The Role of Social Capital in Improved Cookstove Adoption in Lusaka, Zambia

by

Shannon Lloyd

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Associate Professor Pamela Jagger
Professor Arun Agrawal

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Abstract
This study explores the role of social capital in adoption of improved cookstoves in Lusaka, Zambia. Improved cookstoves provide positive health benefits particularly for women and children under five, as well as other benefits including requiring less fuel, reducing greenhouse gas emissions from cooking, and improving overall well-being. Despite being relatively well off in the African context, Zambia has low rates of improved or clean cookstove adoption. We use data from a multi-year impact evaluation study undertaken by the Energy Poverty PIRE in Southern Africa (EPPSA) research team and collaborators. We use data collected during baseline and rapid surveys to understand the role of social capital in adoption of improved cookstoves and fuels marketed by two private sector firms, VITALITE and SupaMoto, who are marketing products to households in high density, low-income neighborhoods in Lusaka. Our study includes a sample of 350 households in two neighborhoods where stoves have already been adopted, and 467 households in two neighborhoods where marketing took place after our baseline data collection. In the latter group, 45% of households adopted stoves after the initial wave of marketing providing us with a total sample of 503 adopters and 343 non-adopters. Based on the results from this study, we found that no singular way we operationalized social capital had an impact on a population level. The two that had the largest impact were if a household agreed to at least one Trust question (if they have faith in most people or can rely on someone do complete a task for them) then likelihood of adoption increases and if a household agree to at least one Community question (if they participate in community decision making or feel part of the community) then likelihood of adoption decreases. This is pertinent specifically for the prospective user population. Other key variables include owning your home and having a female headed household, both of which increase likelihood of adoption. These results have important implications for the two cookstove firms because VITALITE and SupaMoto could use what was found in these results to adapt to the strong parts of their marketing base. This could be spaces that are primarily women occupied, for example, women's savings and credit groups.

Introduction

Clean and improved cookstoves have the opportunity to improve several parts of a population's health and well-being. According to the International Energy Agency (IEA), only 17% of the Sub-Saharan population had access to clean cooking technologies in 2018. Zambia's population is representative of this, with also only 17% having access to clean cooking technologies, meaning that approximately 15 million people in Zambia are reliant on traditional biomass fuel for cooking all meals (IEA 2019). Reliance on biomass fuels for cooking has implications for human health, climate change, conservation of forest resources, and the general well-being of people who rely on biomass fuels.

Household air pollution (HAP) occurs when biomass fuels are used with traditional stoves with low combustion efficiency. When biomass fuels (wood fuel, charcoal, dung, agricultural waste, etc.) are burned, they emit harmful pollutants including CO2 and PM2.5. HAP exposure disproportionally effects women and children under five who are breathing in pollutants leading to negative health outcomes including lower respiratory infection (IEA 2017). According to the Institute for Health Metrics and Evaluation, lower respiratory infection was the number four leading cause of death for all ages globally in 2019, household air pollution was number nine (IHME 2019). In Zambia, lower respiratory infection was the number four leading cause of death for all ages, and air pollution was the number three contributor to death and disability combined in 2019 (Murray et al. 2019).

At a household level, improved cookstoves (ICS) aim to reduce HAP and fuel consumption by burning fuel more efficiently or by burning cleaner fuel. Traditional cooking in much of Africa still includes burning wood fuel on a traditional (e.g., three stone) fires. This type of cooking and fuel do not fulling combust, so the cook and others in the household are breathing in dangerous particles that lead to many health problems. It is also dangerous because cooks can burn themselves easily on open flames. ICS look to move up the energy ladder from primitive fuels (wood fuel, agricultural waste, animal waste), to transition fuels (charcoal, kerosene, coal), to advanced fuels (liquified petroleum gas (LPG), electricity, biofuels) (van der Kroon et al. 2013). However, even with moving up from primitive to transitional fuels, there is still a risk for health and safety from toxic fumes, fire hazards, and burn related injuries (Kimenia et al. 2014; Kimenia & Van Niekerk 2017; Mills 2016; Pailman et al. 2018).

Biomass fuels have negative effects on the environment. This includes the production of greenhouse gas emissions both when burned at the end of the lifecycle and because of deforestation, land degradation at the beginning of the lifecycle. Deforestation in Zambia impacts urban areas as well as rural. According to Global Forest Watch, in the urban area of Lusaka, Zambia, from 2001 to 2019, 171 hectares (ha) of tree cover has been lost, which is equal to 26.8 kiloton (kt) of CO2 emissions. This same area has a total carbon storage of 1.89 million metric tons (Mt), with most being stored in the soil (Global Forest Watch n.d.). When above ground vegetation is removed, this leaves the soil exposed to erosion and other forces which further degrade the environment. Nationally, between 2001 to 2019, 1.71 Mha of tree cover was lost, equal to 467 Mt of CO2 emissions (Global Forest Watch n.d.). This deforestation and land degradation, coupled with the emission from traditional forms of cooking contribute to regional climate change (Campbell-Lendrum and Prüss-Ustün 2019).

As for impacts on general wellbeing for those who rely on biomass fuels, analyses done by the World Health Organization (WHO) found that reliance on these fuels resulted in significant time loss and drudgery for children, especially girls (WHO 2016). As previously discussed, women and children under 5 are disproportionately affected in terms of health risk from HAP, and this extends to the amount of time lost for children and girls as well. In addition to this, in the same

report, the WHO concluded that in order to improve the health of urban populations, pollution from household fuel burning needs to be addressed. This shows the significance of research conducted on household energy usage and transitions in urban contexts.

According to Cecelski (2004), "Women/gender and energy has emerged as one of the critical pathways for linking energy interventions to the Millennium Development Goals [MDGs]." While the MDGs have been replaced by the Sustainable Development Goals (SDGs), the same premise still holds true. This body of work looks to connect SDGs Three – Good Health and Well-Being, Five – Gender Equality, and Seven – Affordable and Clean Energy through the same premise of women/gender and energy. One hypothesis Cecelski (2004) offers to be explored in future work is looking at gender as a necessary variable in household energy and household air pollution, which is also a key part of this thesis, specifically in household cooking technology.

Building on this, and the current state of the literature which has often studied clean energy as a driver of women's empowerment, what has historically not been studied is women's empowerment as a driver of clean energy. Because women and children under five are bearing the brunt of the negative health impacts associated with more primitive fuels, by empowering women you can begin to overcome this disparity. This body of work will look at women's empowerment as a driver of clean energy, specifically women's social capital, and what kind of effect this has on ICS adoption and interdependence of social capital variables within the study population.

This study addresses the question: 'How does social capital influence improved cookstove adoption among low-income populations in Lusaka, Zambia?' We test the hypothesis that with greater social capital are more likely to adopt improved cookstoves than households who have more limited social capital.

To test this hypothesis, we use data from the baseline and first rapid assessment survey of a quasi-experimental impact evaluation study designed to evaluate the impact of adoption of improved cookstoves marketed by two private sector firms in Lusaka, Zambia. VITALITE markets the EcoZoom stove, and improved charcoal stove. SupaMoto sells the micro-gasification stove, the Mimimoto, which uses on biomass pellets, also sold by the firm.

Literature Review

Drivers of Clean and Improved Cookstove Adoption

It has been well documented and accepted that improved cookstoves (ICS) have three main benefits: reducing HAP which negatively impacts health, preserving forests and ecosystems, and reducing climate emissions (Bailis and Wang 2015; Bielecki and Wingenbach 2014; Jan 2012; Jeuland and Pattanayak 2012; Kar and Zerriffi 2018; Kumar and Igdalsky 2019; Lewis and Pattanayak 2012; among others). However, what is lesser acknowledged in the literature is the impact on gender equality (Vulturius and Wanjiru 2017). Women are generally the main cook of the household, often accompanied by young children, so they bear the greatest health burden from cooking with biomass.

In a case study from Himachal Pradesh, India, where biomass covers 70% of the household fuel needs, it was found that girls under age five and women in the 30-60 age group have a higher proportion of respiratory symptoms than males in the same age categories (Parikh 2011). This is noteworthy, because this is the age range, generally, of primary household cooks and the

ages of children who accompany them. In addition to this, it has been documented that women exposed to HAP are three times more likely to have chronic obstructive pulmonary diseases (COPD) than women who cook with cleaner fuels like electricity or gas (Malla 2009; Naeher et al. 2001; Parikh 2011). In an analysis for the same region (Himachal Pradesh, India), it was found that fuelwood was the most common fuel because of "availability, lack of alternatives, and lack of infrastructure" (Jagadish and Dwivedi 2018).

In addition to health benefits, ICS also have environmental benefits. In Sub-Saharan Africa annually, more than 300 million tons (Mt) of wood is consumed for the production and use of solid fuels for cooking (Lambe et al. 2015; Rysankova et al. 2014). This is causing mass deforestation and biodiversity loss from clear cutting, an incredibly unsustainable practice. ICS seek to alleviate this problem by both decreasing the amount of fuel households need as well as shifting people away from biomass fuel towards cleaner forms of energy. Of that 300 Mts of wood, 130-180 Mt is for charcoal production (Lambe et al. 2015).

