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Evaluation of the preference for and viability of clean cookstove adoption in rural Tanzania

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Abstract

Background Sustainable Development Goal (SDG) 7 calls for "universal access to affordable, reliable, modern energy services" for the 2.6 billion individuals lacking access to clean cooking fuels and stoves. Low- and middle-income countries are designing policies towards clean fuels, but often prioritize World Health Organization defined 'clean' fuels and stoves to urban areas. As clean solutions are explored, it remains unclear what rural households prefer as their clean alternative.

Methods This study conducted household energy surveys with main cooks across four villages in Shirati, Tanzania to understand rural household preferences within the viable clean fuels. Data analysis includes descriptive statistics and a generalized linear model with the Poisson family and log link to estimate prevalence ratios, all of which were conducted in Microsoft Excel and STATA 16.1.

Results The results revealed that while 83% of households ($n = 187$) stacked a combination of firewood, charcoal, liquified petroleum gas (LPG), and/or kerosene, 82% [95% Confidence Interval: 74%, 89%] of households stated a preference to use LPG. We found that aggregate expenditure on LPG was less than daily purchases of charcoal and firewood. Our analysis found that all villages had a higher prevalence of stacking firewood, charcoal, and LPG, than areas further from the main trading center. Both areas with trading posts had a lower prevalence of using only firewood.

Conclusions Household preference should be systematically incorporated into clean cooking policy decisions. Our results imply that LPG should not be pursued only in urban contexts. We discuss how preference affect adoption and the need to include user preferences to meet universal clean cooking access (SDG 7).

Keywords Clean cooking, Preferences, LPG, Rural, East Africa

Background

Sustainable Development Goal (SDG) 7 calls for "universal access to affordable, reliable, modern energy services" (pg.1) for the 2.6 billion individuals lacking access to clean cooking fuels and stoves [1]. The provision of clean cooking fuels and technologies has health, climate, and gender implications. Universal access would help prevent up to 2.3 million annual untimely deaths that are attributed to household air pollution (HAP) [2]. HAP leads to lower respiratory infections, ischemic heart disease, stroke, and cancer [3]. Globally, women account for over 60% of all premature deaths from HAP, because they are typically the primary cooks [4]. Finally, domestic biomass

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use for cooking produces ~ 2% of global greenhouse gas emissions [5]

The International Energy Agency (IEA) identified Tanzania as one of the top-20 deficit countries for clean cooking indicators for SDG 7. In Tanzania, over 96% of the population of roughly 51 million people rely on polluting fuels [6]. The Clean Cooking Alliance estimates that biomass burning contributes to 20,000 Tanzanian deaths per year attributed to indoor air pollution [6]. Therefore, transitioning Tanzanian households to clean stoves and fuels is a top priority.

What are the clean options?

The WHO reports progress towards SDG 7 in terms of access to "clean" stoves according to a very specific standard [7]. The WHO definition of a "clean" stove is based on the International Organization for Standardization (ISO) 19867-3 Voluntary performance targets (VPTs) which range from Tiers 1 through 5 after laboratory testing. To be considered "clean" for health, a stove must meet Tier 4 or 5 for the particulate matter ($PM_{2.5}$) category and Tier 5 for the carbon monoxide (CO) category[1] from the ISO VPTs. Solar, electric, biogas, natural gas, LPG, and alcohol fuels (i.e., ethanol), meet the Tier 5 criteria for both $PM_{2.5}$ and CO [7]. Currently, the only improved biomass pellet stove, the Mimi Moto, has met the Tier 4 standard of the World Health Organization's air pollution limits in field conditions [8]. All other pellet, improved firewood or improved charcoal stoves have not met these standards in the field. Throughout, this paper we will explicitly refer to fuels or cookstoves as "clean" only if they meet this Tier 4 standard.

Sustained adoption

Modern fuels, although clean, come with barriers to adoption including affordability (initial stove and recurring fuel costs), unreliable supply, social acceptability, household education levels, household socio-economic and demographic characteristics, and low total perceived benefits [9–11]. Sustained adoption is crucial to maintain the positive effects of reduced exposure to indoor air pollutants. Levels of exposure must be significantly reduced to affect health outcomes [12–14]. However, low adoption rates of clean stoves such as ethanol, biogas, induction stoves can be partially traced back to a misunderstanding of local preference and context [15–17]. Often, designers create environmental technology for efficiency in laboratory conditions, but rarely consider specific consumer needs, leading to lower adoption rates.

Understanding preferences

To achieve sustained use, the literature has begun to recognize the importance of incorporating user preferences and cultural considerations. Researchers reviewing clean cooking in India suggested that engineers make technologies user friendly, but households should also be informed on the social and cultural aspects of the technologies [18]. This finding requires an understanding of what qualities or preferences influence user friendliness [18]. A review of behavior, environment, and health in developing countries found that demand for improved cookstoves was low because of preferences, circumstances, and constraints [19]. Research suggests that "a technology innovation requires a complementary investment from the households, which needs to be sustained over time" [20] (pg. 81). Technology innovation should include forethought into the context and culture. Understanding household preference in cooking is key to a household sustaining use of the technology.

Household preference was initially thought to follow a purely economic trajectory—an energy ladder—that progresses from primitive fuels (firewood, agricultural and animal waste) to transition fuels (charcoal, kerosene, and coal) to advanced fuels (LPG, electric, biofuels). However, the energy ladder has been disproven. Rather with increased income, households diversify their energy options and rarely abandon a fuel type, a concept known as "stove stacking" [21]. Economics, cooking practices, cultural preferences, and health impacts all affect household decisions [21]. To obtain these higher rates of adoption, researchers must ask what factors influence fuel choice and what are user preferences.

