomass, in order to cook and provide for their families. In Tanzania, 96% of the population [1], rely on polluting or "unclean" fuels, which leads to 20,000 Tanzanian deaths per year attributed to indoor air pollution [1] . The combustion byproducts from unimproved stoves are harmful for human health as particulate matter is retained in the lungs and is linked to respiratory infections, COPD, and lung cancer. Overcoming barriers to clean fuel adoption is critical for helping to prevent these illnesses and untimely deaths.

Research suggests that clean fuel programs should focus on measures that reduce average exposure to below $2000\frac{\mu g}{m^3}$ [2]. The World Health Organization (WHO) established tiers for cooking stoves based on standards for thermal efficiency, CO emissions, Fine PM emissions, safety, and durability. Tier 4 is considered the standard for a truly 'clean' stove, and only the "BLEN" fuels (biofuels, LPG, electricity, and piped natural gas)[3] and firewood pellet stoves[4] meet this criteria. Modeling has also shown that even partial LPG or fossil fuel cooking fuel adoption could prevent 1.3 million deaths annually across sub-Saharan Africa [5]. Research coupling satellite data of particulate matter (less than 2.5μm PM) and infant mortality rates in Africa found that even an increase in 10 $\frac{\mu g}{m^3}$ of PM is associated with a 9% (4-14%) rise in infant mortality, regardless of income [6].

Despite the vital need to even partially reduce emission exposure, moving away from firewood and charcoal is challenging due to low adoption of new technologies and the availability and cost of BLEN stoves. In rural North-East Tanzania, households have the option of firewood, charcoal, gas, or electric. Electric cooking options require either household battery storage, a minigrid [7], or the national grid, neither of which are available to the poor in these rural settings [8]. Additionally, electricity for cooking has also been found to outstrip demand at peak hours. Countries such as South Africa have tried to transition families to LPG from electricity to avoid this issue [9]. LPG is a biproduct of oil and natural gas refining, thus producing a global surplus [3]. The US EPA carried out a life cycle assessment of different cooking fuels in China and India which found that LPG has a lower Global Climate Change Potential than charcoal and lower black carbon emissions than firewood[10]. The UN Sustainable Energy for all Initiative launched the Global LPG Partnership under the premise that LPG was the preferred solution for the next 15-20 years [3].

There is increasing research into the health impacts of LPG while countries globally set targets for LPG. The Household Air Pollution Intervention Network (HAPIN) has trials in India, Guatemala, Peru, and Rwanda which focus directly on the health impacts by providing pregnant women LPG stoves for free and an 18-month supply of LPG (HAPIN) [11]. Members of the Economic Community of West African States and the Central African Economic and Monetary Community, as well as Kenya, Uganda, and Tanzania have all set national LPG expansion targets[3]. In 2015, Tanzania announced a goal to increase the population with access to modern cooking fuels to greater than 75% by 2030 [3].

Despite a wave of many African countries setting goals for increased or exclusive LPG use, LPG programs faced common barriers to adoption of the clean fuel. Previous LPG studies in Ghana, Peru, and India have focused on the barrier of the high initial cost by providing the initial stove for free or free refill vouchers[12] [13] [14], yet still observed low rates of exclusive use or even partial adoption [13, 15]. Kopa Gas in Tanzania offer pay-as-you-go LPG that allows the customer to obtain a gas cylinder, single burner, and a smart meter to address the challenge to purchase the initial cylinder and even the subsequent refills[16]. There is not yet information on adoption rates with Kopa Gas technology. The International Growth Centre conducted a randomized control trial in Tanzania that showed subsidies reduced charcoal use more than access to credit, but still did not reach exclusive use [17]. Kenya is piloting Bottled Gas for a Better Life, which is a microfinance loan program for LPG stoves, which increased consumption of LPG; however, benefiting households still used dirty fuels for 11.2 hours of cooking over 7 cooking events[18]. The low rates of adoption that the field has observed is due to identified barriers such as a the high upfront cost, but also the lack of education/need for household training [3, 4, 9, 12, 15, 19], household safety concerns [3, 8, 19–22], and cultural issues [23, 24].

This work focuses on overcoming these barriers that go beyond economics and affordability of LPG—education on use and safety, maintenance, and social issues. For example, Indonesia has pursued a strong LPG program to end the use of kerosene, which was largely successful. In the initial 500 household market trial, the program noted the need for education on proper LPG handling and use[25]. LPG cylinder explosions occurred daily due to the consumer not using the stove properly[25], and accidents increased annually from 2007-2010. The media coverage of these accidents led households to mistrust LPG and choose unclean fuels[25]. South Africa also pursued a national LPG intervention, which Kimemia and Annegarn found would have been more successful if there was a long-term maintenance plan and safety education. In South Africa, there were only minor non-fatal LPG accidents, but the perception in the community was that LPG was dangerous [9]. An evaluation of the project noted "an apparent need to impart household energy safety knowledge to the local population" [9]. The program in South Africa explained that a maintenance plan for common problems with flame control knobs or the rubber hose would have led to higher rates of adoption as only 11% of the households had used LPG before[9]. The households reported disliking the lack of community education and maintenance within the LPG rollout. Providing this training in the form of cooking demonstrations was found to increase demand for LPG in Sudan[26]. Finally, USAID and the World Bank found that cultural factors such as the preference for food tasting of smoke affected LPG update in Mozambique and Nicaragua [23, 24]. These barriers of lack of education, safety issues, maintenance, and cultural issues are not unique to LPG, but the majority of BLEN interventions [8].

Community involvement has often been suggested as a way to mitigate these barriers. Ronzi and co-authors respectively identified the need for community perspective in LPG adoption and utilized community participatory research to investigate barriers and awareness of LPG [20]. In Peru, Holada even suggested that prominent community members should become early adopters to encourage mass local adoption of LPG [14]. Inyenyeri in Rwanda employed Customer Service Representatives (CSRs) t0 visit the households during the first and fourth weeks after initial adoption of their firewood pellet stove. Jagger and Das found that these in person household visits were very important to adoption and that considerable training for the family was crucial for sustained use [4], yet only 22% of the households' they approached with their finance package (a pay-as-you-go price plan with no initial startup cost and free stove distribution) adopted and continued their contracts with the company[27]. Envirofit delivers LPG in a pay-as-you-go technology and each visit is an opportunity to check stove performance and to help customers, but there has been no investigation of the adoption rates of their customer base [28]. Finally, in Sudan, providing educational training in the form of cooking demonstrations was found to increase demand for LPG [26]. The literature speaks to the viability of community engagement to increase LPG adoption, but also suggests that it is not sufficient at the current levels being pursued.

There is a vital need to overcome these barriers in their entirety to improve health outcomes. Smith and Sagar [29] argue for the reduction in barriers to LPG adoption stating that as a development community, we need to "make the clean available, instead of trying to make the available clean [29]. Smith also acknowledges that making the available clean is still worth pursuing [30] but offers this critique to encourage practitioners and the research community to investigate how to overcome barriers to LPG adoption (or other Tier 4 fuels) for both urban populations and rural households. A common theme in the above literature is the importance of community participation in methods to promote clean cooking. This research hypothesizes based off of this literature that providing increased training, safety information, maintenance support, and local mentors for LPG adoption would be a way of making the "clean available."

Community Technology Workers

In this study, we looked for analogies in other international development fields that overcame barriers in behavior change and need for community transitions. Specifically, this research turned to the literature on Community Health Workers, local workers who link their underserved communities to health systems. Weak health infrastructure [31] combined with the global shortage of 4.3 million health care professionals and the high cost of training doctors and health professionals [32], presented a need for a local worker to fill this health care void. The Community Health Worker (CHW) was implemented at the village level to provide individual care that was both effective, culturally appropriate, and cost effective. The World Health Organization, WHO, defines CHWs as "members of the communities where they work, [who are] selected by the communities, answerable to the communities for their activities, [and are] supported by the health system, but not necessarily a part of the organization, and have shorter training than professional workers" [33]. An in-depth review of eight CHW programs by the WHO found that trained, supervised and supported CHWs [33] can increase health outcomes through maternal and child health services, case management of uncomplicated illnesses, and through education on malaria, Tuberculosis (TB), HIV/AIDS and Noncommunicable Diseases (NCDs) [34].

Tanzania has attempted to expand its national CHW programming and has deployed different types of CHWs who received various training ranging from 5 days to 9 months, depending on their responsibilities [35]. In 2014, a Community Based Health Program was approved by the Tanzanian Ministry of Health, which called for locally trained and selected CHWs that would work on Reproductive, Maternal, Newborn, Child and Adolescent Health (RMNCAH), connect households to facility services, engage in preventive and curative services, and provide disease surveillance[36]. In a typical 8-hour workday, CHWs in Tanzania were found to spend 27.8% of their time traveling house to house, 33.1% on health education, 9.9% on health promotion, 12.3% on direct patient care, and the rest on documentation and supervision [35]. An ethnographic study of CHWs in Morogoro Region, Tanzania found that although initially motivated by altruism, CHWs need transportation, communication devices, and financial incentives to effectively do their jobs [36]. The gender of the CHW also affected how a community member received the CHWs and their services [37] in Tanzania, a very patriarchal society.

Understanding the range of training lengths, responsibilities, and program challenges, but also observing the success of CHWs, this project considered the model for the technology adoption of gas stoves to achieve clean cooking. A pilot study in Rwanda utilized CHWs to inform, encourage, and trouble shoot problems for a cookstove intervention [27]. The health implications of clean cooking lead to the logical extension that CHWs could cover this work as well. However, USAID in their reference guide for program managers and practitioners warns “there is a tendency to add tasks to CHWs as the program progresses, resulting in overworked CHWs, a lack of programmatic focus, and too many functions for a CHW to be effective” [38].