These benefits act as drivers for clean energy adoption.

However, even though it is well documented the benefits of ICS, they are idealistic. To receive the intended benefits, the cook in the household must use the stove consistently, but what is realistically taking place, according to the literature, is known as cookstove or energy stacking (also referred to as fuel-switching) (Ngoma et al. 2018; Pailman et al. 2018; Piedrahita et al. 2016). This is where the cook uses an ICS alongside their traditional form of cooking or switches back and forth. Jürisoo, Lambe, and Osborne (2018) found that in order to achieve long-term health and climate benefits, the users needed to not only have sustained, and proper use of their clean cookstove, but also maintain the "disuse of inefficient polluting stoves." In addition to this, the authors found that there were a number of "complex factors" that impacted people's decision-making regarding purchase and use of clean cookstoves, which needs further attention to map out (Jürisoo, Lambe, and Osborne 2018). Without a full transition and sustained use, there are no real health benefits to the user, as found in a randomized control trial in India (Hanna, Duflo, and Greenstone 2016).

Fuel-switching can also take place because of outside influences. For example, during the Zambian energy crisis, where load-shedding was implemented up to eight hours per day, fuel-switching, load-switching, and conservation strategies were widely utilized (Ngoma et al. 2018). However, it was also estimated that there was an increase in fuel-related expenses and consumption of almost 50%. Most of this is attributed to switching to charcoal, which most of urban Zambia uses, especially those without access to electricity (Mulenga, Tembo, and Richardson 2019; Ngoma et al. 2018). This puts additional economic pressure on already vulnerable households, making their transition to cleaner technology that much harder.

A full, clean cooking transition requires behavior changes of the cooks, financial decision makers, and other family members, within the household (Kar and Zerriffi 2018). This may be what leads to the greatest barrier for ICS uptake, because not everyone benefits equally from clean energy, and those who benefit the most, also happen to be the ones with the least amount of power in these household decisions, generally.

Barriers to Clean and Improved Cookstove Adoption

There are many socio-cultural, economic, political, and institutional barriers that limit the uptake of improved cookstoves (ICS) (Jan 2012; Ravindra et al. 2019). The most studied determinant of clean cooking adoption is income (Lewis and Pattanayak 2012; Vigolo, Sallaku, and Testa 2018). Economic barriers to uptake are considerable, cleaner energy is generally more

expensive, and poses a challenging to households below the poverty line. In several studies, price of the stove was a clear barrier (Adane et al. 2020; Lewis et al. 2015; Vigolo, Sallaku, and Testa 2018).

A trend emerging in cookstove literature is that women are the key to increased uptake rates of ICS. However, a barrier to this is women's level of intra-household bargaining power and the knowledge of their social networks. Because of gender roles, women may have decreased decision making or bargaining power since men generally have greater budget control (Rehfuess et al. 2014).

In a systematic review by Lewis and Pattanayak (2012), head of household education and female education were positively associated with ICS adoption. In addition to this, the authors considered the sex of the head of household (because this is a variable rarely included in ICS literature) and found that female headed households are more likely to adopt cleaner fuels (Lewis and Pattanayak 2012).

Gender impacts men and women's experiences, especially within the home, which can be seen as a "place of negotiation" because of unequal distribution of resources and power (Clancy et al. 2012; Fingleton-Smith 2018; Wilson 2015). This poses an intra-household bargaining dilemma. Clean forms of cooking come along with a higher price tag, and as men are generally the head of households, it requires their approval to purchase. This is a stark contrast to the fact that this technology largely benefits women. Miller and Mobarak (2013) found that women have a "stronger preference" for ICS adoption, but often lack the intra-household bargaining power (Bonan, Pareglio, and Tavoni 2017; Miller and Mobarak 2013).

Qualitative data was collected across Kenya, and it suggests that there is a "disconnect" from the people who benefit from modern household energy (mainly women) and the people purchasing the energy (mainly men) (Fingleton-Smith 2018). The finding of this study was that women do not have enough decision-making power in the home to advocate for cleaner energy access.

In a study out of Sudan, a largely patriarchal society, relative advantage, housewife's exposure to messages about improved cookstoves, educational level of the housewife, and the average educational level of the female household's members all had significant positive effects on whether or not households adopted ICS (Muneer and Mohamed 2002). Relatedly, a study from rural India found that as women moved towards "more formal employment" the chances of choosing cleaner fuels significantly increased (Sehjpal et al. 2014).

In a cover essay by Smith (2015), the author introduces several paradigm shifts in clean cooking. One of the new paradigms they offer is called "it takes a village." The reasoning behind this is research has shown that if only a few households in a community transitioning to cleaner technology it does not have the same exposure decrease one would anticipate, so in order to have maximum, intended health benefits, the entire community, or a majority of the community, should make the shift. Smith (2015) offers that interventions should happen at a community level, with two advantages begin present: 1) it is more efficient and reliable to provide fuels, stoves, accompanying services on a community scale and 2) you can rely on "social pressure" to help adopt new social norms (i.e. wanting to create a smokeless village).

This second advantage sets up a system of social capital, which, when looked at through a gender lens, can begin to show how women influence and empower each other to adopt cleaner technology in the home.

With regard to both drivers and barriers, the demand side factors addressed previously are what most of the literature currently contains. As noted in Bonan, Pareglio, and Tavoni (2017), there is more research needed into supply side factors and the causal role played in ICS adoption, and that these demand side variables are only effective "in the presence of a stable and accessible supply of ICS." It has been stated in other pieces that strengthening the supply chain is a necessary pre-requisite (Bonan, Pareglio, and Tavoni 2017; Lewis et al 2015), as well as the involvement of local institutions in the development of policies (Bonan, Pareglio, and Tavoni 2017; Pattanayak and Pfaff 2009).

Conceptualizing, operationalizing, and measuring social capital

Social Capital Definitions

Social capital can stretch to fit many disciplines across the social, political, and economic spectrum, thus taking on varied meanings as well. While the potential benefits of social capital have been well agreed upon, there is no central definition.

Adrianzén (2014) wrote about groups of researchers that seem to favor some indicators over others in their definitions. Some relate social capital with trust (Bowles and Gintis 2002; Glaser et al. 2000; Karlan 2005), trust, norms, and networks (Knack and Keefer 1997; Putnam et al. 1993), or emphasize the "associational essence" of social capital where trust is purely a byproduct of (Dasgupta 2005; Narayan and Pritchett 1999; Woolcock 1998). Similarly, Kumar and Igdalsky (2019) define social networks as "groups of individuals who are linked by social relationships." Many still view measuring it as both complicated and controversial (Adrianzén 2014).

Adrianzén (2014) also highlights in the conclusion of the study the importance of clearly defining what the specific dimensions of social capital of importance and the role each specific dimension is expected to show.

For the purposes of this study, I'll be using the definition from Dasgupta (2005), where they defined it as only "interpersonal networks," and nothing more as to not assume any more of the nature of the relationship. In this definition the members of the networks determine its own use and quality.

Social Capital Framework

Robert Putnam has been credited for popularizing the concept of social capital, notably through his 1994 book on regional government in Italy, *Making Democracy Work*, and his 2000 book study looking at social capital and public health in the US, *Bowling Alone.* Putnam (2000) categorized social capital into two areas: bonding and bridging. A third category, linking, was popularized by Szreter and Woolcock (2004), and since then all three have become a singular framework in the social capital literature.

Bonding social capital refers to your closest, horizontal connections in your network – family, friends, neighbors. These individuals are similar to your own identities with respect to gender identity, class, race, socioeconomic status, etc. Putnam has described this first kind as "empirically, if you get sick, the people who are likely to bring you chicken noodle soup are likely to represent your bonding social capital" (Dubner 2016, 14:20).

Bridging social capital is also your horizontal connections, but more distant relationships, these may be weaker ties with people who do not share the same key identities as you. This is where community level aspects come into play, and whether or not you trust the broader society you belong to. Measuring trust is an important part of measuring social capital, however, in diverse environments, according to Putnam, "…in the short run, increases in diversity seem to be correlated with decreases in social capital… [but] diversity in the long-run, is a big advantage" (Dubner 2016, 18:30; Putnam 2007).

Linking social capital is vertical connections to institutions and people with social or political power. These connections may be with people who are completely unlike you in identity, and even outside your community. Linking social capital can also encompass political activism and trust (Poortinga 2012).

Measuring Social Capital

Across many disciplines and fields, three structural measures of social capital have been widely used and have high internal validity: name (Burt 1997), position (Erickson 2004; Lin and Dunn 1986; Lin and Erickson 2008), and resource generators (van der Gaag and Snijders 2005) (Appel et al. 2014). Name generators are questions that are answered by producing a list of names (Appel et al. 2014). It can be summarized by simply "with whom do you talk about personal matters" (van der Gaag and Snijders 2005). This measure is largely accepted as unsatisfactory (Appel et al. 2014; van der Gaag and Snijders 2005). Position generators are analyzing people's different social locations and the understanding that different locations give differing access to information and resources (Appel et al. 2014). However, the basis of this measurement was "traditionally molded in access to higher occupational prestiges and access to diverse networks" (van der Gaag, Snijders, and Flap 2010). Finally, resource generators aim to overcome the shortfalls of the previous two measures. Resource generators "asks about access to a fixed list of resources, each representing a vivid, concrete sub-collection of social capital, together covering several domains of life" (van der Gaag and Snijders 2005).