Understanding preferences within available options

Policy environments and specific contexts affect which clean fuels are promoted, available, or viable for distribution, and thus the household's ultimate fuel choice. The International Energy Agency's 2021 report "Net Zero by 2050: A Roadmap for the Global Energy Sector" models LPG as the main fuel adopted in urban areas, while improved biomass cookstoves are the main option for rural areas [22]. Numerous low- and middle-income countries have also set clean fuel adoption targets, but often specify separate goals for rural vs. urban communities [23]. For example, Burkina Faso, The Gambia, Niger, and Rwanda all specified LPG adoption targets for urban or peri-urban areas [23]. Rural areas typically have lower LPG targets and improved cookstoves are prioritized. This is not inherently problematic, except that currently only one improved biomass stove meets the WHO's criteria for clean. We must prioritize clean options for both urban and rural populations, although clean fuels such as LPG have been considered less suitable for rural

[1] $<35\ \mu g/m^3$ Particulate Matter (<2.5 microns in width) and $<7\ mg/m^3$ Carbon Monoxide.

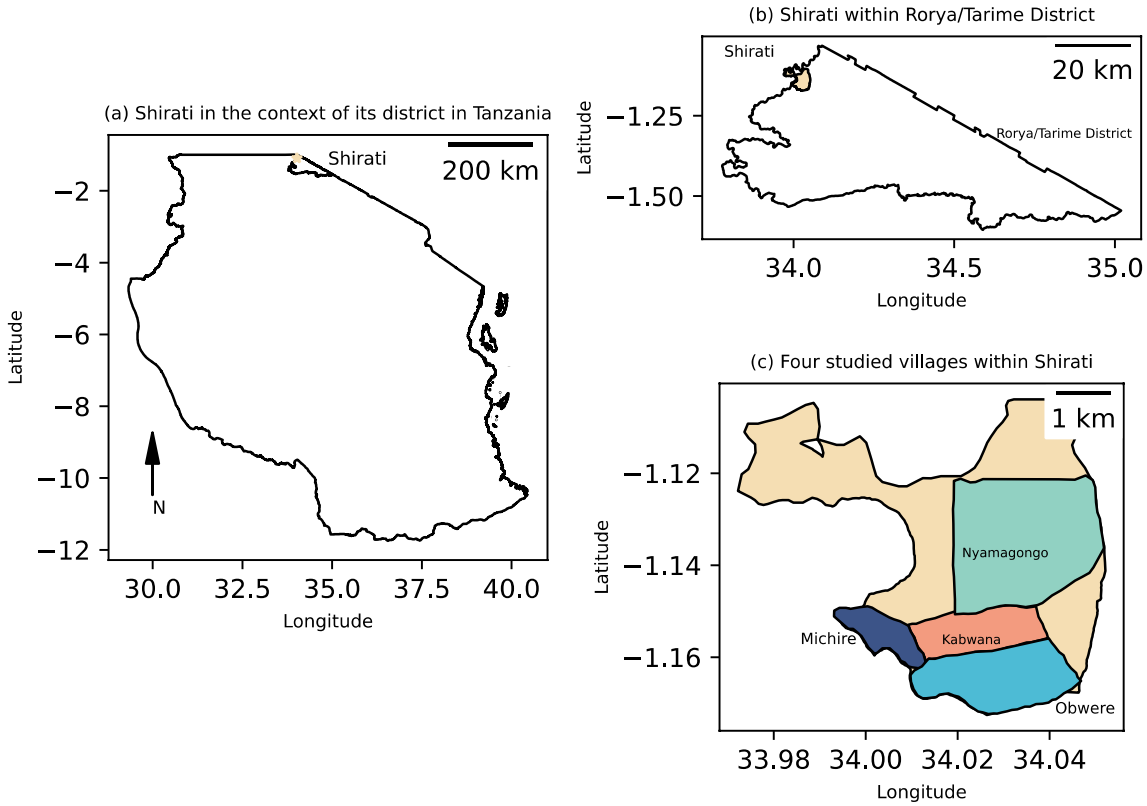

Fig. 1 **a** depicts Shirati within the country of Tanzania. **b** provides the context of Shirati within Rorya (previously Tarime) district. **c** identifies the villages of Michire, Kabwana, Nyamagongo, and Obwere within Shirati

populations. Despite this paradigm, research has found that rural communities can adopt LPG when accessible, available, and affordable [24, 25]. It is also important that policy does not simply prescribe a certain fuel to certain areas without considering preference. This is increasingly important as countries pursue policies banning polluting fuels.

In 2017, Tanzania's Ministry of Energy and Minerals banned exporting firewood and charcoal beyond the region of origin [26]. The Tanzanian government also outlawed the selling of charcoal and was planning within the 2017 financial year to introduce some form of a gas subsidy. However, the policy was poorly enforced and ultimately abandoned [26]. Regardless of policy strategy, to achieve SDG 7, households using firewood and charcoal must be transitioned to cleaner options. It is unclear what rural households favor as their sustainable alternative, given the current market structures in the region. Therefore, the purpose of this study conducted in rural Tanzania was to ask:

1. *Which stoves and fuels are households currently using for their cooking needs?*
2. *Which clean cooking fuel options are available?*
3. *Among the available clean cooking fuel options, which do households prefer?*
4. *Do these preferences differ between different rural settings?*

This paper investigates the stated preferences of households within the available clean options in rural Tanzania to incorporate those preferences into infrastructure and policy to achieve higher rates of clean stove adoption.

Methodology

We conducted the household energy survey in four villages (Nyamagongo ($n=40$), Michire ($n=39$), Kabwana ($n=43$), and Obwere ($n=44$) (see Fig. 1)) within Shirati, Tanzania, a rural town of roughly 50,000 people situated two miles from Lake Victoria and ten miles from the Kenyan border. We also conducted 21 surveys with respondents from various "Other" villages which were within 10 kms of the studied villages and still within Shirati.[2]

[2] We refer to these survey responses as "Other" for their village category.

Study setting

Situated in Northeast Tanzania, all four villages experience distinct dry and rainy seasons (light rains from October to December and heavy rain from March to June) within the tropical climate.

Kabwana is a peri-urban area and hosts the smaller of the two main trading centres in Shirati. Kabwana has roughly fifteen shops, including salons, pharmacies, vegetable stands, and multi-purpose shops selling household necessities. The main grid runs through the main road of Kabwana.