Integrating cooking assistance, or any other technical assistance, into the CHW role could compromise their success in improving the health outcomes that they currently directly address. Therefore, we investigated the creation of another trained worker, a Community Technology Worker, in parallel with Tanzania's Community Health Worker program. This study addresses the feasibility of this worker, the CTW, to provide support for LPG adoption, but ultimately this role could be expanded to more technologies in rural areas. However, within the scope of LPG adoption, we first defined the position and evaluated the economics compared to other models.

Definition of a CTW.

Community Technology Workers provide vital local infrastructure for technology adoption in rural villages. Technology infrastructure is as equally fragmented and weak as the health systems in many developing countries. The role and responsibility of the CTW was built off the duties of a Community Health Worker. The study defines a Community Technology Worker (CTW) as an individual with background knowledge and local expertise who has strong ties to a specific community to which they will be assigned. CTWs assist households to adopt new technology through the following actions. The workers conduct outreach to the households to deliver the technology and navigate the repair of the technology.

The workers provide training for the family in the technology's use and safety measures. They are a constant resource for education about the technology, maintenance, and optimization of welfare acquired from the technology. This expertise consists of, but is not limited to, evaluation of broken technology, understanding the general mechanism of the technology, understanding usual or expected maintenance, and connecting to networks for efficient replacement of parts. The worker report back detailing the households' struggles and successes in LPG adoption. The CTW also holds the household accountable to adopt the technology and provide the individuals the resources to continue the adoption.

Economics of a CTW

In order to evaluate the cost/benefit assessment of the CTWs, we compare LPG/higher tech stoves to other fields such as lighting, improved stoves, and healthcare. All of these fields require social infrastructure to assist participants to have access to the service and ensure high rates of adoption. The CTW model is based on physical visits, which are more costly and logistically intensive compared to other models. M-KOPA is a solar company that targets the poorest by offering a home solar system for 35 USD upfront and then 45 cents a day for a year [39]. The payments are made through a mobile phone, and the sim card can be shut off remotely if the payments are not made [39]. Lighting however is not as culturally entrenched in the communities compared to cooking. There is a larger behavior change associated with the switch of cooking fuel than the switch from kerosene to solar. Without physical visiting, reach and scale are easily and quickly attainable; however, lighting does not have the adoption issues that health and cooking pose. Even companies like Envirofit, who pursue large scale cookstove deployment mostly through IT-based communication [28], admit that "while investing in training resources increases costs, it also increases adoption" [28].

The advantage of this model for cooking over an IT-based solution (i.e. text message education or reminders) is that human workers can respond and adapt to the specific issues of the household and provide helpful advice. Particularly, the behavioral change and social aspects of technology adoption require the in-person visits to overcome these barriers as opposed to telephone conversations or text messages, even if specific focused feedback. A review of programs that promoted mobile phones to improve community health workers' performance never replaced the physical visits but augmented the visits [40]. The success of community health worker programs is rooted in the relationships and trust of the local professional[33, 37]. This taps into the fact that a telephone conversation cannot adequately substitute for an in-person visit, especially when behavior change is necessary. A study in India found that households are more likely to adopt improved stoves if they have had prior exposure to a trusted organization promoting the product [41]. Additionally, these local trainers could also be utilized to solve other community problems, such as water and sanitation technology or mini-grids. Finally, adopting a model resembling the CHWs may allow for "closer integration of health in energy management" [42]. Although physical visiting is time and cost intensive, the CTW model is well suited for reach and scale because the individuals are locally sourced and trusted within the villages. Each village could adjust the model slightly to fit their community dynamics and needs. This role could not be filled by the local retail hardware dealer who sells the stoves and fuel as the in-person visits and hands on education are beyond the scope of their job.

In order to address this array of barriers and test the flexibility of a human centered model, this study, "Pilot of Community Technology Workers in Shirati, Tanzania" investigated whether or not the presence of a locally trained expert, a CTW, checking in on families would be feasible and effective at increasing technology adoption.

Methods and Materials

Study Design

As part of her Senior Capstone, the first author implemented the CTW project in Shirati, Tanzania in May of 2018 through a grant from the University of Notre Dame to both implement this feasibility study and conduct the research on the effect on LPG adoption. Before expanding this model at scale, this work intended to investigate the practicality of the model and scope out possibilities and necessary adaptions for a program at scale. If successful, this pilot could lead to future investigation and longer (2-3 years) research.

CTW Selection & Training

Each village was assigned a CTW, who the local non-profit, ReachShirati, helped identify. ReachShirati runs a local primary school, whose director is well known throughout the community. This director identified two women who were trustworthy, highly respected, interested in community development projects, and available for the entirety of the year-long study. They live in the villages that they represented in the study. One has lived in Shirati her whole life except for her years at university in Dar es Salaam, and the other moved to Shirati with her family roughly a decade ago. No previous technical experience was required as all necessary training could come from the program. We did not insist on female CTWs; however, as gender affected CHW program, it proved to be beneficial as women were more likely to listen to other women on cooking practice, as women are traditionally the main cooks in Tanzanian society. The role of CTW would be a part-time job for the women, who also cared for their households and ran a hair salon respectively. The first author interviewed the proposed CTWs, explained the role, and the work that would be expected. The CTWs were then offered contracts for a year, which outlined their salary and discussed expectations. The local gas company, Mihan Gas Co., sent a regional manager to Shirati to train the CTWs on the LPG stove. Additionally, the first author prepared a safety manual which the CTWs studied and then practiced teaching individuals at ReachShirati how to use the LPG stove, before entering the field to teach the households in the study. We trained the CTWs on data collection and research etiquette. Throughout study, the research team monitored data collection on a weekly basis and held weekly meetings to discuss research findings throughout the study to ensure data quality. We ensured that the two women did not have any relation to the households in the study and no other conflicts of interest. Finally, we stressed that neither they (nor the family) received any benefit for higher rates of adoption.

Data Collection and Analysis

Surveys and Interviews.

We conducted baseline energy surveys, which collected demographic information, the poverty probability index questions, energy consumption data, and gauged household's energy preferences. Figure 1 gives a sample of the survey, which was all translated into Swahili or KiLuo, the tribal language. It also collected demographic information, asked questions about the national grid, generators, etc, and their view/preference for the grid and cooking fuels.

Do you use solar?	If yes, do you have panels or dlights? How many panels/slights do you have?_____panels	How much was each panel/slight? _____Tsh/panel How much was it to install the panels? _____Tsh	What activities do you use solar for? • Lighting Refrigerator • Cooking Radio/TV • Telephone charging Other
Do you use charcoal?	____sacks per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	What activities do you use charcoal for? • Lighting Refrigerator • Cooking Radio/TV • Telephone charging Other
Do you use firewood?	If yes,____loads per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	• How much time do you spend collecting fire wood? ____ hours per • day week month year
Do you use kerosene?	If yes,_____liters per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	

Figure 1. Sample of the initial survey that gauged the family's energy consumption in regard to cooking, lighting, and other appliances.

A full copy of this household energy survey can be found in Appendix A. The CTWs and the first author then conducted initial household visits in which the CTW trained the household on how to use the stove and provided additional safety and maintenance information. A week after this initial visit the CTW returned to check-in with the family and conduct a shorter survey to gauge gas/charcoal/firewood consumption, stove issues, and report any problems or concerns to adopting gas (Appendix B). The CTWs conducted this survey weekly from Mid-June until the end of December, the period of initial adoption. After six months, the first author conducted hour long interviews with all heads of the households regarding the program, their comfort level with the CTW, and the challenges to adopting gas. She also conducted hour long interviews with both CTWs regarding the benefits/drawbacks of the program and their assessment of the feasibility of the project and areas for improvement and adjustment. Finally, the CTWs and the first author held a two-hour long focus group with six of the families from the program to address similar program evaluation.

Based on the recommendations from these preliminary results in the first six months, we were interested in studying why the families were refilling their gas cylinders and discerning how often the CTW needed to visit. Over the course of two and half weeks in January of 2019, we conducted 29 household interviews with the families and the CTWs (Appendix C). All interviews were conducted guided by the grounded theory approach. We followed the open coding method, which allowed for the creation of generative and comparative questions that we could return to the field within further expansion of this work[43]. The results of these interviews led to us adjusting the check-in survey to every two weeks, as opposed to weekly, in the final four months (Appendix D), which we will refer to as subsequent monitoring.

All quantitative data from the surveys were exported from Qualtrics and analyzed in Microsoft Excel. All qualitative data was recorded, transcribed, and then open coded[43] for themes by hand.

Location/Fuel Context

Shirati, Tanzania is a town of ~50,000 on the edge of Lake Victoria near the Kenyan border. Within Shirati, there are sub-villages including Kubwana and Michire. Kubwana is a larger, electrified trading area with the regional hospital, small shops, and unofficial vendors selling vegetables, fruit, and charcoal. Michire is closer to the lake and has a smaller trading post without grid electrification (Some shops have single panel solar). Households can also purchase charcoal at the Michire trading post. LPG can be refilled in Kubwana or a slightly further sub-village, Obwyere, which has the largest trading post in Shirati. Firewood is easily obtainable in Michire, a largely wooded area. Kubwana is more urban and firewood is only collected within individuals' yards. There, women and children have to walk far distances to obtain free firewood.