Social Capital as a Driver of Technology Adoption

Technology

Social capital can influence clean energy adoption, as evident from the literature. Looking at solar home systems (SHS) in Sri Lanka, McEachern and Hanson (2008) found that "if the village priest or temple has a SHS, the village adoption rate is higher," and that solar companies were correctly assuming this and supplying them with one. This is an example of the solar companies leveraging social capital for their advantage. These companies in conjunction with the Energy Forum NGO have provided educational materials on SHS to students, which led to knowledgeable students going home to relay the benefits to their parents.

This introduces the idea of an "opinion leader." Kumar and Igdalsky (2019) define opinion leaders as "prominent or highly regarded community members whom other members of a community emulate." Additionally, the authors go on to say that early adopters of clean energy are considered opinion leaders, as they often influence the opinions of others.

When deciding to adopt a new crop technology, it was found in Northern Mozambique that the "social effects are positive when there are few adopters in the network" as well as "the adoption decisions of farmers who have better information about the new crop are less sensitive to the adoption choices of others" (Bandiera and Rasul 2006). Finally, it was also found that "adoption

decisions are more correlated within family and friends than religion-based networks, and uncorrelated among individuals of different religions."

Water

In the case of access to clean water, after analyzing social capital, collective action, and access to water in Kenya, it was found that "social capital may be necessary but not sufficient for improving access to water and sanitation in marginalized communities" (Bisung et al. 2014). The authors note this may be because of structural inequality, in particular with the structures that govern who manages the water resources and who gets access at what price.

On the same topic of water, in Greece willingness to pay (WTP) for improved water was studied in conjunction with social capital, and it was found that "social capital is a significant explanatory parameter of WTP" (Polyzou et al. 2011). The authors identified four areas of social capital to focus on, since social capital is multi-dimensional: "social trust concerning trust towards people in general or to specific social groups (Uslaner and Conley 2003)," "institutional trust, referring to trust in institutions functioning in a community (e.g. Government, Local authorities, NGOs) (ie Paxton 1999)," "social networks and civic participation, relating to the involvement of individuals in formal and informal networks and also their interest for collective issues of their community (Putnam 2000)," "compliance with social norms, hence the tendency of individuals to comply with formal or informal community rules aiming to the protection of the common good (van Oorschot et al. 2006)" (Polyzou et al. 2011).

Health

The intersection of health and social capital have a large body of literature, however most of it is in high income country (HIC) settings. In a systematic review of the social capital and health literature in low- and middle-income countries (LMICs), it was found that, in most studies, social trust, social cohesion, and sense of belonging were associated with positive health outcomes (Agampodi et al 2015). The most common health outcomes studied were those with "subjective" assessments, including mental health status and self-reported health. It was also found that most social capital measurements used in these LMIC settings were originally developed in HIC, and that cultural adaption of the measurement tools was only mentioned in less than half of the papers included in the review (n=17). While this finding is consistent with HIC social capital research, validation of measurement tools and causality relationships are still needed in LMIC settings.

Clean and Improved Cookstoves

Previous research has suggested that people adopt ICS out of their own vested self-interest, but uptake rate is still very low, even with efficient, healthy stoves on the market (Bielecki and Wingenbach 2014; Hanna, Duflo, and Greenstone 2016; Mobarak et al. 2012). This alludes to the fact that there is more to the ICS adoption story, and that, specifically, women's social capital could be a key component of this. This theory is partially supported by Ramirez et al. (2014), where, based on their findings, the authors hypothesize that "communications between women play a more critical role in adoption than in the information diffusion at a regional scale analyzed in this paper."

In a review of existing ICS literature, Kumar and Igdalsky (2019) found that "there is a lack of systematic literature examining the role of social networks in accelerating the dissemination and implementation of ICS." They also highlight that in "gender segregated systems" women's social networks are crucial for information to be spread at a community level.

Separate from adoption, it has also been found that social networks have helped make the transition, as dis-adoption of traditional cookstoves (Bailis and Wang 2015).

In a random experiment done to assess the impact of ICS information and then given the opportunity to purchase the product at market price, it was found that women are more likely to purchase the product if the "information they receive is on a peer who purchased the product and whose opinion is respected" (Bonan et al. 2019). In a randomized control trial in Uganda, Beltramo et al. (2015) were testing whether neighbors who bought and received stoves had more of an effect than neighbors who had bought but not yet received their stove. The result was that "neighbors of buyers who have experience with the stove are not detectably more likely to purchase a stove than neighbors of buyers who have not yet received their stove." In addition to this, the authors found "evidence of peer effects in opinions about efficient cookstoves." This sets up the idea of "opinion leaders" within communities.

With regards to influence on opinion, this is supported by Beltramo et al. (2015), where the authors observed that "knowing that a prominent member of the community has the efficient stove predicts 17–22 percentage points higher odds of strongly favoring the stove." However, having a more favorable opinion, it was found, had no impact on whether or not that person went on to purchase a stove. Miller and Mobarak (2011) found that "revealing information about technology choices by respected community members ("Opinion Leaders") influences adoption decisions more for technologies lacking self-evident benefits and more before common experience accumulates."

It is important to keep in mind that opinion leaders are not always a positive thing. In Miller and Mobarak (2013) their opinion leader experiment found that when cost and benefit information was not obvious, opinion leaders were important, but otherwise made no difference. This was supported by Sapp and Korsching (2004). Additionally, if one person in the social network had a *negative* experience with a "non-traditional stove," this reduced the chance of the network adopting (Miller and Mobarak 2013).

Research Gaps this Study Fills

This work not only contributes to the literature on improved cookstove adoption in Sub-Saharan Africa, it also contributes to the very limited literature on the role of social capital in cookstove adoption. Particularly, this study is novel because of the attention to social capital in an urban setting in Sub-Saharan Africa. In addition, this work is robust because it considers the role of social capital in the adoption of two different cookstoves, with regards to technology (one is improved charcoal and the other is a micro-gasification, biomass pellet-fueled stove) and marketing models.

Methods

Study Design

The data used for this study were collected in between June and August 2019 through the baseline round of an impact evaluation organized by the University of North Carolina at Chapel Hill, Copperbelt University, the Center for Energy, Environment and Engineering (CEEEZ), the University of Michigan – Ann Arbor, and the Stockholm Environment Institute as part of a National Science Foundation (NSF) Grant called Energy Poverty PIRE in Southern Africa (EPPSA).

The impact evaluation design is a quasi-experimental multi-year impact evaluation study using a before-after-control-intervention or difference-in-difference study design. The study is designed to understand factors driving adoption and sustained use, and the impacts of use on charcoal consumption, household expenditures on cooking energy, exposure to household air pollution, and self-reported indicators of health for two private-sector improved cooking interventions in Lusaka, Zambia.

Following the baseline survey, a rapid assessment was done in Spring 2020 to quantify which households had adopted the marketed cookstoves in the prospective user compounds. This assessment was administered in person to the VITALITE Prospective User Compound (Ng'ombe), and over the phone to the SupaMoto Prospective User Compound (Kalingalinga) because of the COVID-19 pandemic. The assessment comprised of seven questions asking the respondent their familiarity with either SupaMoto or VITALITE and the companies' respective stoves, if their household purchased a stove, if yes, how many months since purchase, and if the household has moved within or outside the compound.

VITALITE is a private sector firm in Zambia. This firm sells a wide array of products from solar home systems to solar irrigation pumps. The EcoZoom improved charcoal stove is primarily sold in urban areas. When tested in a lab setting, these stoves reduce charcoal consumption up to 80%. The VITALITE Prospective User Compound (Ng'ombe) marketing strategy was to go door-to-door to all households in the compound. If someone was home, they were informed about the company and stove and given a physical voucher. The voucher allowed the receiver to get a discount on the stove, normally priced at 350 ZMK, so the new stove price would be 150 ZMK. For the household to purchase the stove, they needed to answer a few questions and willing to sign a carbon contract (EPPSA and PEER Study Team 2021).