Obwere is the most urban setting with the largest trading centre in Shirati. Women from most of the surrounding villages flock to Obwere on Mondays for market day to buy food, clothing, and miscellaneous items. Sellers travel from Tarime, which is roughly an hour drive away. The main grid also runs along the main road in Obwere.

Nyamagongo is a rural village on the outskirts of Shirati. It is a 10-min drive from Kabwana and 15 min from Obwere by car or motorcycle. There is no major trading post, and most families rely on farming for income. The most common crop grown is corn. Construction of the national electricity grid is in process along the main road through this village.

Michire is a rural fishing village bordering Lake Victoria. There is one trading post with small shacks selling vegetables, sodas, paraffin, and other small supplies. It is a 10-min drive to Kabwana and 15 min to Obwere. Most households rely on farming and fishing for income. The Rural Electrification Agency, REA, is working in conjunction with the national company, TANESCO, to reach houses in Michire along the main road. It should be noted that grid connection prices mentioned for Michire assume that the house is along the main road and does not require any extension.

Survey procedure and data collection

The main focus of the semi-structured survey was to investigate current cooking practices and cooking preference, but baseline energy information was also collected to understand the energy landscape within the village. The survey included questions on the national grid, solar (for both lighting, cooking, etc.), kerosene, and other fuels. Although the study's main objective was not focused on electricity, we attempted to understand what energy options were currently available and in use. As a proxy for income, the survey incorporated the 10 question Progress Out of Poverty Index Survey to construct this index [27] to gauge the socio-economic status of households surveyed. The survey collected socio-demographic information (education level, occupation, religion, etc.). The survey was written in English, and then translated into Swahili by both the first author who speaks Swahili and a local translator to ensure the accuracy and clarity of the survey. The survey questions were finalized after pilot testing with various local individuals whose responses were not included in the official results. All data collection occurred between June and August of 2017. Questionnaires were administered face-to-face by the first author and her translator. Although the majority of questions were quantitative, the instrument did include a few open-ended questions regarding stated cooking preference. Any qualitative commentary throughout the survey was recorded to complement and for us to triangulate with the quantitative results.

We surveyed main cooks who were typically female; however, if the male head of household was culturally expected to be interviewed, the surveyors did not object. We systematically sampled and selected every fourth household, geographically covering each village, aiming for roughly 40 households per village to obtain a sample size of 160. According to the 2012 census, there were ~ 3,500 household throughout the ward, which encompasses numerous "Other" villages. A sample size of at least 160 would ensure for a margin of error of < 10% at a 95% confidence level for the entire ward. The four villages were selected in an effort to compare and contrast rural and more urban settings with different income generating options and economic levels. The surveys conducted with individuals from "Other" villages were based on a convenience sample.

Although not included in the formal analysis, we interviewed key informants throughout the village to inform the interpretation of the core data set and provide additional context. Those interviewed included: four charcoal sellers, the Shirati Hospital medical director, a primary and a secondary school headmaster, two LPG distributors, a representative from the Rural Electrification Agency, and local mechanics that installed solar panels.

Data analysis

All quantitative data from the surveys was exported from Qualtrics and analyzed in Microsoft Excel and STATA 16.1. Descriptive statistics such as cross tabulations and percentages were calculated to evaluate differing average responses between villages. Given our cross-sectional data set, we used a Generalized Linear Model with the Poisson family and log-link to estimate prevalence ratios (PR) to investigate the association between each of our dependent and independent variables [28, 29]. Our outcome variables were binary variables, indicating the fuel combinations that household used for cooking and their fuel/stove preference. We took this approach, because Poisson regression models with robust variance can be more appropriate for binary outcomes than a logistic model, which may overestimate the association

Table 1 Household demographic information

Panel A: demographic	Overall ($N=187$)	Kabwana ($n=43$)	Michire ($n=39$)	Nyamagongo ($n=40$)	Obwere ($n=44$)	Other* ($n=21$)
Household Size (Individuals) Mean (s.d.)	6.3 (3.6)	5.9 (2.6)	5.8 (3.5)	6.5 (3.2)	6.6 (4.8)	7.2 (3.2)
Age (years) Mean (s.d.)	39 (16)	37 (16)	40 (18)	41 (16)	38 (16)	42 (13)
Female-headed Household	30%	40%	21%	25%	27%	38%
Female Main Cook (%)	80%	91%	64%	73%	82%	90%
Occupation (%)						
Cares for Home and Children	17%	21%	26%	15%	16%	0%
Farmer	31%	23%	38%	35%	14%	62%
Business	31%	33%	21%	28%	45%	24%
Other	21%	23%	15%	22%	25%	14%
Marital Status (%)						
Single	12%	23%	8%	10%	11%	4%
Married	65%	54%	72%	68%	68%	64%
Divorced	1%	0%	2%	0%	2%	0%
Widow	20%	21%	18%	15%	18%	33%
Education Level (%)						
No Education	10%	15%	15%	5%	5%	5%
Primary School	62%	51%	62%	63%	61%	86%
Secondary School	21%	28%	15%	20%	27%	5%
University	7%	6%	8%	12%	8%	4%
Progress Out of Poverty Score (Index: 0–100) Mean (s.d.)	50 (13)	57 (12)	48 (13)	43 (13)	53 (13)	45 (12)

All percentages and indices rounded to whole numbers which may lead them to not sum to 100%

*We also conducted 21 surveys with respondents from various "Other" villages which were within 10 kms of the studied villages and still within Shirati. We refer to these survey responses as "Other" for their village category

particularly when the outcome prevalence is low [28, 29]. We controlled for the independent variables of progress out of poverty index (PPI) (as a proxy for income), education level, occupation, marital status, age, household size, and female headed households. Our explanatory variables were the different villages. The base cases for variables included residing in one of the "Other" villages, having received no education, having an occupation in the other category, and having been divorced.