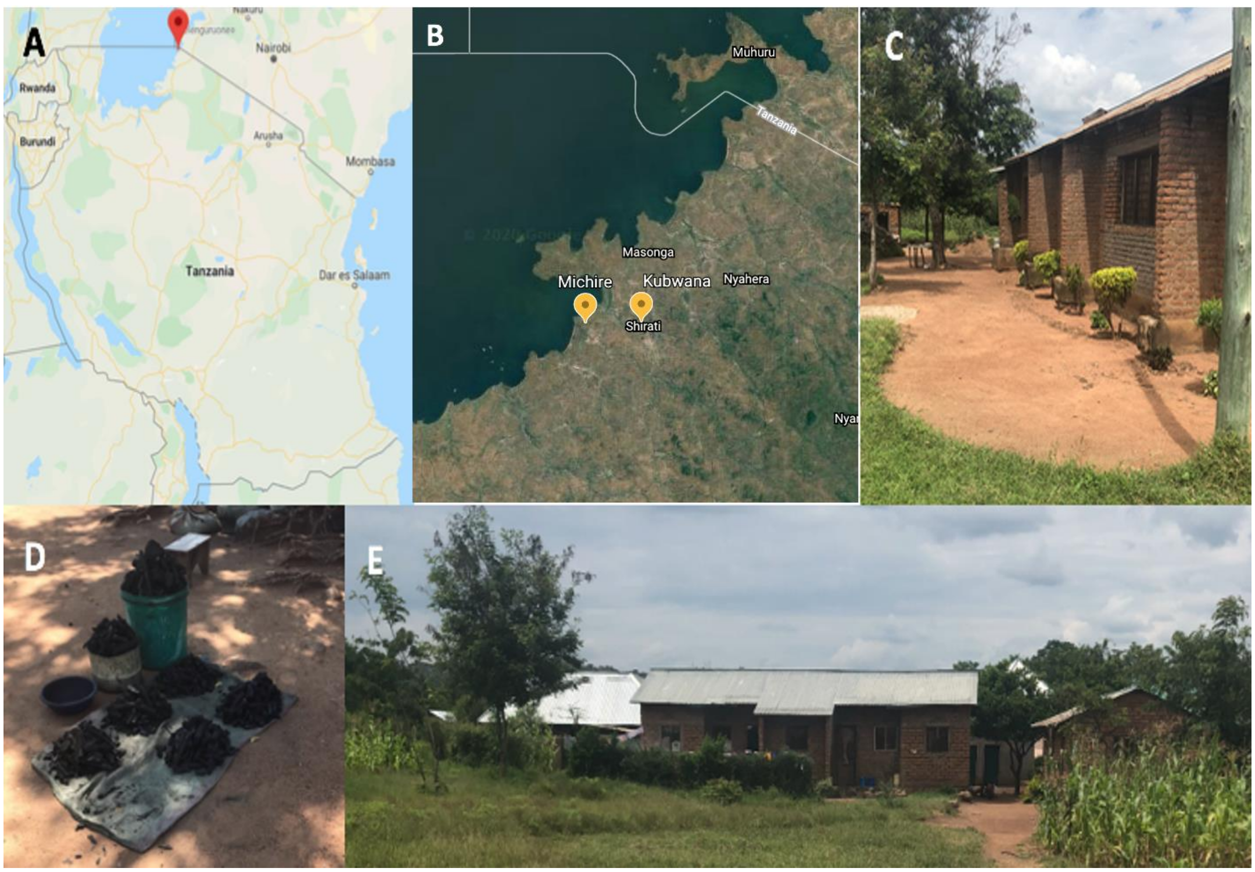


Figure 2. Panel A depicts Shirati within the Country of Tanzania. (B) Panel B identifies the villages of Michire and Kubwana within Shirati and in relation to the Tanzanian and Kenyan border. (C) A typical home in Kubwana. (D) Charcoal for sale at the trading post, which can be found both in Kubwana and Michire. (E) A typical home in Michire.

Household Demographic Results.

Table 1 provides information on household level baseline demographic characteristics and current energy use. It should be noted that no families in the pilot used LPG, Natural Gas, or a generator. Only one household had a main cook who was male. Household size ranged from 1 to 10 with an average of 6. 1. Main cooks ranged in age as well as occupation (Table 1). The age range (Table 1) ensures that the pilot is indicative of both young and old cooks' response to adoption. The occupation of each family proved important as those with businesses reported a higher confidence in refilling due to the steady income. The connection to the main grid (Table 1) alludes to proximity to the main road, overall income and the possibility of electric as a fuel source. Fuel stacking is the practice of using more than one fuel type [44], instead of replacing a type entirely. Thus, it is challenging to gauge how many meals are cooked with gas or with an unclean fuel. If the family is stacking, they may cook the vegetables of a meal with gas, but the ugali—water and cornmeal, which is a staple of Tanzanian cuisine—with firewood. Finally, the majority use both charcoal and firewood (54% in Table 1), suggesting a willingness to diversify fuel source, but also reflects proximity to free fuel within the forests. The method by which each family obtained firewood is important as collecting is a free source of fuel, and therefore the family may not have any budget for cooking fuel. Households struggled to answer how many hours per day and how many days per month they used the national grid. They were unable to estimate the outage frequency and length. They struggled to quantify how much firewood they used, often reporting that they used as much as they could carry on their heads. The only other fuels that two individuals used was agricultural waste called magoonzi and one individual purchased a dollar worth of batteries for a flashlight every 4 days.

Table 1. This table outlines demographic and baseline energy information of the 30 households.

Demographic & Baseline Fuel Information				
Panel A: Demographic	Overall	Kubwana	Michire	
	Mean (s.d.)			Units
Household Size	6.1 (2.2)	6.7 (2.1)	5.3 (2.2)	Individuals
Age	48 (18.72)	43.9 (17.6)	51.4 (19.6)	Years
Female Main Cook	97%	100%	93%	
Occupation				
Cares for Home and Children	23%	13%	27%	
Farmer	47%	53%	40%	
Business	33%	33%	33%	
Marital Status				
Single	17%	20%	13%	
Married	60%	60%	60%	
Divorced	0%	0%	0%	
Widow	23%	20%	27%	
Education Level				
No Education	13%	7%	20%	
Primary	67%	80%	53%	
Secondary	17%	7%	27%	
University	3%	7%	0%	
Panel B: Baseline Energy Usage				
National Grid	23%	20%	27%	
Access to the National Grid	97%	100%	93%	
Wish to Connect to National Grid	100%	100%	100%	
National Grid Affordability	87%	33%	33%	
Willingness to Pay Upfront Cost	73%	87%	60%	
Upfront Cost Suggestion	42.3 (51.1)	27.5 (40.2)	64.6 (74.7)	USD
Cost per Month	5.1 (3.7)	3.8 (3.8)	5.9 (4.3)	USD/month
Solar				
Panels	17%	20%	13%	
Dlights	43%	33%	53%	
Cost per Panel	60.3 (42.8)	73.9 (67.6)	46.7 (67.6)	USD/panel
Installation Fee	76.0 (64.6)	30.4 (0)	121.8 (0)	USD
Cooking Fuel Type				
Firewood Only	33%	13%	53%	
Charcoal Only	13%	20%	7%	
Firewood and Charcoal	54%	67%	40%	
Charcoal				
Sacks per Month	1.6 (2.25)	2.1 (3.0)	1.0 (.9)	Sacks/month

Cost per Day	0.4 (0.24)	0.3(0.2)	0.5 (0.26)	USD/day
Firewood				
Cost per Day	0.53 (0.26)	0.2 (.0.3)	0.08 (0.2)	USD/Day
Hours Collecting Firewood per Day	0.8 (0.60)	0.7 (0.6)	0.8 (0.5)	Hours/Day
Kerosene	23%	40%	7%	
Liters per Day	0.14 (0.11)	0.14 (0.12)	0.165 (0)	Liters/Day
Cost per Day	0.15 (0.07)	0.14 (.07)	0.21 (0)	USD/Day

Results

In the first six months of the study, the CTW visited weekly and recorded if their households consistently had or were using LPG for every meal. This time series data is depicted in Figure 3. After six months, 70% of the households in the study were using LPG for every meal. The families reported the number of meals they usually cooked each day and if they were using gas for each meal. Figure 3 represents the percentage of families using gas for every meal was consistently high. The dips in using gas for every meal occurred in 3 to 4-week cycles because that is when the gas would run out and there would be a few days lag before the family refilled the cylinder. Without a meter, households struggled to know when the cylinder would run out. Over time, the household became able to estimate how long the cylinder would last. Refilling was not always consistent, having a few days gap between refills. In person interviews revealed that the Christmas holiday and New Year’s Holiday set families back economically, leading them to revert back to firewood or charcoal use. Additionally, the majority of households in Michire were relying on businesses and more stable income, which allowed them to consistently refill.

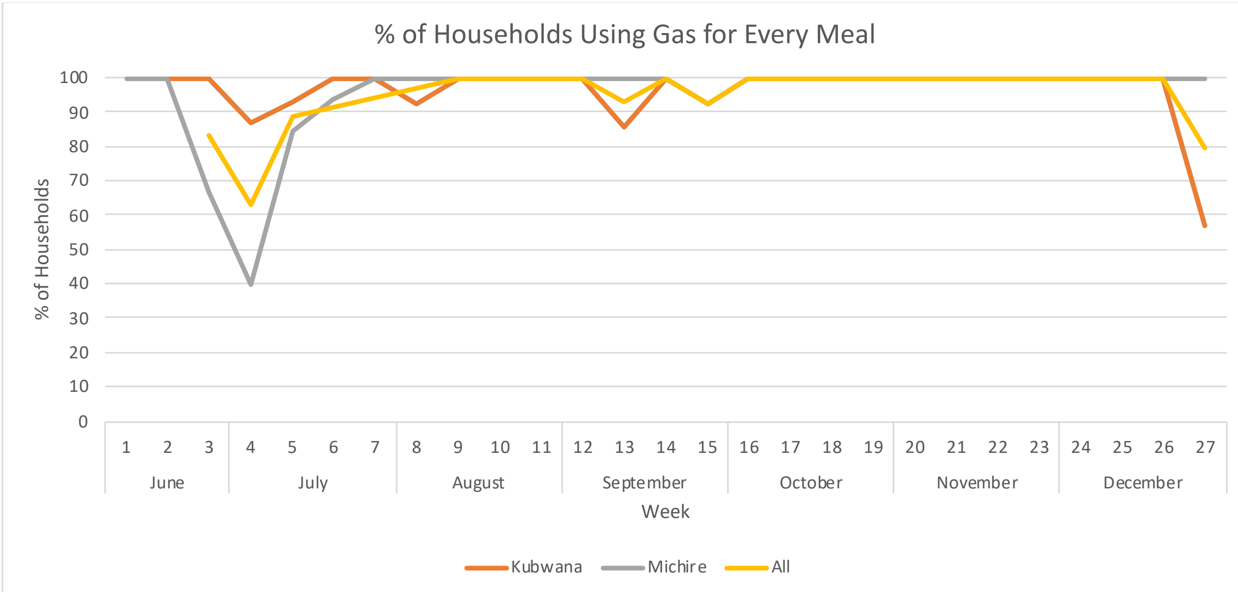


Figure 3. Trends in using gas for every meal. The x-axis is the number of weeks after the receival of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