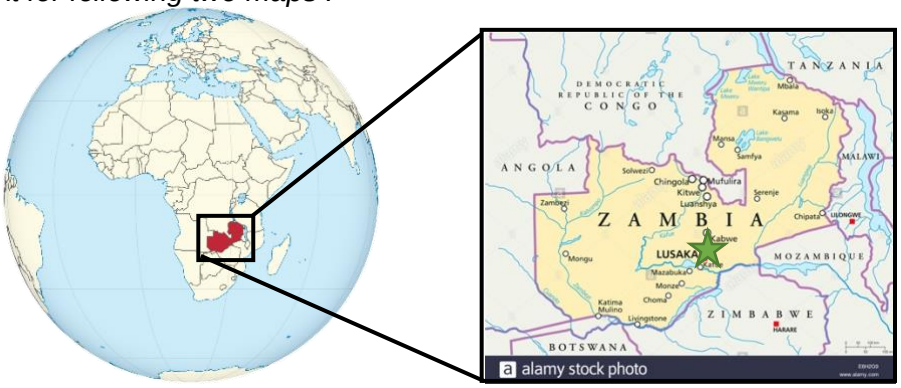
SupaMoto is also a private sector firm in Zambia. This firm's primary products are micro-gasification stoves and biomass pellets. When these products are used together, the expected outcome is reduced emissions from household air pollution to the level of LPG stoves (Champion and Grieshop 2019). The biomass pellets are competitively priced, comparable to charcoal, and there are payment plans available through SupaMoto. The SupaMoto Prospective User Compound (Kalingalinga) had a two-part treatment: promotion and sales. In early 2020, sales representatives went door-to-door in Kalingalinga promoting the Mimimoto stove. However, after violence and tension arose in the compound, the promotion strategy pivoted and a SupaMoto company vehicle drove around the compound blasting loud music accompanied by a promoter with a loudspeaker dressed in bright orange. The promoter informed residents about the product, payment plans, and where to purchase the product. Following promotional activities, sales locations were set up within the compound, in addition to the 14 already established shops (EPPSA and PEER Study Team 2021).

Study Area

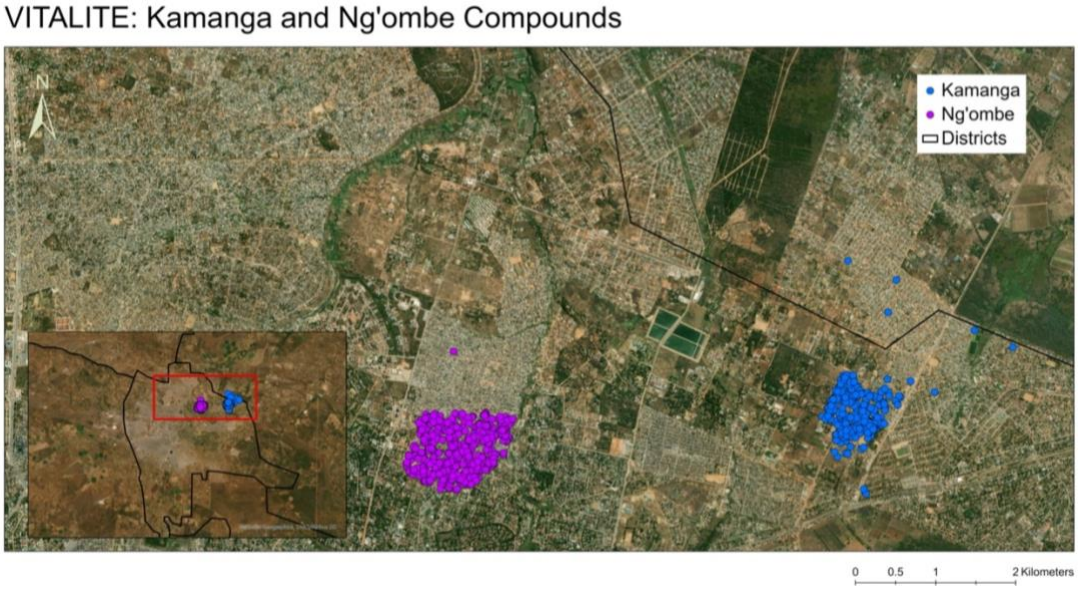
The study area is comprised of four high-density low-income compounds in Lusaka. Of the four compounds, there is one prospective user compound and one already user compound for each firm. "Prospective user" meaning households that are going to be marketed to in this evaluation, one for each respective stove firm (they do not already own the improved cookstove being sold). "Already user" meaning those who already have a cookstove that is being marketed, one for each respective stove firm. Because the firms are marketing to different compounds, there is no risk of contamination (or spillover effects) between them. This is to say that none of the households in different groups should be sharing information or marketing materials from another compound.

The two VITALITE Compounds are Kamanga (already user) and Ng'ombe (prospective user) (Map One). The two SupaMoto Compounds are Matero (already user) and Kalingalinga (prospective user) (Map Two).

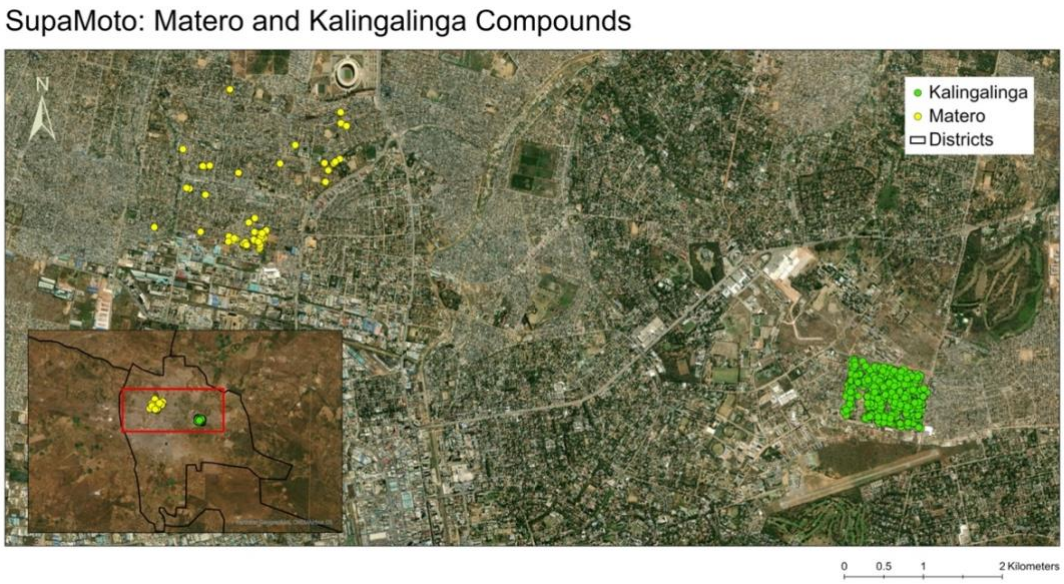
Global Context for following two maps :



Map One, Source: EPPSA and PEER Study Team 2020



Map Two, Source: EPPSA and PEER Study Team 2020



Based on the Baseline Data collection, Figure One shows the household breakdown per compound of monthly income across cash income, in-kind income (from charcoal and non-charcoal sources), and remittances (EPPSA and PEER Study Team 2020). 86% of surveyed households are electrified, 99/8% of which receive electricity from the national grid. At the time of data collection, 80% of respondents reported an average of four hours of load-shedding per day.

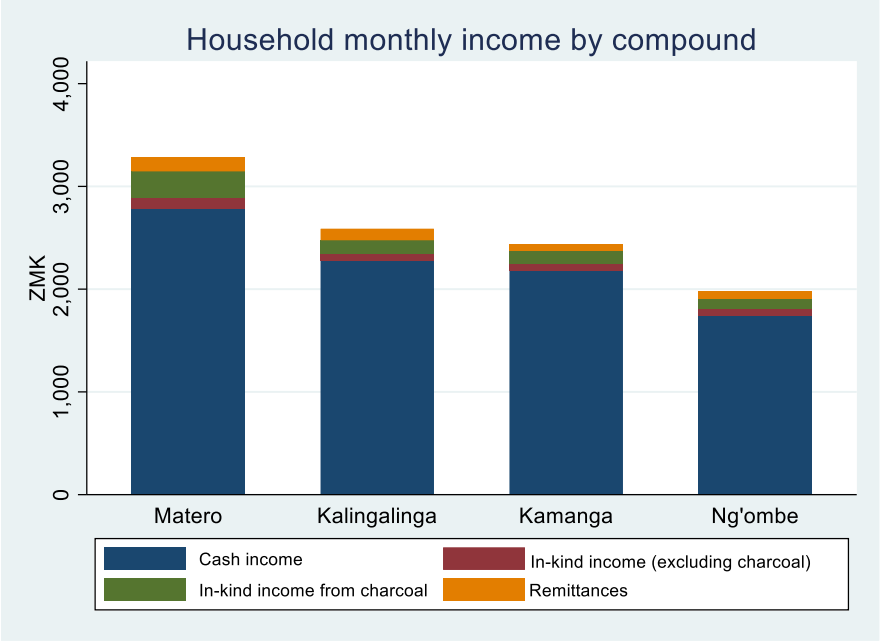


Figure One: Household Monthly Income by Compound, Source: EPPSA and PEER Study Team 2020

Sampling

Compound Selection

Compounds were selected purposively in collaboration with VITALITE and SupaMoto based on if they had been marketed to, and which compounds were similar to be marketed to for the purposes of this evaluation.

Household Selection

The Already Users sample was drawn by asking each firm to provide 300 households that were already in their customer base (Kamanga and Matero). SupaMoto was unable to meet this number for the Matero compound, so the sample sizes provided were Kamanga (n=305) and Matero (n=59). Households were then randomly ordered, and the first 300 households were selected to participate. Households were deemed ineligible if the main respondent was less than 18 years old, or if the main cook was less than 15 years old.