Results

Study area and socio demographic characteristics

Characteristics of the survey respondents are summarized in Table 1. The average household size was 6.3 individuals, while the average respondent was 39 years. We targeted main cooks as our primary respondents as in Tanzania main cooks are typically female. In addition, main cooks were the most knowledgeable regarding the household's energy consumption as cooking is responsible for the majority of the household's survival energy needs. However, we do note the limitation of collecting household level information from individual female respondents. Eighty percent of main cooks (the primary respondent) were female. Most main cooks interviewed were married and had only completed primary education. Most respondents obtained some income from agriculture or business. However, most households pursued farming in addition to their primary occupation as a supplemental income source. The average PPI was 50 across all surveyed respondents.

The socio-demographic characteristics of survey respondents differed slightly by village. Thirty-three percent of households in Kabwana relied on business ventures as their source of income given the proximity to the trading post. At 40%, Kabwana had a slightly higher percentage of female-headed households and was slightly wealthier with a PPI of 57.

In Obwere, 45% of households relied on business from the market for most of their income. Obwere was slightly wealthier with a PPI of 53. Through our qualitative work, we found that there are nine shops, where customers can purchase solar panels and solar lanterns. The solar lanterns were available at most shops that sold drinks, bread, soap, and miscellaneous items. The solar shops sold both branded and generic solar products. Sundar was the most trusted brand in Shirati. Solar sellers either obtained their products from Mwanza or Dar es Salaam, the two largest cities in Tanzania.

Table 2 Any firewood, charcoal, and LPG Use

	Kabwana (n = 43)	Nyamagongo (n = 40)	Michire (n = 39)	Obwere (*n* = 44)	Other (*n* = 21)	Overall (*n* = 187)
	Mean (95% Confidence Interval)					
Charcoal	93% (85%, 100%)	78% (64%, 91%)	90% (81%, 99%)	98% (94%, 100%)	91% (74%,100%)	90% (85%, 94%)
Firewood	67% (53%, 81%)	100%	95% (88%, 100%)	82% (71%, 93%)	100%	87% (82%, 92%)
Gas	40% (25%, 55%)	5% (0%, 12%)	3% (0%, 8%)	11% (2%, 20%)	0%	13% (6%, 19%)

In Nyamagongo, 35% of respondents farmed for most of their income. Nyamagongo had a slightly higher percentage of respondents attending university (12%), but a lower percentage of female-headed households (25%). Nyamagongo had the lowest PPI of 43.

In Michire, 38% of households farmed. Michire had the highest rate of marriage with 72% of respondents. Michire had the lowest percentage of female-headed households (21%) and a slightly lower PPI of 48.

Overall energy landscape

To understand the preferences of the households for cooking, it was crucial that we understood the current energy mix and fuel sources that were available in Shirati. Common themes arose within each village and across villages in relation to the main grid, solar, kerosene, diesel, and other fuels.

Twenty three percent of households were connected to the national grid, TANESCO, and paid ~ 5USD (11,700 TSH) per month through their mobile phones, 50 cents at a time. None of the households used electricity to cook. Ninety seven percent of households wanted to connect to TANESCO, but there was a lack of education on costs, when the construction of poles would begin, and how to get connected. Although the monthly fee was not perceived as expensive, connecting to the grid was cost prohibitive (e.g., having the wires and poles extended to the home). Overall, the interviews revealed that women value electricity for lighting first, followed by radio and television, but not cooking.

Cooking fuels

Most households used firewood and charcoal for their cooking needs, but LPG has a market and some users in Shirati as shown in Table 2. The wealthier, more developed areas of Kabwana and Obwere had lower percentages of firewood and charcoal users and higher percentages of gas users (although they still stacked with firewood and charcoal). Many women cited that firewood was faster than charcoal, so they used it to boil large pots of water for drinking and bathing. They favored the portability of the charcoal stove, while the firewood stove was fixed in the ground. Households in Kabwana and Obwere often rent their homes from wealthy citizens who own the property in town. Families often do not have the option to have a firewood stove, as the owner of the home does not want a "mafiga" or three stone fire on their rental property. Tenants thus turn to charcoal or gas.

No family used solar or kerosene for cooking, only for lighting. Despite its use only for lighting, solar was praised for the lack of smoke associated with kerosene. However, families did not understand the payment plans of solar retailers. Women often asked, "[if] the energy is free, why do we keep having to pay every month?" One family out of 187 utilized diesel for cooking, but only to boil water for chai. Only 5 households mentioned the use of magoonzi (i.e., dried corn husks that women combine with firewood to cook in the traditional stove). The use of magoonzi occurred twice a year around harvest, but only if there was a substantial yield, which there had not been for the last few years. The women preferred charcoal and firewood to the faster burning corn biomass.

Stacking: economics or cultural

The percentage of families that used only firewood or charcoal was approximately 20% in each village. It is important to note that not one household throughout all 187 surveys used only LPG. Figure 2 provides the complete stove stacking breakdown, revealing that 83% of households used some combination of fuels. Using firewood and charcoal was the most popular combination. Even women who had LPG continued to use charcoal and firewood.

While all villages were statistically more likely to use LPG, firewood, and charcoal, Kabwana had the highest prevalence of stacking all three options (PR = 5.0E6[3]) followed by Obwere (PR = 3.2E6), Nyamagongo (PR = 1.9E6), and Michire (PR = 0.6E6) (Table 3). However, only households in Kabwana had a higher prevalence of stacking LPG and charcoal (PR = 1.7E8) compared to the other villages. Households in Michire and Obwere actually had a lower prevalence compared to various "Other" villages of using LPG and charcoal (PR = 0.015 and PR = 0.012, respectively). Households

[3] We only report results at the 1% significance level.