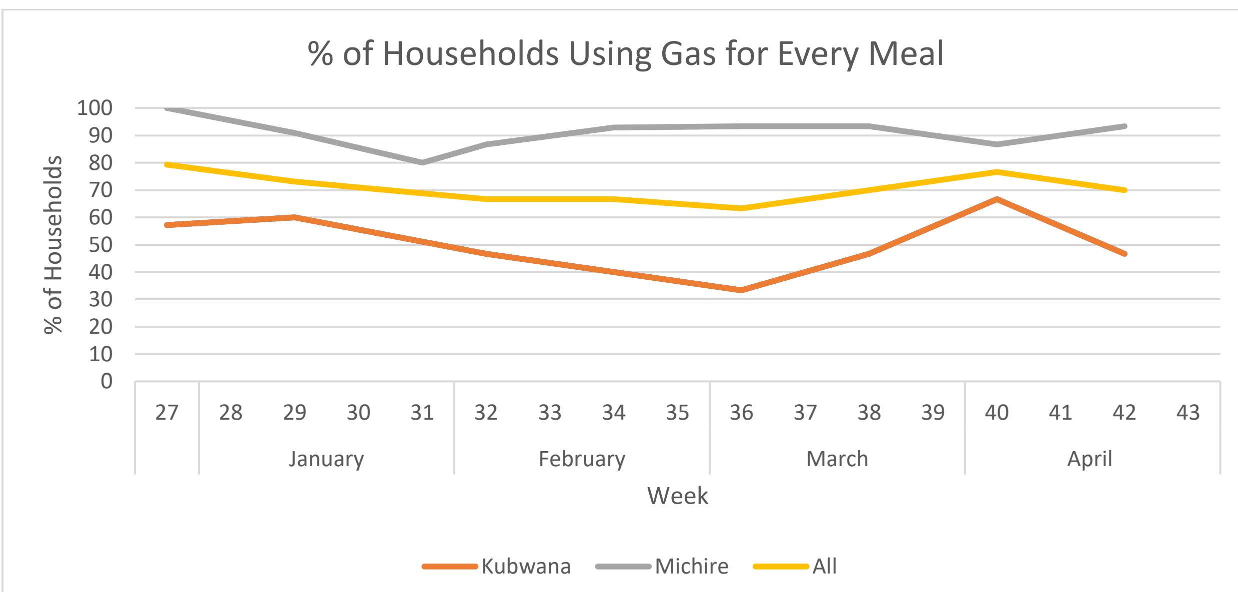
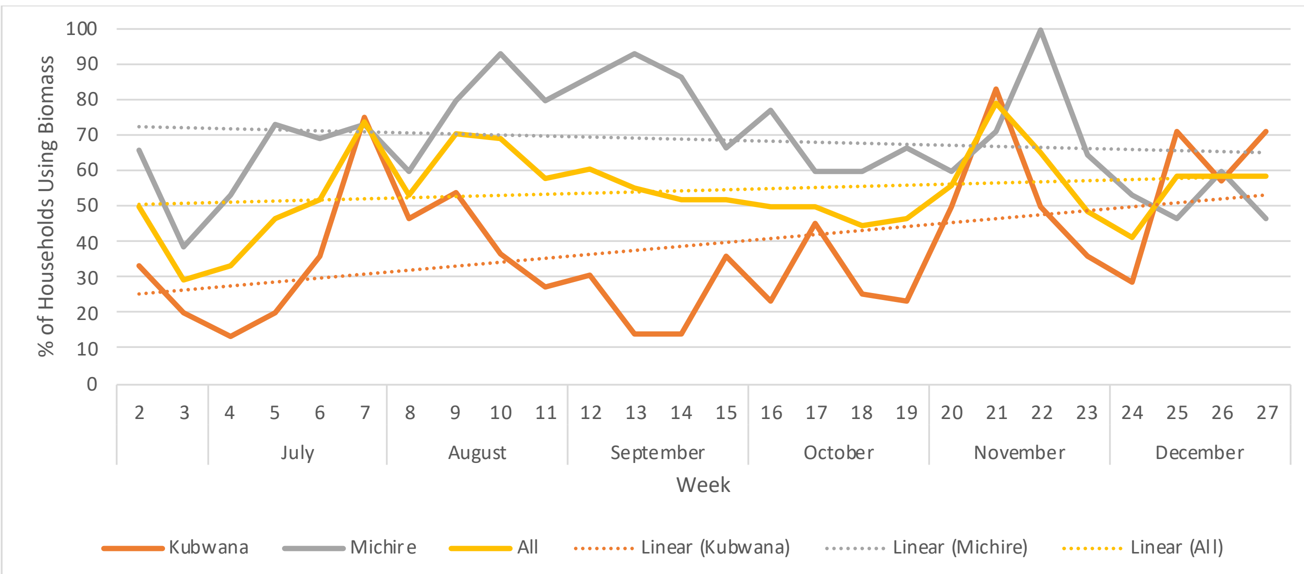


Figure 4. Trends in using gas for every meal. The x-axis is the number of weeks after the receival of the stove and initial household visit, but in the second period of the study; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

In the subsequent refilling period from January to April, Kubwana households using LPG for every meal ranged from 33% to 66%, while Michire ranged from 80 to 100% (Figure 4). Households in Kubwana never recovered from the economic holiday hardship and exhibited lower rates of LPG use at every meal for the remainder of the study. The small sample size allowed us to follow individual households. At the end of a year, 3 households had stopped refilling after 6 months of consistently refilling due to sickness, loss of a parent (who provided the income), and loss of a business. Twenty-four families are consistently refilling the gas stove each month. The other three families are in consistent refillers due to economic setbacks from school fees or slow business but eventually returned to the gas stove. Thus, 90% of families were able to refill most months and 80% every month. However, this fluctuated slightly and both the initial adoption period (first six months) and the subsequent refilling period (last 4 months) ended with 70% of households having used LPG for every meal.

Although families were adopting gas, we tracked families primarily for their continued use of firewood or charcoal (see Figure 5 &6). This fuel stacking fluctuated but ended with 53% in both Michire and Kubwana using unclean fuels by the final week of the pilot (Figure 5). The



village of Michire experienced higher continued biomass use, but consistently refilled their gas, suggesting a partial transition to gas. Kubwana typically had a lower percentage still using biomass in the first six months, with the exception of the final week due to the holidays.

Figure 5. Trends in the continued use of firewood or charcoal after receipt of LPG stove and education from the CTW. The x-axis is the number of weeks after the receipt of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

In the final four months, Kubwana had lower rates of using biomass (Figure 6) and using LPG for every meal (Figure 4), suggesting that households in Kubwana either completely abandoned unclean fuels or were unable to refill the gas stove. By contrast in Michire, a higher percentage of households were using biomass on average, but also using LPG for every meal. By

April, while the two villages had the same percentage of biomass use (53.3%), the context of LPG use reveals that Michire had higher rates of fuel stacking.

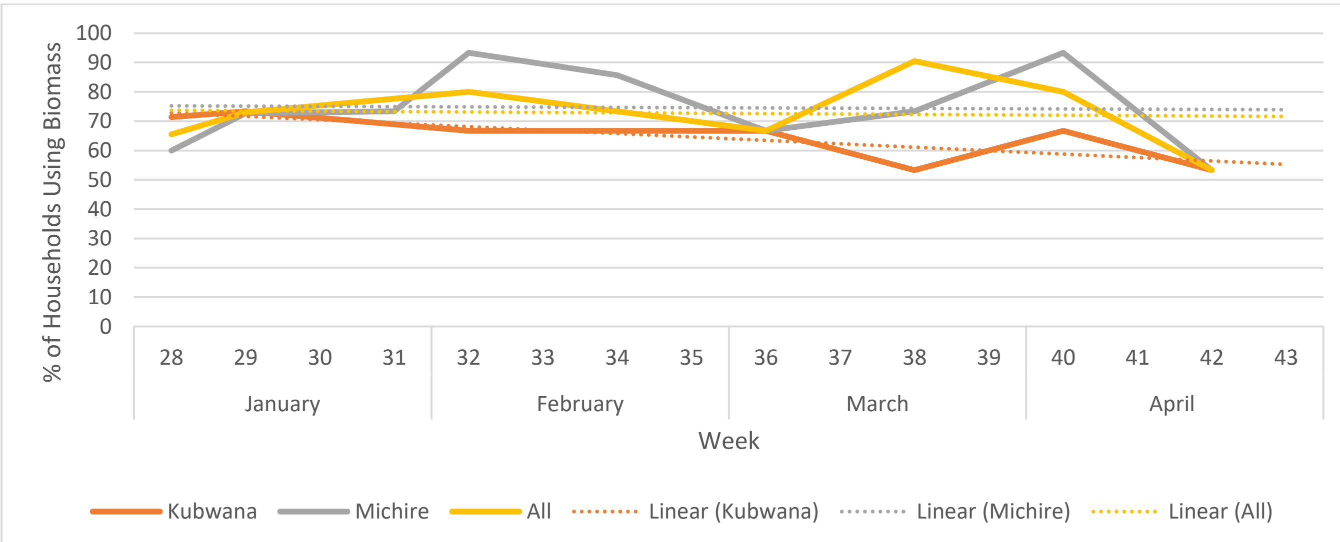


Figure 6. Trends in the continued use of firewood or charcoal after receipt of LPG stove and education from the CTW. The x-axis is the number of weeks after the receipt of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

Figure 7 depicts the percentages of families using LPG exclusively, for 34% or more of their meals, less than 34% of their meals, and not at all during the first six months. Michire had consistently higher rates of partial adoption and consistent fuel stacking. Kubwana had higher rates of exclusive adoption, but also higher rates of complete drop off. This suggests that households in Kubwana either experienced total adoption of gas or a sustained inability to refill, while the households in Michire are balancing their fuels. Throughout the first six months, the majority of households either used LPG for over 34% of meals or exclusively, but over time, use of only biomass rose slightly.