The Prospective Users sample was drawn by identifying two compounds, one for each firm, where the firms planned to market to immediately following the baseline survey. Then, using a geographically bound census of households created by the EPPSA team, 834 households in Kalingalinga and 1,496 in Ng'ombe were randomly ordered and randomly selected for recruitment. Ultimately, 478 households in Kalingalinga and 535 households in Ng'ombe were interviewed.

The total sample size at baseline is 1,377 households (already users N=364, prospective users N=1,013) (Figure Two).

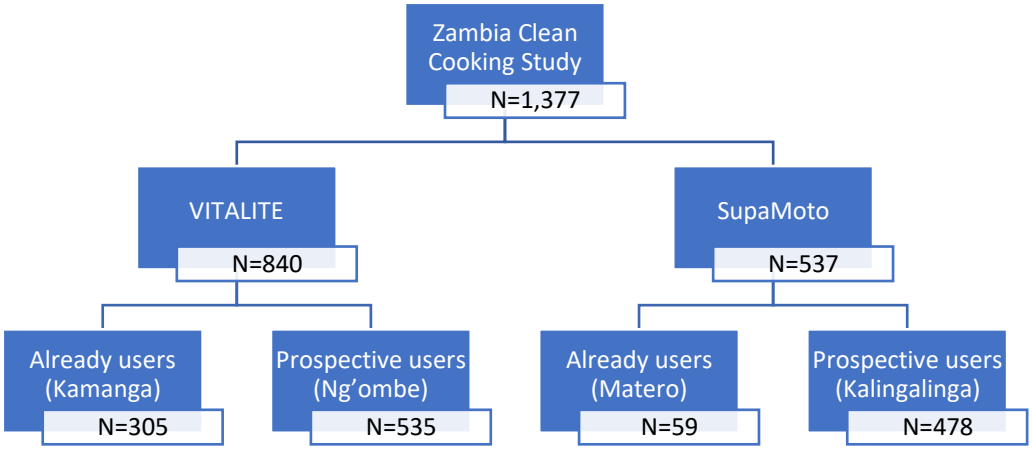


Figure Two: Overview of Baseline Sample, Source: EPPSA and PEER Study Team 2020

From the rapid assessment, 68% of households were able to be reached from Kalingalinga and 82% from Ng'ombe. Households were dropped from this dataset for two reasons: not able to be reached in the rapid assessment, were not promoted to, and/or did not answer the question regarding stove purchase. Figure Three shows the final numbers that were used in this analysis.

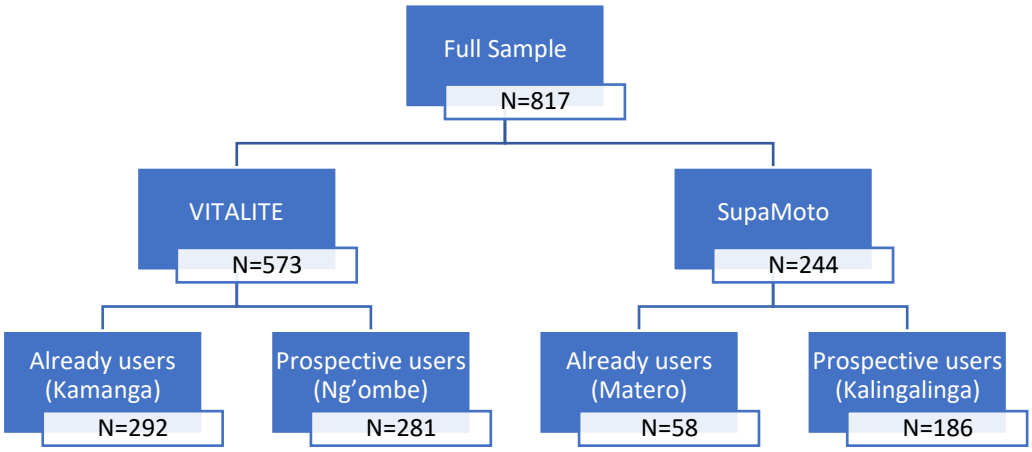


Figure Three: Analysis Sample following Rapid Assessment[1]

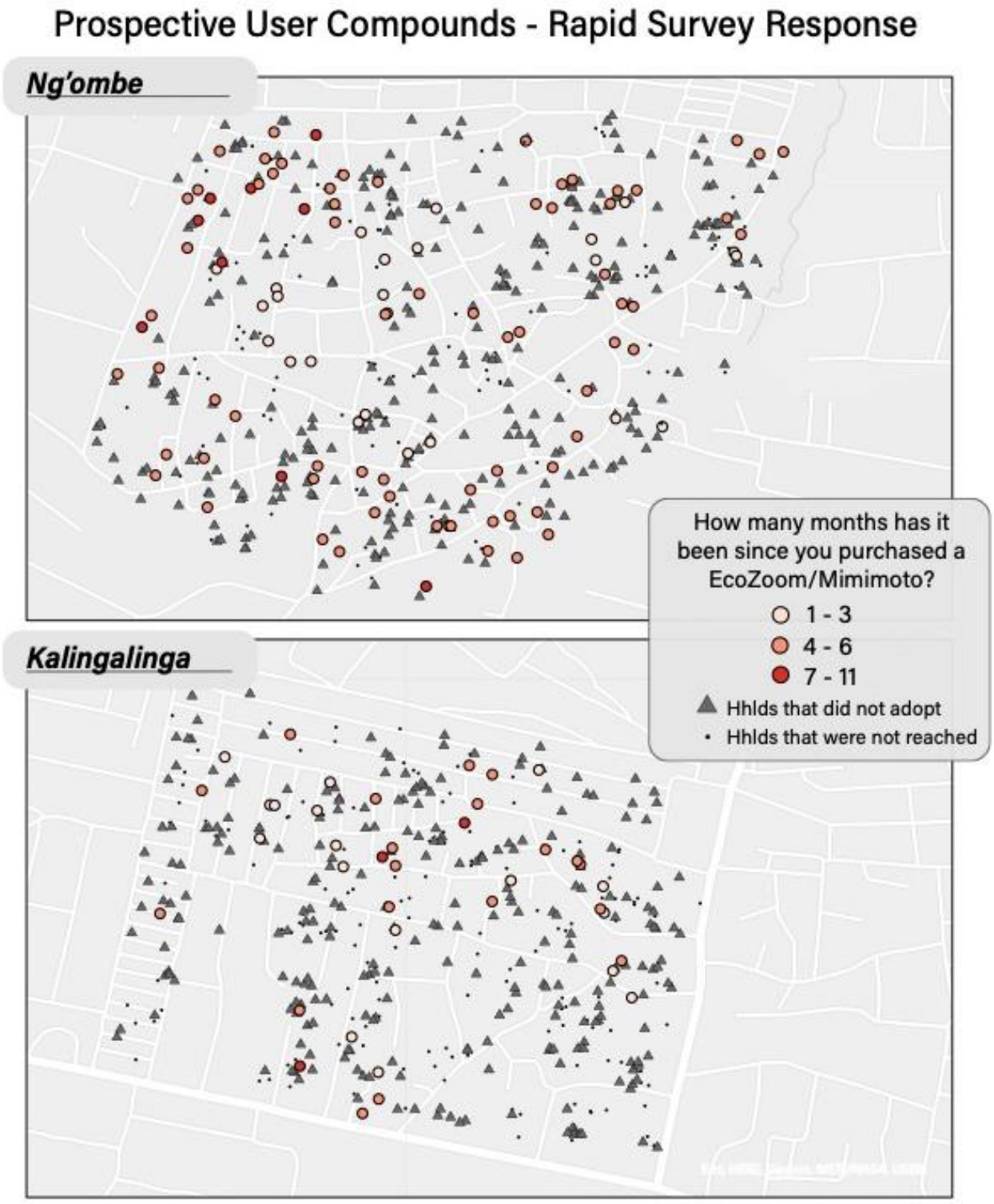
Map Three shows the spatial distribution of households that were reached and did or did not adopt in Ng'ombe and Kalingalinga. There is potential bias because of the way the rapid assessment data were collected. For Kalingalinga (the compound where the rapid survey was done over the phone), it required respondents to 1. Have a phone, 2. Have the phone charged enough to receive and answer the call, 3. Not be at work or otherwise busy. This third point also contributes to whether or not the household was promoted to, if they were not promoted to, they were dropped from this study. Because of the aforementioned load-shedding in Lusaka, if the household relied on their household electricity connection to charge their phone, this could also complicate the requirements on respondents. Kalingalinga was surveyed over the phone because of the COVID-19 pandemic, the effects of which could also have impacted whether or not a household was able to be reached.

Overall, 233 households were dropped from VITALITE and 284 households were dropped from SupaMoto prospective user compounds (Ng'ombe and Kalingalinga, respectively). This equals 52.52% dropped from Ng'ombe and 38.91% from Kalingalinga, which suggests that the biases may have been unequally distributed across firm compounds. Households were also dropped from the Already User Compounds (Kamanga and Matero) because they had missing values for at least one variable included in the regression, and only complete cases were used.