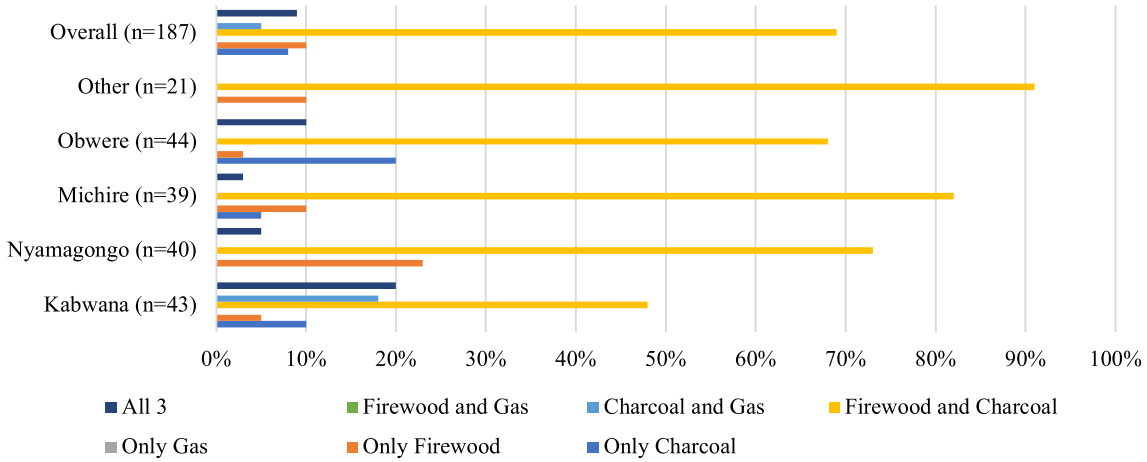

Fig. 2 Current Stove Stacking shows that firewood and charcoal were the most prominent combination. The combination of charcoal and gas was more common in Kabwana, while Nyamagongo had higher percentages of firewood only use. Twenty percent of households in Obwere used only charcoal. Michire and the various "Other" villages had the highest rates of stacking firewood and charcoal. No household only used gas. Overall, the categories of only charcoal, only firewood, and all three (firewood, charcoal, and gas) hovered under 10%

in Nyamagongo and Obwere had only a slightly lower prevalence of stacking firewood and charcoal (PR = 0.87 and PR = 0.79, respectively) compared to various "Other" villages, while households in Kabwana had an even lower prevalence (PR = 0.54). Kabwana, Obwere, and Michire all had a statistically significant higher prevalence of using only Charcoal (PR = 2.5E7, 4.1E7, and 1.5E7, respectively) than the households in the various "Other" villages. Finally, households in Kabwana (PR = 0.41) and Obwere (PR = 0.41) had a lower prevalence of using only firewood than various "Other" villages (Table 3).

The diversification of household cooking options is not purely economic. The respondents stated that they preferred to cook beans, ugali (a traditional dish of corn flour and boiled water), and Maranda (a traditional mixture of corn and beans) on the charcoal stove, because they felt that the gas or electric stove is unable to cook these foods "properly." The respondents complained that unlike charcoal, gas cooks food too quickly. The foods do not taste the same using gas. This is a key insight into consumer preferences. Although gas eases the work of cooking and shortens the time spent cooking, women still want to use unimproved sources, even when they can afford gas. As outlined in Table 4, gas does not cost more than charcoal overall, but the payment timing is different. Households have to buy a 6 kg cylinder for an entire month (21,000 TSH (~9 USD in 2017[4])), which prohibits most families from buying gas over charcoal. Buying firewood is actually the most expensive, but most families balance firewood with charcoal.

The breakdown of families collecting or buying firewood revealed insights into location-specific fuel choice (see Fig. 3). Families in Nyamagongo collected firewood, which is free and thus an easy option for families who have access to brush. Kabwana and Obwere have fewer trees, and, therefore, less firewood use.

Stated preference

With Tanzania's plan at the time to ban firewood and charcoal, respondents were asked what they would prefer to use if charcoal or firewood were no longer options. Gas was overall the preferred option among consumers at 82% [95% Confidence Interval: 74%, 89%] (Table 5).

The "Other" villages that lack as strong of an LPG market had the lowest percentage using gas. The households that chose paraffin either did not know how to use gas, thought it was too expensive upfront, or already owned the paraffin stove. Many respondents laughed at not being able to use firewood or charcoal, and said that they would starve, eat only at the neighbors, or eat only raw food. Although most respondents want to use gas, they see it as far out of reach—despite the fact that in aggregate, it is comparable to their monthly firewood expenditure. Thus, the 82% [95% CI 74%, 89%] preference for LPG must be evaluated understanding that most of the women who chose kerosene over gas, would have preferred gas, but saw the fuel choice as not economically viable and did not know how to use it. The preference for gas percentage may have been higher if LPG would have been perceived as an obtainable alternative. In essence, those who chose kerosene may have ideally chosen LPG. The interviews revealed that most households do not know the cost

[4] As of 2021, this price has increased to 23,000 TSH (~10 USD).