Figure 7. Trends in levels of LPG adoption from exclusive use to only biomass. Panel A represents Kubwana households in Kubwana (n=15); Panel B is Michire households (n=15); Panel C is all study households (n=30). The x-axis is the time since the initial intervention up until December 2018, while the y-axis is the percent of households.

In the final four months of the study, most households in Michire had a trend of consistent LPG use of over 34%, while households in Kubwana were either exclusive users or only relying on biomass (Figure 8). Overall, at the end of the study, 47% of all households were exclusive LPG users, while 23% were using LPG for over 34% of their meals. 7% were using LPG, but for less than 34% and 17% of households were only using biomass (Figure 8 Panel C). It is important to understand the percentage of meals cooked with LPG, as it is not enough to simply have a refilled cylinder to combat the health risks. The higher level of LPG use correlates with decreased exposure to emissions. Any LPG use, even if for a third of meals, lowers the main cook's emission exposure; however, exclusive adoption of clean fuels is the goal.

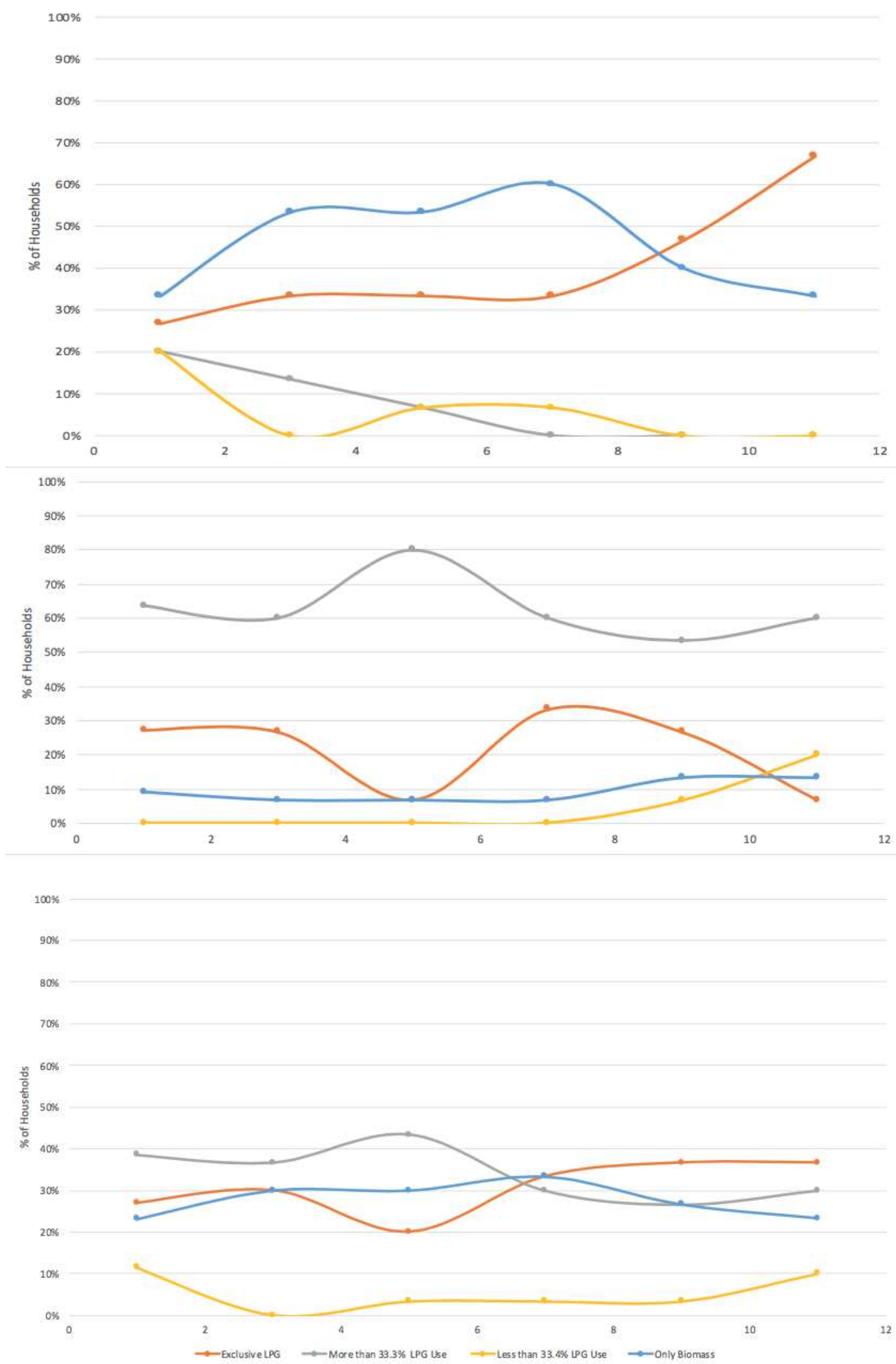


Figure 8. Trends in levels of LPG adoption from exclusive to only biomass. Panel A represents Kubwana households (n=15); Panel B is Michire households (n=15); Panel C is all study households (n=30). The x-axis is the time since the study switched to bi-weekly visits in January 2019, while the y-axis is the percent of households.

Compared to the 1.8 meals a week the evaluation of an improved cookstove program in India [45] found, the 22% adoption rate found by the biomass pellet company, Inyeyeri, the 63.7% partial adoption found in a study in Rwanda in conjunction with water filters [27], and 8% refilling LPG rate found at 18 months in Ghana [13], our study demonstrates high rates of adoption with ~70% using LPG for every meal and 47% exclusive LPG use. Without income data, we are unable to speak to the relative poverty between our sample and the other studies, as income is a factor in the ability to refill. However, as all low-middle income countries, the ~70% LPG adoption rate still stands out in the literature.

To further understand why this study observed higher refilling among the poor, qualitative interviews were conducted with the households. The themes that arose in these interviews are outlined in Table 2. Families noted that they had adjusted to the gas stove and were not refilling to please the CTW, but rather refilling for their own benefit. One woman posed the question, “How can [the CTW] pressure me when the gas helps me not the CTW?” The families discussed how the gas stove eases the work and allows them to finish the cooking faster and continue with other activities. The majority of families claimed that it was their responsibility to refill the cylinder as it was benefiting their family. One family noted that ‘it is my responsibility to refill it even without being monitored because I know how valuable it is.” A few families additionally mentioned that smoke was no longer associated with cooking, but only two discussed health effects of charcoal and firewood.

Table 2. This table lists the themes which arose from the interviews and focus groups.

Theme	Sub- Theme
Challenges	
	Fluctuating Prices
	Heavy Pots
	A Place to Save
Refilling for Themselves	
	Adjusting to Lump Sum
	Health Effects
	No Smoke
	Saving Money
	Responsibility
Visits	
	Friendship
	Reminder to Save
	Privacy
	Timing of Visits
	Types of Questions
	Household Lying Over Phone
Appreciation for Education	
Community with CTW and Program	Trust Associated with Education
Impressed with Gas Stove	
Pride	
Obligation	
Expansion of the Project	

Holistic Role of CTW

In addition to tracking adoption, our research wanted to investigate the role of the CTW in regard to maintenance, education, and behavior change. In post household visit interviews, families stressed the importance of the education that the CTW provided on stove use and safety. However, households rarely had any problems with the stoves. None were reported after five months. When problems were reported, it was usually due to a defective, flimsy burner, which the CTW helped replace. In theory, the household could in fact reach out to the Mihan dealer and purchase another burner; however, the CTW provided a level of convenience and speed to minimize the number of meals cooked with unclean fuels in the interim of getting the new part. On occasion, the CTW would review stove use and safety training again with the household. There were no serious accidents. The CTW was trained to safely check for gas leaks, put out uncontrolled flames on the burner, and protect against improper use accidents by training the households. Additionally, CTWs provided the households confidence in LPG, as compared to previous studies that noted fear of LPG use [9].

The consistent need for sterilized water prohibited full LPG adoption in 25% of all households (35% Kubwana and 15% Michire). The Food and Agricultural Organization's review of firewood and charcoal use in developing countries revealed that a third of all biomass collection is used on heating and boiling water [46]. Masera et al. found that in mixed fuel households 60% of households used LPG for boiling water [44], so LPG could be used instead of water guard, but based on the stated preference of the households, we chose to pursue water guard. Although the CTW's main role was to increase LPG adoption, in parallel, they also play a role to stop all biomass burning. Households did not want to boil water with LPG, as they preferred to use it for cooking, therefore, the CTW educated the households on Water Guard, a purification tablet, to help eliminate biomass burning for water purification. After 10 months, no households in the program were using biomass to boil.

Families appreciated and encouraged the CTW visits to promote education, but mostly to remind them to save for the next cylinder. Households noted the friendship and trust that they had built with the CTWs. Households suggested the use of phone calls for emergency situations, but implied that they may not be honest about their LPG use over the phone. Overall, the role of the CTW was holistic engaging many aspects of household fuel consumption.