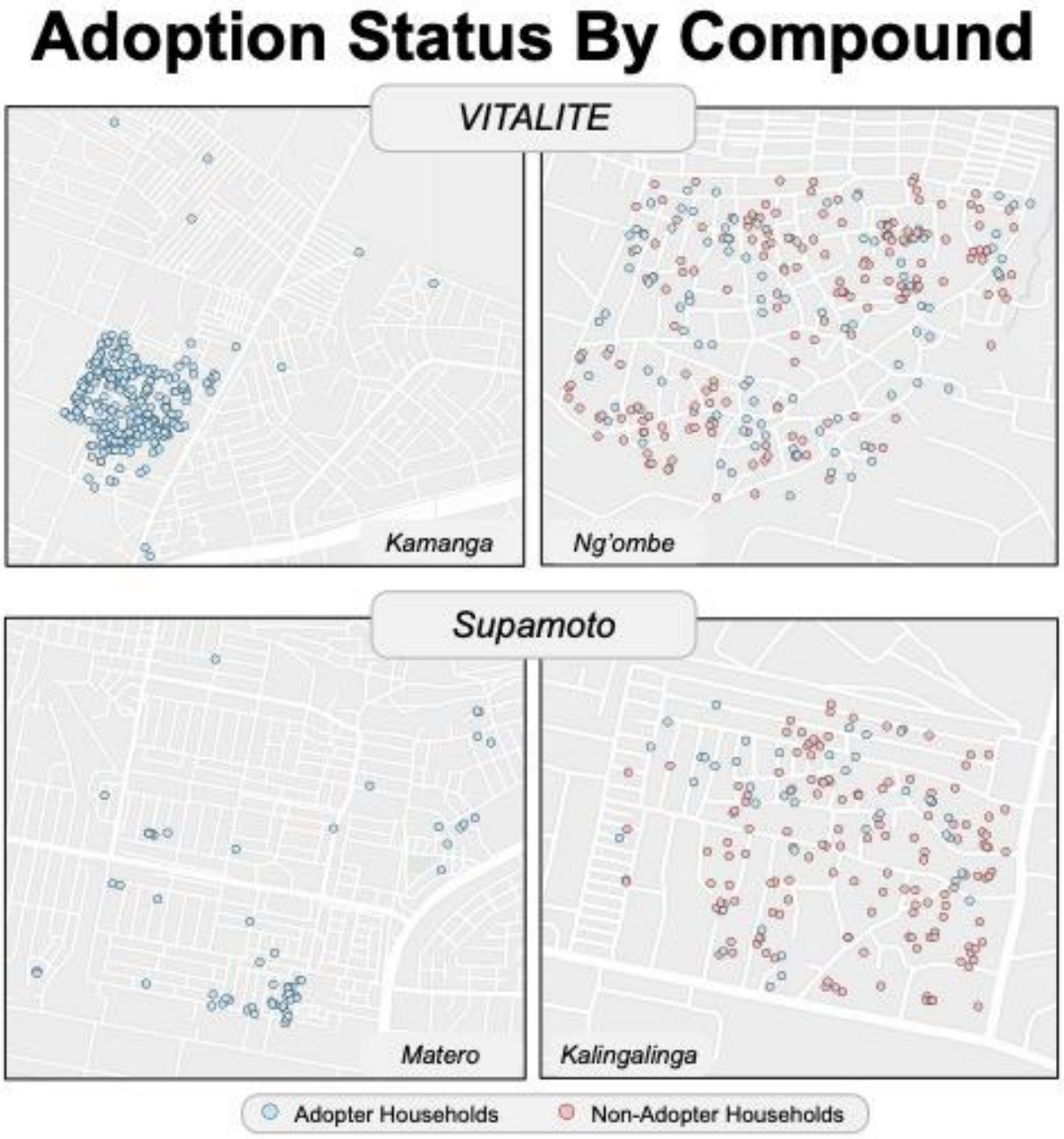
Map Four shows the distribution of households used in this analysis across adoption status, by compound. Blue indicators are adopter households and red indicators are non-adopter households.

[1] Some households were also dropped from already user compounds, Kamanga and Matero because of missing values in household characteristic variables. This missingness is from unanswered or invalid answers to baseline survey questions.

Map Three:


Prospective User Compounds - Rapid Survey Response
Ng'ombe
Kalingalinga
How many months has it been since you purchased a EcoZoom/Mimimoto?
1 - 3
4 - 6
7 - 11
Hhlds that did not adopt
Hhlds that were not reached

Map Four:



Data Collection

The survey, *Impacts of Improved Cookstove Interventions on Human Welfare and Energy Use Patterns of Urban Households in Lusaka, Zambia Survey,* was administered in person to the household decision maker (may or not be the household head) and primary cook, who answered respective modules based on their role in the household. The baseline questionnaire modules included: household roster; primary cook health and time use; household facilities; household assets; savings and credit; cooking practices, recall, and characteristics; best/worst scaling; willingness to pay/accept; household energy expenditures; other expenditures; social capital; perceptions of cooking; awareness of ICS firms; and fuelwood weighing.

For this study, I looked primarily at questions answered by the household head regarding the household's demographic information and answers to social capital (for full list of questions, see Appendix One).

Analysis

The dependent variable, adoption, is a binary variable quantified by "already user" compounds automatically equaling one (did adopt), and based on the stove purchase rapid assessment questions, "prospective user" compounds received a zero (did not adopt) or one (did adopt). In the case of already user compounds being considered adopters, this was a researcher-based decision with no evidence of sustained use, only of ownership. The same is true of prospective user compounds with respect to stove usage, the only difference is that it is respondent-based.

For purposes of this analysis, I aimed at building on the framework from Putnam (2000) and Szreter and Woolcock (2004) of bridging, bonding, and linking social capital. The questions I have did not fit precisely into those three categories, so I designed five groups: linkages, trust, community, personal, and intra-household / connections (see Appendix Two). Linkages is not a reference to "linking" social capital, instead it is a count (zero to four) of number of people with assumed education and power the respondent has a relationship with. Trust is closely associated with bonding social capital and is comprised of two questions about having confidence (or faith) in most people and depending on a neighbor to complete an important task. The next three categories can be thought of as a series of expanding spheres an individual exists in – personal, intra-household/connections, and community (Figure Three). Personal involves questions about if the respondent agrees that their life is defined by the actions and choices they make; Intra-household/connections are questions regarding having close friends/relative you can talk to and participating in financial matters within the household. Finally, community captured participating in decision making in the community and feeling apart of the community.

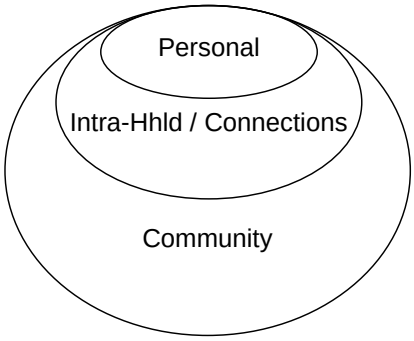


Figure Three: Social Capital Spheres

For all of the social capital groups (trust, personal, intra-household / connections, and community), they are quantified by first coding each individual question into a binary agree/disagree from the original four part strongly agree, agree, disagree, strongly disagree, with agree equaling one and disagree equaling zero. Then, for the two questions in each group, add the two variables together. For example, if the value for one household for the community variable was a 0 then that respondent agreed to neither of the questions in that group; if the value was a one then they agreed to one question; and if the value is a two then that respondent agreed to both of the questions in the community group.

The following independent variables were chosen to be included in the regression model to control for outside characteristics that may lead to differences; for this study I was interested in

social capital's role, so controlling for these factors helps account for differences across the sample. The household head variables included are gender, age, highest education level achieved, and a binary code for if the number of years the household head has lived in the City of Lusaka. Household level variables include household size, dependency ratio, whether or not men make decisions on purchasing of cooking devices in the household (no opinion, agree, disagree), number of durable goods[2] and dummy variables for whether or not the household has an electric stove and rent or own their home. Expenditure variables were included for energy, hygiene, and all other expenditures for the last four weeks, in Kwacha. For a full list of questions included see Appendix One.

In addition, basic descriptive statistics were generated by compound for the dependent variable (Table One), then disaggregated by adoption status (Table Three), and then disaggregated again by gender of the head of household (Table Two).

Logit Model

A binary logistic (logit) multivariate regression was used to analyze the relationship between social capital and improved cookstove adoption for the full sample (Eq. 1); where Y is the outcome variable of interest, β_0 is the intercept, β_1 represents social capital variables, β_2, β_3, and β_6 represent the household production function (land, labor, capital), β_4 represents the factor variable (disagree, agree, no opinion) on whether or not men make decisions on purchasing of cooking devices in the household, β_5 is a dummy variable for whether or not the household's primary stove is electric, and β_7 is a dummy variable for whether or not the primary stove is electric, and δ is the error term. Models were also run for the Prospective User, VITALITE, and SupaMoto compounds, which include the same variables.[3]

$$Y = g(\beta_0 + \beta_1 Social\ Capital + \beta_2 Land + \beta_3 Labor + \beta_4 Opinion\ on\ Men\ Making\ Cooking\ Tech\ Decisions + \beta_5 Primary\ Stove\ is\ Electric + \beta_6 Capital) + \delta$$

Eq. 1

The outcome variable for all three models was the log odds of improved cookstove adoption (Eq. 2).

$$Y = \log\left(\Pr(No\ adoption) \Big/ \Pr(Adoption\ of\ Improved\ Cookstove)\right)$$

Eq. 2

Regression diagnostics

All four models met the assumption of having heteroskedastic standard errors. I assume that all observations are independent across compounds, but not necessarily within compounds. All three models were also checked for multicollinearity with variance inflation factor (VIF), and all were well below 10. Akaike's Information Criterion (AIC) and Bayesian Information Criterion (BIC) diagnostic tests were also run and included in the models results. All analyses were conducted using RStudio version 1.3.1093.