Table 3 Poisson regression model results for cooking fuel stacking combinations

Variables	(1) Firewood, Charcoal, and LPG	(2) Charcoal and LPG	(3) Firewood and Charcoal	(4) Charcoal only	(5) Firewood only
	Prevalence Ratio [95% Confidence Interval]				
Kabwana	4.95e + 06***	1.74e + 08***	0.54***	2.47e + 07***	0.41***
	[513,430–4.77e + 07]	[1.94e + 07–1.56e + 09]	[0.46–0.65]	[1.66e + 06–3.69e + 08]	[0.32–0.53]
Nyamagongo	1.87e + 06***	0.63	0.87***	0.11	1.34*
	[208,452–1.67e + 07]	[0.028–13.9]	[0.82–0.93]	[0.0046–2.82]	[0.95–1.89]
Michire	632,687***	0.015***	0.99	1.48e + 07***	0.86
	[70,395–5.69e + 06]	[0.00066–0.32]	[0.87–1.12]	[1.19e + 06–1.85e + 08]	[0.50–1.48]
Obwere	3.16e + 06***	0.012***	0.79***	4.13e + 07***	0.39***
	[310,410–3.22e + 07]	[0.00055–0.27]	[0.70–0.90]	[4.37e + 06–3.91e + 08]	[0.33–0.47]
Female	2.51*	105***	0.86	0.73	0.40*
	[0.99–6.34]	[105–105]	[0.70–1.05]	[0.37–1.46]	[0.13–1.18]
Female headed	1.56	6.2e–07***	1.26	3.29	5.35e + 06***
	[0.13–18.2]	[6.2e-07–6.2e-07]	[0.81–1.96]	[0.080–135]	[1.04e + 06–2.74e + 07]
Single	938,162***	1,225	0.84	8.45e + 06***	8.2e–07***
	[50,771–1.73e + 07]	[–]	[0.65–1.10]	[432,461–1.65e + 08]	[3.1e-08–0.000022]
Married	7.57e + 06***	0.55***	1.08	1.15e + 07***	0.47
	[983,765–5.83e + 07]	[0.55–0.55]	[0.86–1.35]	[1.03e + 06–1.29e + 08]	[0.049–4.46]
Widow	731,671***	0.011***	1.14	4.74e + 06***	1.9e–07***
	[10,069–5.32e + 07]	[0.0012–0.095]	[0.71–1.82]	[452,402–4.97e + 07]	[1.9e-08–1.8e–06]
Cares for Home	1.40	0.011***	1.06	6.67	1.40
	[0.21–9.11]	[0.011–0.011]	[0.55–2.03]	[0.12–358]	[0.40–4.85]
Farmer	1.43	1.3e–09***	1.11	3.36	0.94
	[0.17–12.2]	[1.5e–10–1.2e-08]	[0.79–1.56]	[0.072–156]	[0.27–3.32]
Business	0.42	0.12***	1.25	15.7**	0***
	[0.029–6.23]	[0.12–0.12]	[0.86–1.81]	[1.53–160]	[0–0]
Household size	1.05	0.65***	1.00	0.71*	1.03
	[0.90–1.22]	[0.65–0.65]	[0.97–1.04]	[0.48–1.04]	[0.83–1.27]
Primary	0.20***	0.054***	1.65***	0.37	1.17
	[0.13–0.30]	[0.054–0.054]	[1.35–2.02]	[0.047–2.93]	[0.65–2.12]
Secondary	0.23***	0.39***	1.63***	0.75	0.95
	[0.13–0.40]	[0.39–0.39]	[1.31–2.03]	[0.021–26.5]	[0.20–4.51]
Proxy for income (POP Score)	1.02	1.12***	1.00	1.02	0.96*
	[0.98–1.07]	[1.12–1.12]	[0.98–1.01]	[0.99–1.04]	[0.91–1.01]
Age	1.00	1.10***	1.00	0.98	1.03
	[0.98–1.02]	[1.10–1.10]	[0.99–1.01]	[0.92–1.06]	[0.97–1.09]
Constant	0***	0***	0.56	0***	0.55
	[0–0]	[0–0]	[0.21–1.48]	[0–0]	[0.0059–51.8]
Observations	183	183	183	183	183

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

of gas but assume that it is expensive. A few respondents said that their friends who used gas had told them it was cheaper. Overall, households lacked information on the prices of different fuels. Several of those interviewed asked the researchers for information on the price of LPG. Other respondents championed LPG claiming that it "eases the work and [they] can go do other business." Many families mentioned the speed and ease of LPG. There was a lack of education on the safety and proper use of gas stoves. Even when women could afford it, they often feared that the gas cylinder would explode.

Table 4 Charcoal, Firewood, and Gas Expenditure (cost per day)

	Kabwana (*n* = 43)	Nyamagongo (*n* = 40)	Michire (*n* = 39)	Obwere (*n* = 44)	Other (*n* = 21)	Overall (*n* = 187)	
Charcoal	1070	673	938	587	666	799	TSH/day
	0.47	0.29	0.41	0.26	0.29	0.35	USD/day
Firewood	932	1514	1491	1093	582	1178	TSH/day
	0.41	0.66	0.65	0.48	0.25	0.51	USD/day
Gas	641	538	289	910	N/A	675	TSH/day
	0.28	0.23	0.13	0.40	N/A	0.29	USD/day

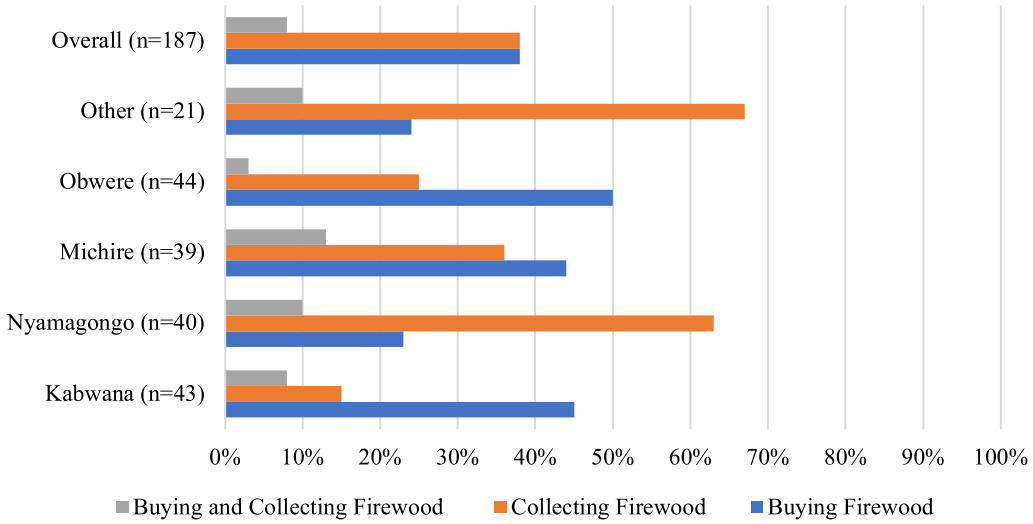

Fig. 3 This figure depicts the percentage of each village for the method that households utilize to obtain firewood

Table 5 Stated preferences for alternatives to firewood or charcoal across villages