Importance of Community

One of the benefits of the CTW program is the close connection with the community and the CTW. Thirteen of 30 interviews expressed an appreciation for education and for the knowledge that we did not foresee as an effect of the program. These families appreciated learning and gaining the education about the gas stove. A woman in Michire said, "There is nothing that has passed me...I have memorized it." Women in Kubwana asked "if there were any more teachings." A woman in Michire offered "I do welcome you anytime if there is anything else that you want to teach me." The CTWs also enjoyed providing education as Michire's CTW said, "My favorite part of my job is teaching families how to use the stove." The CTWs feel a desire to help the community.

Households also alluded to a continued relationship with the CTW in a positive light. Many families wanted to continue and sustain the relationship with the Community Technology Worker. For example, one Kubwanan woman, when asked about CTW visits, said "Come in the morning, afternoon, evening. Wake me up. There is no problem." Another woman in Michire revealed the intimacy of the program and the importance of proximity. When asked if she felt comfortable contacting the CTW, she responded "yes and if she does not answer, I will send a kid to her house."

The focus group reiterated the importance of community between the CTW and the households. For example, one woman from Kubwana said, “we have become friends, we greet each other, you find out what the problem is and you help. If there is a problem, we find a solution.” The CTW model takes advantage of the strength in grassroots solutions

All families suggested the expansion or continuation of the project. They wanted to include other community members and even expand it to other topics such as HIV, orphans, and solar lights. A main cook in Michire said, “This project should not just focus on cooking.” This speaks to the need for community involvement for any project for sustainable change. In Kubwana, one woman suggested “expand the program to bringing electricity,” which indicates that further expanding the project to other forms of technology may be a natural transition. This narrative demonstrates the importance of community in achieving solutions.

Necessary but Insufficient

The barriers to adoption that arose from interviews were the fluctuating LPG prices and an organized mechanism for saving. Households noted that it was hard to save that large of a lump sum compared to spending smaller sums more frequently on biomass, especially when the price changes month to month. If we factor in the opportunity cost of the time and the 0.8 hours a day the households were collecting firewood, gas also becomes a more attractive option as women could use that time for economic activity. However, the pattern of the spending remained a challenge. The survey did not collect any direct household income information, but Tanzania reported in 2015 that the GDP pc was 834 USD (1,918,928 TSH) or 70 USD (159,910 TSH) per month [47]. Fuel is therefore a large part of household expenditure. Refilling the gas stove monthly is 13% of that average monthly income. This is a large percentage of monthly income to accumulate at one time.

Despite these financial hardships, 86.6% of families overall (80% in Kubwana and 93.3% in Michire) reported feeling confident about being able to refill their cylinder. The families did not experience an overbearing economic burden in refilling the stove. The Christmas holiday lead to the lowest levels of confidence at 50% (n=15), 93.3% (n=15), and 73% (n=30) for Kubwana, Michire, and overall respectively.

With the CTWs visits, families in Kubwana saved, on average, from ~ 2- 8 USD (5,000TSH-18000TSH) for the refill, which cost ~9 USD (21,000 TSH). It is interesting to note that the families in Michire claimed they were able to save for the next cylinder, but then revealed that they had no amount saved. The CTW in Michire reported that families were not saving incrementally as the weeks continued, but rather were relying on business incomes or pensions. Michire families seemed to have more stable sources of income and did not need to save money little by little. Therefore, CTW may be more useful as financial advisers in areas without steady flows of income, like Kubwana.

We acknowledge that we are unable to isolate the effect of the CTW. However, these barriers of adoption overlap and cover a range of disciplines, and thus may be best addressed together. Households are financial managers, but also have educational, social, cultural facets that shape their ultimate behavior. This feasibility study suggests that the CTW is helpful in addressing LPG adoption in the context of all the barriers. However, the financial barriers still remain, which implies that the CTW model is necessary, but still insufficient in removing every barrier. Therefore, we will now discuss further areas for research to achieve sufficient support for the households to exclusively adopt LPG.

Discussion

The CTW does not remove all barriers to gas adoption, specifically the economic aspects. Additionally, on the supply side, it stretches the private sector's business models to work with customers who consume small amounts of gas. However, these results suggest that a CTW does mitigate a wide range of barriers through education and maintenance support. These results imply that the CTW program simply should adjust and continually strive for holistic programming to overcome all barriers to LPG adoption.

There are a multitude of opportunities to combine the CTW model with programs to address the economic barriers. A possibility would be to pair the CTW with a savings bank or pay-as-you-go technology. These technologies do not negate the need for the local worker for behavioral, safety, education, and maintenance issues. Bboxx in Rwanda recently launched Bboxx Cook, which combines IoT (Internet of Things) technology to remotely manage financial payments, financial products, and technicians and employees. East African companies such as Envirofit that focus on widespread improved stove deployment are interested in further research into the ability for education and maintenance assistance through cellphone technology [28]. This could potentially prove to be a financially efficient model for the CTW program to provide support and education through text messages; however, in addition to the concerns on honesty over the phone, the households were hesitant to use texts and calls due to the added cost. Despite this, there is a financial incentive for the program implementers to reduce the physical visits.

Even reducing the physical visits to once a month (coupled with a weekly text message), compared to physical visit on a bi-weekly basis could cut CTW costs in half. The program could provide phone credit, an inexpensive alternative to an additional visit. Further research into comparison studies between a physical visiting model and a remote check in system could assist policy makers decide if the financial burden of the CTW salaries was necessary to provide this support for adoption. From interviews, the community and personable aspect of the CTW proved to be very important, but further research is advised. Even companies like Envirofit admit that "while investing in training resources increases costs, it also increases adoption" [28]. Further research could also compare pay-as-you-go technology, which removes the challenge of the lump sum refill, to the CTW model with a savings bank which financially manages the lump sum.

The CTW financial management model does not require that the private sector offer a new product. The private sector has the challenge of supplying a dispersed customer base, while still providing the maintenance, repair, and sales support. The safety of LPG distribution networks is often also a challenge for the private sector; the CTW also provides further confidence that safety issues will not pop up at the household level. The CTW lessens the burden on the private sector, while simultaneously addressing household adoption.

Further research should be pursued regarding the families that shifted towards exclusive use of gas, which is necessary to realize the full health benefits. It will be important to understand why certain families were able to completely abandon biomass. However, even partial adoption is an admirable goal. Steenland et al reviewed the existing LPG literature to create likely particulate matter exposure levels accounting for both exposure and exposure response uncertainty. Partial adoption of LPG results in exposure rates of 70 $\frac{\mu g}{m^3}$ compared to 270 $\frac{\mu g}{m^3}$ from biomass [48]. These ranges were then utilized to model associated LPG health outcomes. Their work found that a transition to LPG (even a partial transition) would result in a 37% decrease in severe childhood pneumonia and a 5-10% decrease in the death rates of women over 50. It would decrease the 32/1000 rate of infant mortality by 4-11 deaths per 1000. Further research comparing self-reported health data as well as spirometry and carbon monoxide monitoring to gauge lung function and particulate matter exposure would add to the credibility of the intervention and weight of the argument for policy change.

There is also an opportunity to study the feasibility of a private-public partnership. A CTW Program could partner with the LPG companies to compromise on a lower price of gas for the families within the program. This local worker program not only acts as advertising for their company, but also promotes the expansion of their markets and distribution networks. Overall, there are a multitude of future research directions that should be pursued to fully understand the possibilities to ensure clean fuel adoption.

Conclusions

These results from the CTW model in Tanzania suggest that this approach would be best pursued in tightknit communities that are reliant on and devoted to traditional modes of cooking, compared to urban areas that may be more open to modern cooking technology. Additionally, this CTW model is most effective in resource scarce areas requiring constant support and reminders to save to refill and change their household financial structure. This model may not be as cost effective in these urban setting where IT-based solutions may suffice, but rural, traditional settings require the intra-community support. This model stresses the need of community empowerment and programming to support community transitions.

Our results encourage a partnership of the CTW model with the private LPG sector or financial institutions to couple the community infrastructure with decreasing the economic hardships. Policy makers should train local workers and address the realities of cash strapped households who do not have formal incomes to purchase LPG. This could include a savings bank or pay-as-you-go on the demand side, or a financial incentive for the private sector to work with these poor customers. Social and economic support are critical to achieving exclusive LPG use.

Based on the discussion of expanding the CTW project, this model may be most cost effective in areas where you could pair the role of this local outreach worker with other rural community needs. As rural communities are being exposed to new technologies, the CTWs could play a wider role in supporting renewable energy technologies as well as other technologies (mobile phones, IT systems, water and waste related technologies). This local worker could also address lighting, water pumps, mini grids, etc. to holistically support rural household energy infrastructure. There is an opportunity for the CTW to play a wider role in energy access, but also development goals in general. Turning back to the literature on Community Health Workers, we recognize the need to support these local workers, with funding, transport, and education, especially as they take on expanding roles in their communities. Community based outreach is invaluable in the effort to provide access and ensure adoption of clean energy for cooking and beyond.

Acknowledgements

We would like to first thank Nayome Aguttu and Mary Frances as without their excellent work and expertise as Community Technology Workers this project would not have been possible. We would also like to thank Fred Chacha, the In-Country Director of ReachShirati for the logistical support throughout my two summers in Shirati and throughout the pilot. We are grateful to each and every household in the pilot that offered their time and opened their families to this research team. We would like to thank Mama Randa for feeding and housing Gill-Wiehl for both summers. We also thank Luke Maillie for his friendship, advice and for connecting us to ReachShirati and the Shirati community. We'd specifically like to acknowledge Holly Rivers, Rachel Thiel, Fr. Bob Dowd, and Professor Ilaria Schnyder vW for their support and guidance at the Kellogg Institute.