[2] Includes a number of functioning household technology (TV, radio, wall clock, kitchen appliances, etc), standard furniture (bed/mattress, table, chairs, etc.), functioning vehicle (truck, motorcycle, bicycle, etc.), borehole and septic tank.

[3] Energy expenditure was only included for the Prospective User model because this would have changed between time of adoption and time of data collection for already users.

Human Subjects Approvals
The Zambia Clean Cooking Study was approved by the University of North Carolina Institutional Review Board (IRB) (study number 19-0061), as well as the Humanities and Social Science Research Ethics Committee (HSSREC) in Zambia (study number 2019-MAY-012). In addition, there is a SMART IRB Master Common Reciprocal IRB Authorization Agreement for the University of Michigan, Ann Arbor. All participating human subjects were required to give their informed consent before engaging in data collection.

Results

Descriptive Statistics
Based on the overall descriptive statistics (Tables One, Two, and Three), there are strong statistical differences between the households of differing adoption status. Adoption status is defined as having purchased the either the EcoZoom or Mimimoto stove, depending on which compound the household is in. Outside of that, adoption does not imply sustained use of the stove.

Table One shows the distribution of adoption status across the full sample and by compound. In regard to the full sample, of the already user compounds and those reached in the prospective user compounds, 60% of households used in this analysis (N=817) are considered adopters. Broken down by compound, 36% are considered adopters in Ng'ombe (N=281), and 23% in Kalingalinga (N=186).

Table One: Descriptive Statistics for Dependent Variable

	Full Sample (N=817)	*Kamanga (N=292)**	*Matero (N=58)^*	*Ng'ombe (N=281)**	*Kalingalinga (N=186)^*
Dependent Variable: Adoption	0.60 (0.49)	1.00 (0.00)	1.00 (0.00)	0.36 (0.48)	0.23 (0.42)

Note: * Denotes VITALITE Compounds; ^ Denotes SupaMoto Compounds

When looking at the social capital groups (Table Two), and disaggregating by adoption status and by gender, female headed households who adopted have higher values for every group when compared to female headed households who did not adopt, for the full sample. This illustrates that female headed, adopter households have more social capital than female headed, non-adopter households. This supported my initial hypothesis that female headed, adopter households have more social capital than their non-adopter counterparts. However, this does not hold true across all compounds.

Neither the male nor female groups in Ng'ombe were statistically significant for any variable. In Kalingalinga, both the male and female, non-adopter households have higher values for the Trust grouping, which is contradictory to what was found for the full sample results previously mentioned. Separately, female headed, adopter households have higher social capital values in the Personal grouping, and male headed, adopter households have higher values in the Intra-Household / Connections grouping, than their respective counterparts.

None of the variables were robust across disaggregation levels for the social capital variables because none of the Ng'ombe variables were significant ($p<0.1$).

By plotting the variables across compounds and adoption status (see Appendix Three), you can see that there is variance across compounds and adoption status. One thing of note is that

Ng'ombe has lower averages values across all social capital variables in comparison to the other compounds.

Based on Table Three, for the full sample, on a household level, adopters have larger households, more durable goods, and spend more on all three forms of expenditures included (energy, hygiene, and all others in the past four weeks). These adopter households are also more often headed by females, who have more education, than non-adopter households.

When disaggregated by compound, for both Ng'ombe and Kalingalinga, adopter households more often own their home and have larger households than non-adopter households. Separately, for Ng'ombe, non-adopters have more education than adopter households, but adopters have older household heads who have lived in the City of Lusaka longer. Adopter households in Ng'ombe have more durable goods and spend more on all three forms of expenditures included (energy, hygiene, and all others in the past four weeks). Separately for Kalingalinga, adopter households are spending more in hygiene expenditures.

This means the only robust variables which held significance ($p<0.1$) across the full sample and compound disaggregation were household size (adopter households were larger) and hygiene expenditure.

Table Two: Descriptive Statistics for Social Capital Variables

	Full Sample						*Kamanga**		*Matero^*		*Ng'ombe**				*Kalingalinga^*					
	Adopter		Non-Adopter				Adopter		Adopter		Adopter		Non-Adopter				Adopter		Non-Adopter			
	Male (N=306)	Female (N=325)	Male (N=136)	Female (N=191)	Male *P* value	Female *P* value	Male (N=17)	Female (N=41)	Male (N=17)	Female (N=41)	Male (N=34)	Female (N=66)	Male (N=75)	Female (N=106)	Male *P* value	Female *P* value	Male (N=14)	Female (N=28)	Male (N=61)	Female (N=83)	Male *P* value	Female *P* value
Linkages (0-4)	2.05 (1.21)	1.89 (1.20)	1.88 (1.19)	1.61 (1.10)	0.21	0.01***	2.10 (1.16)	1.91 (1.20)	2.59 (1.12)	2.37 (1.11)	1.44 (1.31)	1.55 (1.20)	1.61 (1.16)	1.43 (1.06)	0.45	0.66	2.57 (0.94)	1.82 (1.19)	2.21 (1.14)	1.86 (1.11)	0.30	1
Trust (0-2)	1.12 (0.78)	1.25 (0.79)	1.13 (0.79)	1.08 (0.82)	0.97	0.02**	1.19 (0.76)	1.27 (0.80)	0.94 (0.90)	1.34 (0.79)	1.26 (0.67)	1.30 (0.66)	1.39 (0.61)	1.21 (0.63)	0.31	0.70	1.43 (0.65)	1.29 (0.60)	1.49 (0.57)	1.47 (0.57)	0.06*	0.09*
Community (0-2)	1.52 (0.61)	1.48 (0.57)	1.43 (0.59)	1.32 (0.62)	0.16	0.01***	1.64 (0.56)	1.56 (0.52)	1.35 (0.61)	1.56 (0.55)	1.91 (0.29)	1.86 (0.35)	1.93 (0.25)	1.84 (0.39)	0.38	0.31	1.79 (0.43)	1.96 (0.19)	1.97 (0.18)	1.88 (0.36)	0.79	0.15
Personal (0-2)	1.88 (0.37)	1.90 (0.34)	1.88 (0.37)	1.80 (0.48)	0.94	0.00***	1.90 (0.33)	1.91 (0.30)	1.71 (0.47)	1.95 (0.22)	1.06 (0.78)	1.03 (0.80)	0.89 (0.80)	0.98 (0.80)	0.38	0.91	1.00 (0.78)	1.54 (0.58)	1.41 (0.69)	1.20 (0.84)	0.91	0.03**
Intra-Household / Connections (0-2)	1.95 (0.22)	1.95 (0.21)	1.95 (0.22)	1.85 (0.39)	0.96	0.00***	1.97 (0.17)	1.98 (0.15)	2.00 (0.00)	1.98 (0.16)	1.88 (0.48)	1.77 (0.52)	1.85 (0.43)	1.76 (0.53)	0.70	0.78	1.93 (0.27)	2.00 (0.00)	1.92 (0.28)	1.84 (0.40)	0.02**	0.25

Note:

*Denotes VITALITE Compounds; ^ Denotes SupaMoto Compounds
Gender is determined by head of household