	Kabwana (*n* = 20)	Nyamagongo (*n* = 25)	Michire (*n* = 19)	Obwere (*n* = 27)	Other (*n* = 12)	Overall (*n* = 103)
	Mean (95% Confidence Interval					
Gas	100%	84% (69%, 99%)	74% (52%, 95%)	89% (76%, 100%)	42% (9%, 74%)	82% (74%,89%)
Kerosene	0%	0%	0%	0%	33% (2%, 65%)	3.9% (0%,8%)
Electric	0%	0%	16% (0%, 34%)	11% (0%, 24%)	17% (0%, 41%)	8% (2.5%, 13%)
Diesel	0%	0%	0%	0%	0%	0%
Other (i.e., solar)	0%	16% (1%, 31%)	11% (0%, 26%)	0%	8% (0%, 27%)	7% (2%, 12%)

Even if respondents chose a different stove, they often expressed a desire to learn how to use gas as they had heard that it saved time and did not pollute food. In the absence of firewood or charcoal, only 8% of respondents stated a preference for an electric stove. Survey respondents were concerned that given the unreliability of the main grid; an electric stove would fail to provide for their families.

All four villages had a higher prevalence of LPG preference compared to "Other" villages (Table 6). Households in Kabwana had the highest prevalence for LPG preference, followed by Nyamagongo (PR = 2.1[5]), Obwere (PR = 2.0), and Michire (PR = 1.9). Living in Kabwana, Obwere, Michire, and Nyamagongo were the only

[5] We only report results significant at the 1% level.

Table 6 Prevalence ratios from our investigation into cooking fuel preference

Variables	(1) Preference for LPG Stove	(2) Preference for Electric Stove	(3) Preference for Other Stove (i.e., solar, ethanol, etc.)
	Prevalence Ratio [95% Confidence Interval]		
Kabwana	2.33***	9.6e-09***	3.1e-10***
	[2.08–2.60]	[9.4e-10–9.8e−08]	[0–4.8e−08]
Nyamagongo	2.06***	7.6e-09***	1.13
	[1.87–2.26]	[3.6e-10–1.6e−07]	[0.20–6.36]
Michire	1.89***	0.79	0.022*
	[1.64–2.18]	[0.58–1.09]	[0.00040–1.18]
Obwere	2.00***	0.78	4.2e-08***
	[1.69–2.38]	[0.096–6.41]	[2.6e-09–6.8e−07]
Female main cook	0.99	0.59	0.40
	[0.78–1.26]	[0.20–1.74]	[0.085–1.85]
Female headed	1.36	1.6e-08***	0***
	[0.81–2.30]	[1.5e-10–1.6e-06]	[0–1.2e−08]
Single	1.15	4.8e-09***	0.30
	[0.48–2.73]	[0–0.000062]	[0.056–1.66]
Married	1.43	0.048**	0.0032***
	[0.79–2.60]	[0.0037–0.63]	[0.000067–0.15]
Widow	1.01	3.68e + 07***	0.87
	[0.50–2.07]	[1.65e + 06–8.20e + 08]	[0.00045–1703]
Cares for the home	0.95	6.8e-08***	3.69
	[0.83–1.08]	[0–0.0010]	[0.54–25.2]
Farmer	0.93	0.85	16.0***
	[0.71–1.22]	[0.017–43.4]	[3.12–82.1]
Business	0.95	2.06	1.3e-09***
	[0.66–1.38]	[0.085–50.0]	[0–0.000069]
Household size	1.01	0.87	0.79
	[0.98–1.03]	[0.53–1.45]	[0.26–2.43]
Primary	1.14	0.64	0.17*
	[0.85–1.53]	[0.15–2.71]	[0.020–1.36]
Secondary	1.02	1.28	0.054*
	[0.56–1.83]	[0.0075–219]	[0.0027–1.06]
Proxy for income (POP Score)	1.00	0.96	0.91*
	[1.00–1.01]	[0.82–1.12]	[0.83–1.00]
Age	1.00	0.99	0.81***
	[0.99–1.01]	[0.93–1.06]	[0.71–0.92]
Constant	0.22***	49.6	5.38e + 07**
	[0.073–0.64]	[0.000029–8.57e + 07]	[13.3–2.17e + 14]
Observations	102	102	102

***$p < 0.01$, **$p < 0.05$, *$p < 0.1$

variables that were statistically significantly correlated with stated preference for LPG; however, it is interesting that these prevalence ratios were similar regardless of urban, rural, or peri-urban setting. Households from Kabwana and Nyamagongo had a lower prevalence for an electric stove preference compared to the "Other" villages (PR = 9.6E-9 and PR = 7.6E-9, respectively). The main grid is not present in Nyamagongo which could explain this result, while households in Kabwana, who have greater access to the grid, know its unreliability. Households in Kabwana and Obwere have a lower preference for another stove type, such as solar oven or ethanol

stove (PR = 3.1E-10 and PR = 4.2E-8, respectively). This could be related to the fact that LPG and electric have increased visibility in these two villages as the main grid runs through the main road and LPG is sold at the respective trading posts.

Discussion

The aim of this study was to evaluate household cooking fuel choices, available cooking fuel options, household preferences among the available options, and differences between rural settings. We conducted a household energy survey primarily within four villages in rural Tanzania, specifically focusing on cooking fuel use and preference. The study showed that while the majority of households stacked firewood and charcoal, LPG was preferred. Wooded villages, without trading posts had higher rates of firewood collection. Our analysis found that all villages had a higher prevalence of stacking firewood, charcoal, and LPG, while rural areas with and without trading posts had statistically both higher and lower prevalence of LPG and charcoal stacking. Both areas with trading posts had a lower prevalence of using only firewood. We found that all four villages had a higher prevalence of LPG than "Other" villages further from the rural trading center in Shirati. We next interpret our results and propose incorporating household cooking fuel preference into policy.

Visibility and affordability

The village comparison revealed that villages with trading posts were more likely to use LPG and charcoal, rather than firewood. However, a preference for LPG was prominent in every surveyed village. Rural villages with trading posts are the most equipped to adopt LPG; however, even the most rural village covered preferred LPG, but lacked the supply chain. During the surveys, the respondents from "Other" villages explained that they did not perceive LPG to be a viable option, and thus chose another fuel.