Authors' contributions

AGW and SS designed the research and conducted the analysis. AGW and DK developed the discussions and wrote the manuscript.

Funding

This work was supported by the Kellogg Institute for International Studies at the University of Notre Dame under a Summer Research Grant. We gratefully acknowledge support from a NRT training grant from the National Science Foundation Innovation in Food, Energy, Water systems program (NSF-1633740).

Availability of Data & Materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This work was approved under Exempt Research under the University of Notre Dame's IRB Protocol ID:18-02-4425.

Consent for publication

Not Applicable

Competing Interests

The authors declare no competing financial interest.

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Figures

Do you use solar?	If yes, do you have panels or dlights? How many panels/slights do you have?_____panels	How much was each panel/slight? _____Tsh/panel How much was it to install the panels? _____Tsh	What activities do you use solar for? • Lighting Refrigerator • Cooking Radio/TV • Telephone charging Other
Do you use charcoal?	____sacks per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	What activities do you use charcoal for? • Lighting Refrigerator • Cooking Radio/TV • Telephone charging Other
Do you use firewood?	If yes,___loads per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	• How much time do you spend collecting fire wood? ____ hours per • day week month year
Do you use kerosene?	If yes,____liters per • hr week • day month	How much does it cost? ____ Tsh per • hr week • day month	

Figure 1

Sample of the initial survey that gauged the family's energy consumption in regard to cooking, lighting, and other appliances.

Figure 2

Panel A depicts Shirati within the Country of Tanzania. (B) Panel B identifies the villages of Michire and Kubwana within Shirati and in relation to the Tanzanian and Kenyan border. (C) A typical home in Kubwana. (D) Charcoal for sale at the trading post, which can be found both in Kubwana and Michire. (E) A typical home in Michire.

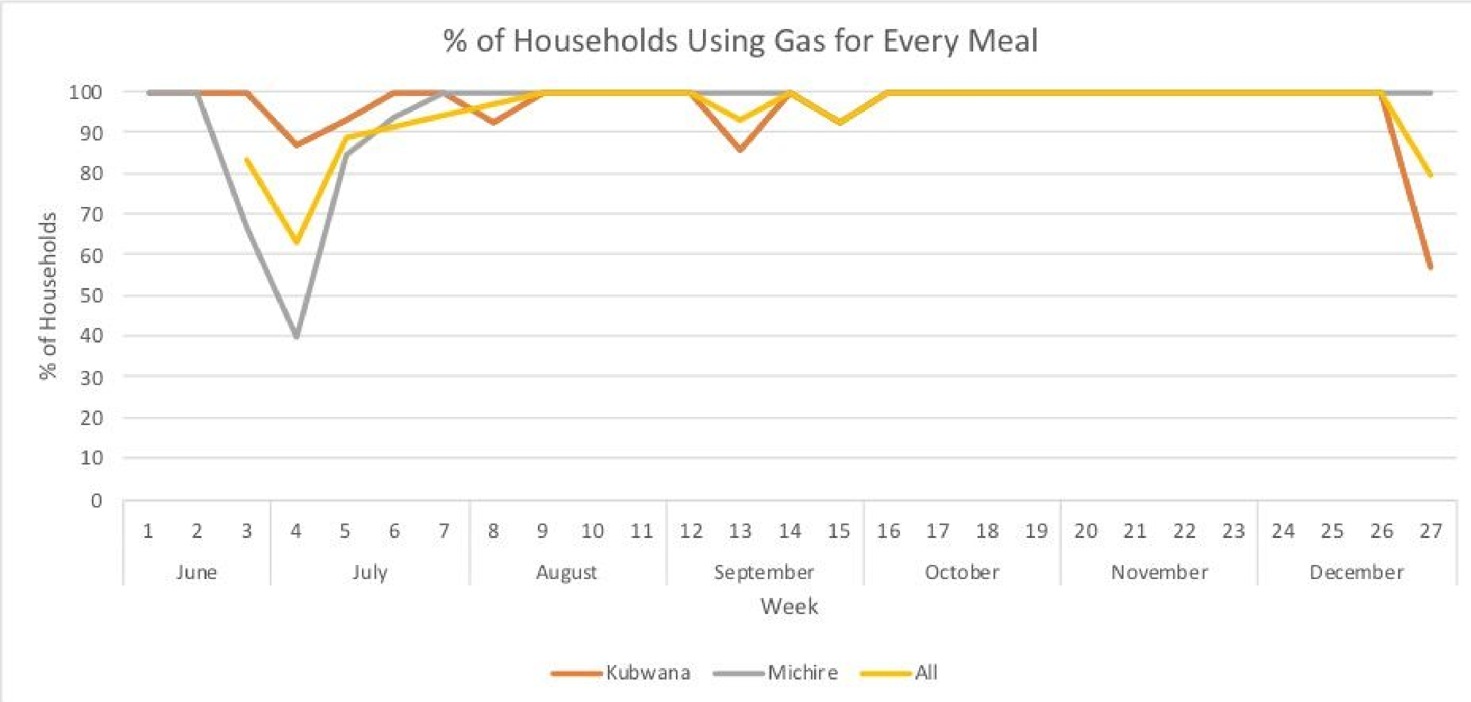

Figure 3

Trends in using gas for every meal. The x-axis is the number of weeks after the receival of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

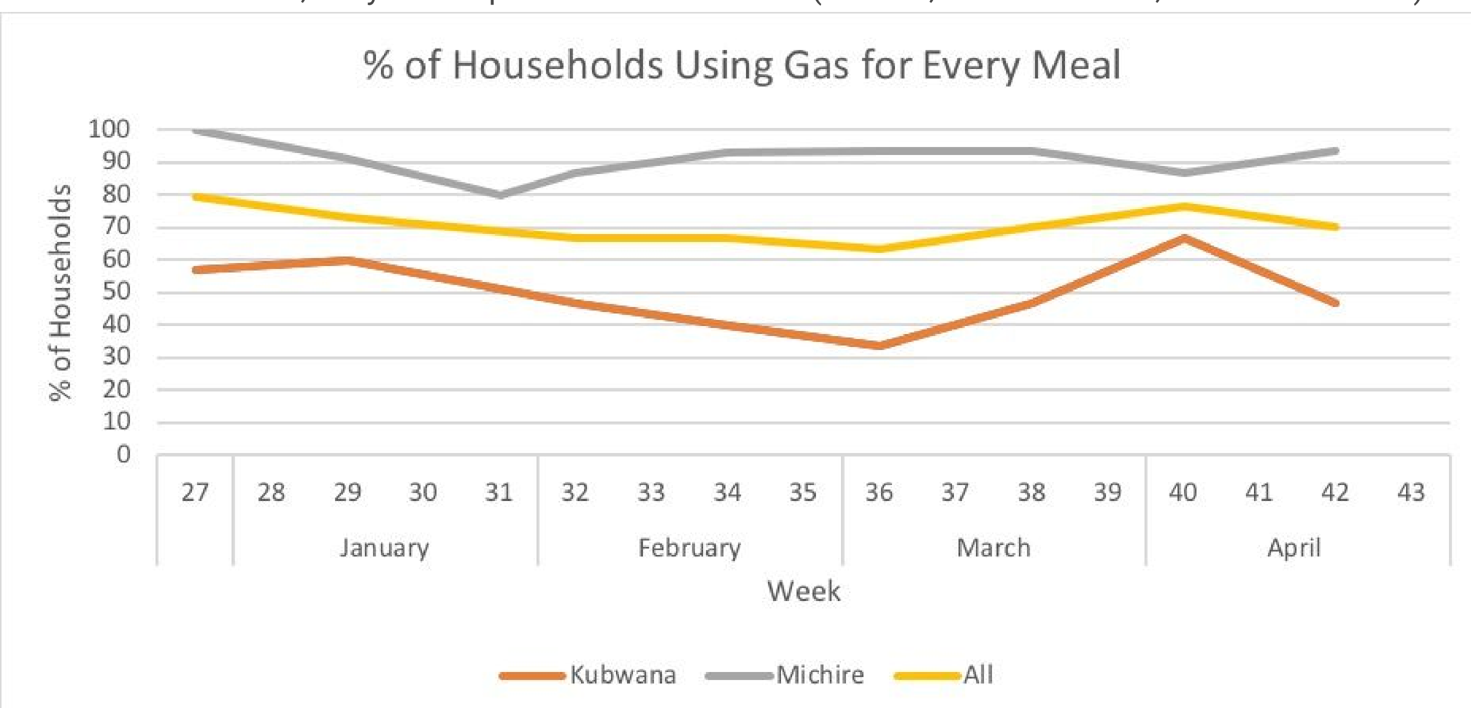

Figure 4

Trends in using gas for every meal. The x-axis is the number of weeks after the receival of the stove and initial household visit, but in the second period of the study; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

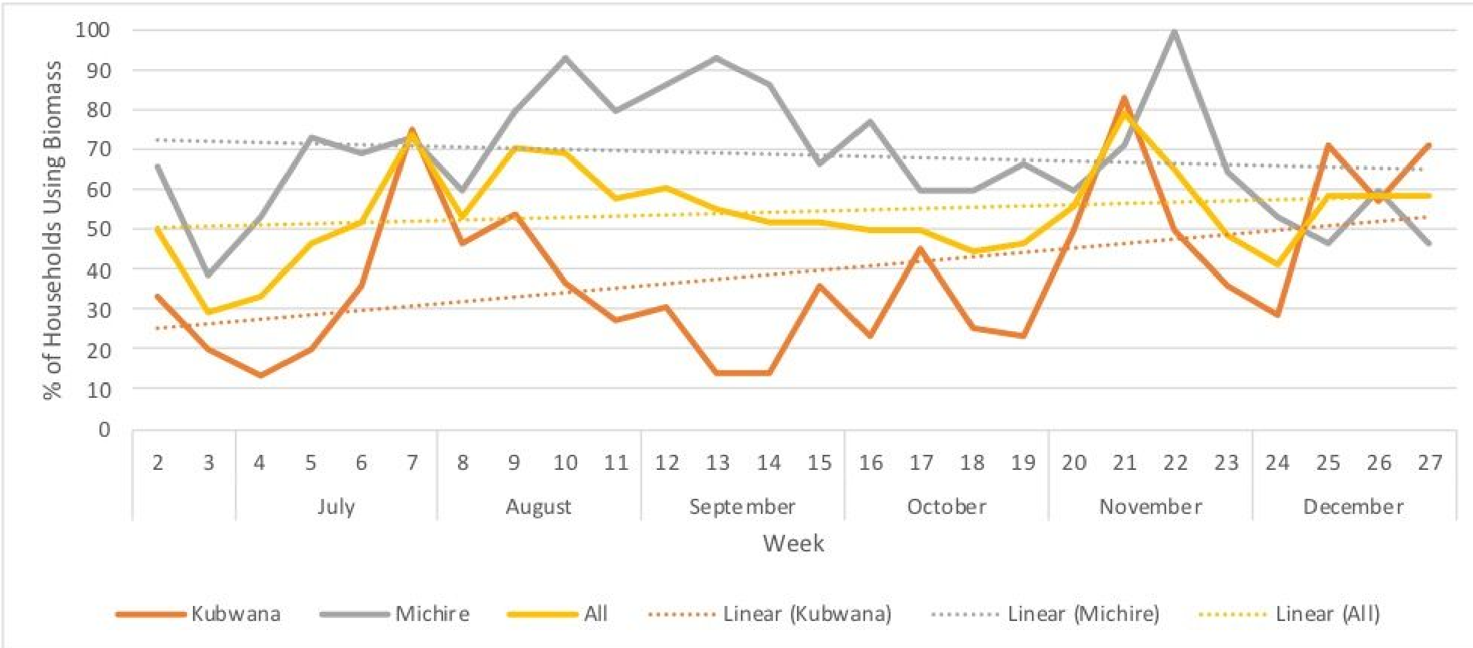

Figure 5

Trends in the continued use of firewood or charcoal after receipt of LPG stove and education from the CTW. The x-axis is the number of weeks after the receipt of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

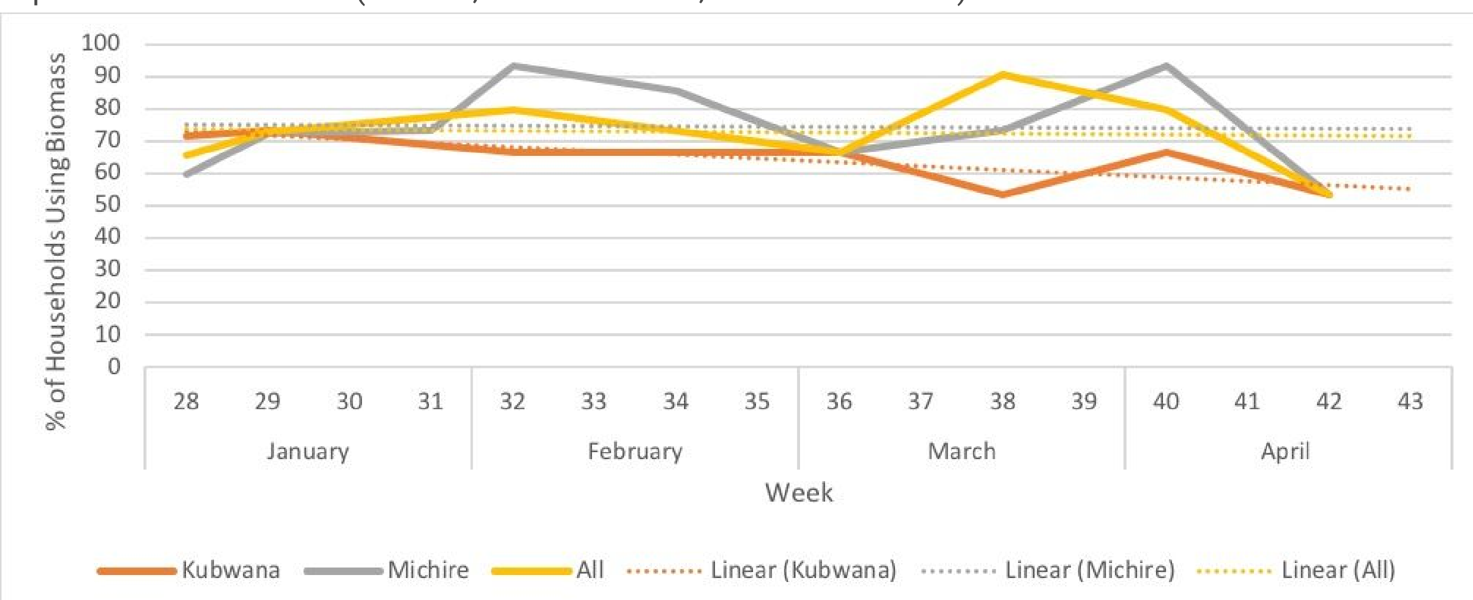

Figure 6

Trends in the continued use of firewood or charcoal after receipt of LPG stove and education from the CTW. The x-axis is the number of weeks after the receipt of the stove and initial household visit; the y-axis is percent of households (30 total, 15 in Kubwana, and 15 in Michire).

Figure 7

Trends in levels of LPG adoption from exclusive use to only biomass. Panel A represents Kubwana households in Kubwana (n=15); Panel B is Michire households (n=15); Panel C is all study households (n=30). The x-axis is the time since the initial intervention up until December 2018, while the y-axis is the percent of households.

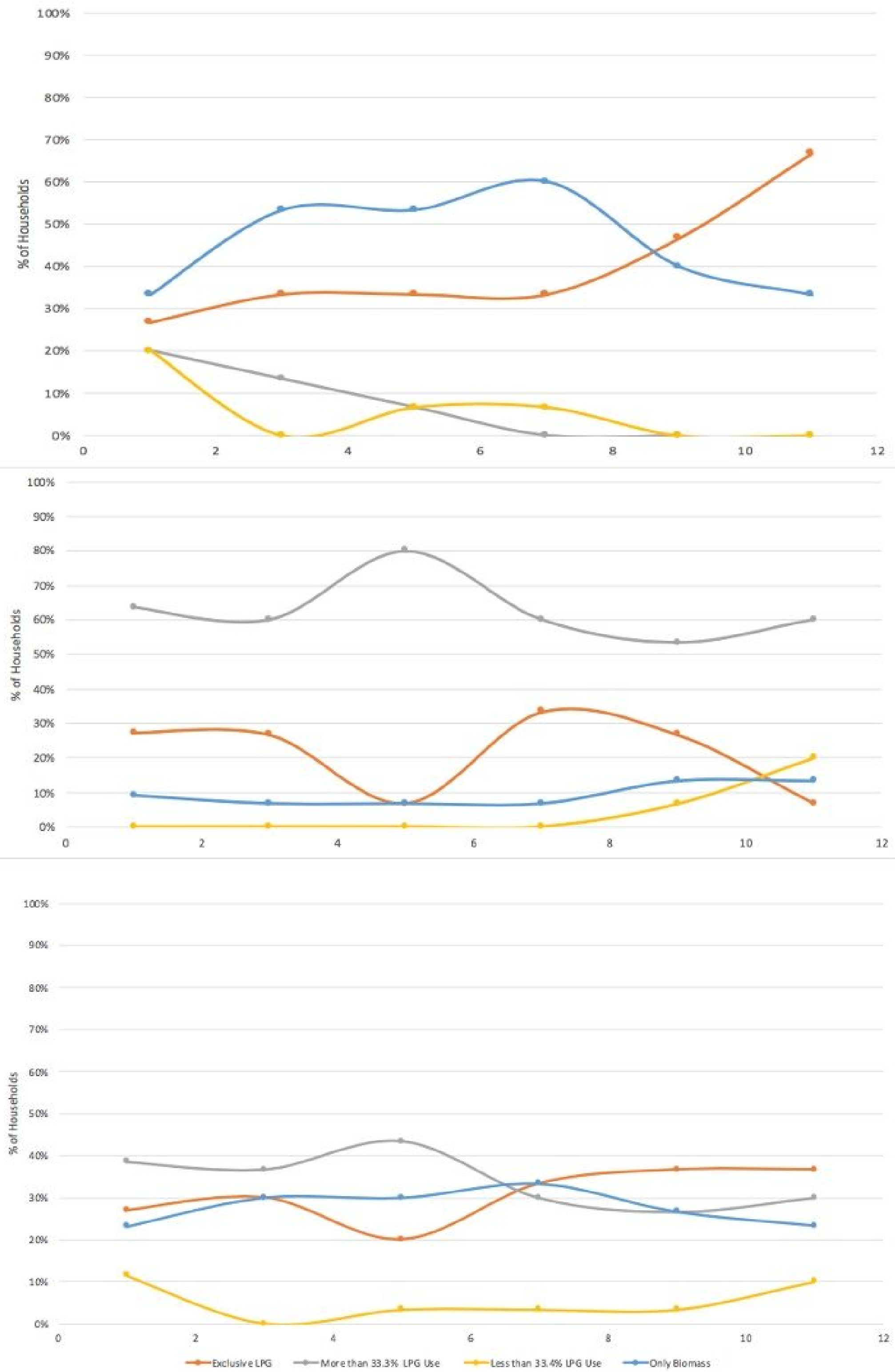

Figure 8

Trends in levels of LPG adoption from exclusive to only biomass. Panel A represents Kubwana households (n=15); Panel B is Michire households (n=15); Panel C is all study households (n=30). The x-axis is the time since the study switched to bi-weekly visits in January 2019, while the y-axis is the percent of households.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- 82020SupplementalMaterialforValueofCTW.docx