In addition, we found that the cost per day for LPG was equal or less than that of polluting fuels. Yet, households still perceived LPG as too expensive given the payment in bulk. Policy makers need to educate rural households on the affordability of different fuels and promote LPG as an affordable option. A review of affordability in clean cooking argues for affordability metrics that reflect nuances in household spending patterns to make information on prices and affordability of clean cooking stoves and fuels more meaningful to households [30]. With additional information, households could act on their stated preference.

LPG vs. electric cooking

Our results show a strong preference for LPG over electric due to the unreliable national grid. The national grid is unreliable and mini grids are subject to common unrestricted access, overloading, and brown outs [31]. However, there is promising new research into electricity for cooking both on the national grid [32, 33] and mini grids [31, 34]. Efforts towards electric cooking still prioritize wealthier households who already have access to the grid [32] or promote it in settings with high rates of electrification from either on or off grid sources [33, 34].

Beyond reliability, LPG has an advantage over electricity as the market is already in Shirati and will not require families who live further from the main road to purchase poles to have the national grid reach their homes. Even in rural locations, where there is no LPG distribution line, LPG access is arguably easier to extend than the national grid. The visible presence of LPG cylinders[6] in Shirati, compared to electric stoves could, however, affect households' stated preference. Further research must be conducted to evaluate preference in rural settings in which both are equally present. Finding development solutions that combine the preferences of households and the health and progress outcomes that development professionals want is key for progress for both parties. Specifically, in clean cooking, the health component is often not the priority of the rural household, but rather the priority of the public health community [35]. Solutions must prioritize the preferences of the household in the pursuit to improve their health and the climate. Based on these results and understanding, LPG may have a pathway for rural, low-income households [36].

Preference in relation to adoption

Stated preference for a specific fuel or stove type does not necessarily imply the subsequent adoption or continued use of that fuel. However, literature from the region suggests that stated preference may reflect true future behavior. A study of households in Eastern Tanzanian had a higher uptake (48%) of improved cook stoves (ICS) when households were presented with multiple ICS options. This suggests that preference and autonomy in choice of ICS are correlated with higher adoption [37]. A study in Western Tanzania found that cookstove users had a higher willingness to pay for their preferred stove option [38]. Beyond cookstoves, but still within the realm of household technology adoption in Tanzania, a study of willingness to pay and user preference in household water treatment and safe storage options in 556 rural

[6] Both single/double burner stoves connected by pipe to a 12 kg cylinder are available. However, the most prevalent LPG stove in Shirati is a burner that screws into the top of the 6 kg cylinder.

households argues that "preferences are an important indicator of what might be adopted and regularly used" [39] (pg. 68–69). This is in-line with other findings in the water literature [39]. These Tanzanian examples imply that preference is a crucial component to willingness to pay and future adoption.

Outside of Tanzania, a discrete choice experiment in India on cookstove adoption found that uninterested households were in fact less likely to purchase and use an improved stove a year later. Households who showed an initial preference for a new stove were more likely to have purchased it a year later. Stated preference did track with adoption [40]. These examples from both Tanzania and India within and outside of the cookstove literature suggest that preference is related to future purchase, adoption, and use. Thus, an 82% preference for LPG is meaningful in our evaluation for potential clean cooking programs for rural communities.

Incorporating preferences

This paper evaluates fuel choice preference, without ruling out LPG or electric stoves in rural areas. As noted in "Praise of Petroleum?", "there are questionable assumptions behind the premise that fossil fuels are unsustainable for the rural poor" [41] (pg. 1847). Our results specifically address the assumption that LPG cannot be sustainable or suitable for rural marginalized communities. This is not to suggest that LPG is the best solution in all contexts, but rather, programs should consider household preference and not immediately exclude LPG for the rural populations.

Local input is a key component, allowing context specifics to drive fuel choice, rather than sweeping claims for certain fuels in certain environments. Clean cooking studies across the world have begun to acknowledge the need to consider user preference [42–46]; however, this trend must continue and not exclude preference for clean options for rural settings.

Beyond prioritizing local voices in the fight for clean cooking, the incorporation of stated preferences in programs should also be attractive for the public health community as this stated preference may correlate with higher rates of adoption of truly clean stoves, which is a key component of health improvement. From a public health perspective, there is a large movement to change household behavior around polluting fuels; however, this is difficult even when the behavior is economically inefficient or harmful to the individual's health. This is precisely why the inclusion of stated preference and local input must be included before pursuing a clean cooking program. More attention needs to be given to household preference within the Tier 4 clean options and considering LPG as an option not just for urban settings, but also for rural populations.

Often, even when pursuing clean options for the rural areas, solutions are selected based on technical criteria or the perceived preferred option (improved biomass) [39]. Mbungu and Kammen argue that "technological stand-alone approaches are often ignorant of the complexity of energy access challenges, especially the individual and contextual factors that limit their acceptance and effectiveness, especially in poor and marginalized communities" [47] (pg.1). It is exactly those individual and contextual factors that this research investigates to improve clean cooking initiatives.

Conclusions

Overall, this paper investigates (1) the current stoves and fuels that households rely on in rural Tanzania, (2) the clean options available, (3) among those clean options, which do households prefer, and (4) how those preferences differ by village setting. We find that the majority of households stack firewood and charcoal, and electric and LPG are the only currently available clean fuel options. Within our sample, 82% [95% CI 74%, 89%] of households would prefer to use LPG, and all four villages studied have a higher prevalence of LPG preference than villages further from the rural center. Our findings challenge the paradigm that LPG should not be pursued in rural contexts. To achieve SDG 7, we must identify and provide access to clean cooking options; however, we must broadly evaluate households and not make deterministic, purely economic evaluations. Further work must be done to scale truly clean fuels for rural populations while meeting user preferences.

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Author contributions

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

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Availability of data and materials

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

Declarations

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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