Table Three: Descriptive Statistics for Household Characteristics

	Full Sample (N=817)			*Kamanga (N=292)**	*Matero (N=58)^*	*Ng'ombe (N=281)**			*Kalingalinga (N=186)^*		
	Adopter (N=492)	Non-Adopter (N=325)	*P* value	Adopter (N=292)	Adopter (N=58)	Adopter (N=100)	Non-Adopter (N=181)	*P* value	Adopter (N=42)	Non-Adopter (N=144)	*P* value
Rent or Own Home	0.51 (0.50)	0.30 (0.46)	0.29	0.50 (0.50)	0.53 (0.50)	0.56 (0.50)	0.30 (0.46)	0.00***	0.48 (0.51)	0.29 (0.46)	0.04**
Household Size	5.79 (2.45)	5.09 (2.30)	0.00***	5.57 (2.34)	5.88 (2.75)	6.36 (2.53)	5.08 (2.43)	0.00***	5.86 (2.33)	5.10 (2.15)	0.06*
Dependency Ratio	68.52 (64.51)	68.02 (63.56)	0.9129	67.12 (64.04)	61.92 (71.41)	74.50 (61.28)	75.73 (68.72)	0.88	73.20 (66.25)	58.34 (55.14)	0.19
Men usually make decisions on purchasing of cooking devices in my household (0=no opinion, 1=agree, 2=disagree)	1.72 (0.46)	1.70 (0.48)	0.53	1.71 (0.46)	1.79 (0.41)	1.67 (0.47)	1.66 (0.51)	0.84	1.79 (0.47)	1.75 (0.43)	0.66
Head of Household Gender	0.65 (0.48)	0.58 (0.49)	0.04**	0.64 (0.48)	0.71 (0.46)	0.66 (0.48)	0.59 (0.49)	0.22	0.67 (0.48)	0.58 (0.50)	0.29
Head of Household School Code (0=no education, 1=some primary school or completed, 2=some secondary or completed, 3=more than secondary)	1.58 (0.79)	1.63 (0.74)	0.30	1.59 (0.77)	1.71 (0.75)	1.39 (0.78)	1.56 (0.74)	0.08*	1.74 (0.89)	1.73 (0.73)	0.95
Head of Household Age	45.09 (13.62)	39.92 (13.20)	0.00***	44.64 (13.46)	46.66 (11.61)	45.92 (14.06)	38.66 (12.57)	0.00***	44.12 (16.66)	41.51 (13.84)	0.36
Number of Years Head of Household has lived in Lusaka	31.76 (15.94)	27.29 (15.93)	0.00***	31.02 (16.52)	34.69 (16.24)	31.85 (13.54)	24.51 (15.16)	0.00***	32.62 (16.71)	30.78 (16.24)	0.53
Primary Stove is Electric (0=no, 1=yes)	0.05 (0.02)	0.08 (0.27)	0.08*	0.02 (0.02)	0.07 (0.26)	0.05 (0.22)	0.05 (0.22)	0.99	0.19 (0.40)	0.12 (0.32)	0.28
Number of Durable Goods	11.53 (3.60)	9.69 (3.88)	0.00***	11.79 (3.57)	12.21 (4.08)	10.59 (3.28)	9.14 (3.99)	0.00***	10.95 (3.46)	10.39 (3.64)	0.36
Energy Expenditure (in Kwacha)	249.54 (145.81)	216.61 (133.18)	0.00***	223.78 (131.20)	270.77 (145.92)	305.43 (164.34)	196.65 (121.06)	0.00***	266.31 (156.04)	241.71 (143.53)	0.36
Hygiene Expenditure (in Kwacha)	224.97 (146.64)	180.35 (120.81)	0.00***	225.46 (144.08)	283.12 (163.39)	168.00 (123.44)	143.54 (99.53)	0.09*	276.93 (144.23)	226.63 (129.33)	0.05**
All other expenditure (last four weeks) (in Kwacha)	486.96 (397.41)	361.46 (306.28)	0.00***	491.85 (420.13)	584.60 (364.33)	413.22 (362.44)	326.28 (279.91)	0.04**	493.72 (331.44)	405.68 (332.24)	0.13

Note: * Denotes VITALITE Compounds; ^ Denotes SupaMoto Compounds

Logit Model Results

Full Sample Results
For the Full Sample Model, none of the social capital variables were significant ($p<0.05$) or approaching significance ($p<0.1$). However, two household characteristic variables were highly significant ($p<0.01$): if the household head is female, likelihood of adoption increased 59.9%, and for every additional durable good, likelihood of adoption increases by 12.6%. Two additional variables were also significant: owning your home increases likelihood of adoption by 58.2%, and for every additional year in age of the household head likelihood of adoption increases by 1.7%.

Prospective User Compound Results
Contrary to the Full Sample's results for social capital variables, two variables in the Prospective User Sample were approaching significance ($p<0.1$), and one was significant ($p<0.05$). The two approaching significance were the first level of Trust and Community, so the respondent agreed to either "Respondent has confidence (or faith) in most people OR Respondent can count on their neighbor to send an important letter or message"; and agree to either "Respondent participates in decision making in their community OR Respondent feels part of the community." The Trust variable increased likelihood of adoption, whereas the Community variable decreased likelihood of adoption. The second level of Community, where the respondent agreed to both questions, was significant, and decreased likelihood of adoption by 36.0%.

As for household characteristic variables: household size was approaching significance and increased likelihood of adoption for every additional member, owning your home was significant and increased likelihood of adoption by 84.3%, primary stove being electric increased likelihood of adoption by 165.6%, and energy expenditure was highly significant ($p<0.01$) and increased likelihood of adoption by 0.3% for every additional Kwacha spent.

VITALITE Results
Similar to the Prospective User Sample social capital variables, agreeing to one Trust question was approaching significance and increased likelihood of adoption. Agreeing to both Trust questions was highly significant and increased likelihood of adoption by 127.6%. In addition, having a female headed household and number of durable goods were highly significant. Having a female headed household increased likelihood of adoption by 83.3%, compared to male headed households; and for every additional durable good, likelihood of adoption increased by 16.0%. Finally, age of the household head increased likelihood of adoption by 2.5% for every additional year of age.

SupaMoto Results
Similar to the Full Sample, the SupaMoto Sample also did not have any significant ($p<0.05$) or approaching significant ($p<0.1$) social capital variables. For household characteristics, owning your home and the log of all other expenditures in the last four weeks both were approaching significance and increased likelihood of adoption. Finally, having a female headed household increased likelihood of adoption by 96.7%, compared to male headed households.

Table Three: Logit Regression Results

	Dependent Variable: Cookstove Adoption			
	Full Sample	Prospective Users	VITALITE	SupaMoto
Social Capital Variables				
Linkages: Among the Respondent's current acquaintances and relatives (one point for each) are: doctors/nurses or work in hospitals and clinics; teachers, school officials, or anybody who works in a school; anyone in government service (other than doctors, teachers, above); works for an improved stove and/or fuel company.	1.040 (0.071)	0.899 (0.105)	1.117 (0.092)	1.091 (0.141)
Trust: Respondent has confidence (or faith) in most people ***OR*** Respondent can count on their neighbor to send an important letter or message.	1.310 (0.203)	1.693* (0.291)	1.604* (0.251)	0.958 (0.425)
Trust: Respondent has confidence (or faith) in most people ***AND*** Respondent can count on their neighbor to send an important letter or message.	1.367 (0.197)	1.197 (0.290)	2.276*** (0.254)	0.794 (0.415)
Community: Respondent participates in decision making in their community ***OR*** Respondent feels part of the community.	0.819 (0.363)	0.431* (0.435)	1.022 (0.433)	0.906 (0.755)
Community: Respondent participates in decision making in their community ***AND*** Respondent feels part of the community.	1.009 (0.370)	0.360** (0.455)	1.495 (0.449)	0.765 (0.765)
Personal: Respondent's life is determined by their own actions ***OR*** Respondent can make important decisions that can change their life.	1.050 (0.619)	0.380 (0.758)	1.287 (0.688)	---[4]
Personal: Respondent's life is determined by their own actions ***AND*** Respondent can make important decisions that can change their life.	1.360 (0.580)	0.815 (0.671)	1.562 (0.629)	1.662 (0.520)
Intra-Household / Connections: Respondent has close friends or relatives they can talk to ***AND*** Respondent participates in financial decision within their own household.[5]	1.670 (0.314)	0.756 (0.376)	1.572 (0.393)	1.375 (0.623)
Household Characteristics				
Own your home	1.582** (0.189)	1.843** (0.275)	1.203 (0.248)	1.998* (0.365)

[4] One SupaMoto household answered disagree for both SC Personal Questions, which was artificially inflating the odds ratio. This household was subsequently added to the factor level where households answered agree to one question and disagree to the other.
[5] Two households (One in VITALITE and One in SupaMoto) answered disagree to both questions, which was artificially inflating the odds ratio. These households were subsequently added to the factor level where households answered agree to one question and disagree to the other.

Household Size	1.036	1.098*	1.019	1.052
	(0.037)	(0.053)	(0.048)	(0.074)
Dependency Ratio	1.002	1.003	1.001	1.004
	(0.001)	(0.002)	(0.002)	(0.003)
Men usually make decisions on purchasing of cooking devices in my household:				
Agree	1.348	0.857	1.471	---[6]
	(1.020)	(1.308)	(1.211)	
Disagree	1.215	0.836	1.397	0.932
	(1.017)	(1.297)	(1.207)	(0.362)
Household Head Characteristics				
Female	1.599***	1.348	1.833***	1.967**
	(0.172)	(0.250)	(0.231)	(0.316)
Highest Education Level Attained				
Some primary school or completed	0.824	0.970	0.913	0.459
	(0.316)	(0.424)	(0.402)	(0.616)
Some secondary or completed	0.704	0.637	0.845	0.576
	(0.326)	(0.445)	(0.429)	(0.605)
More than secondary completed	0.730	1.124	0.747	0.735
	(0.417)	(0.565)	(0.555)	(0.745)
Age (in years)	1.017**	1.013	1.025**	1.015
	(0.008)	(0.011)	(0.011)	(0.015)
Number of years lived in City of Lusaka	0.996	0.995	1.006	0.990
	(0.006)	(0.009)	(0.008)	(0.012)
Other				
Primary stove is electric	0.850	2.656**	1.003	1.259
	(0.328)	(0.416)	(0.526)	(0.480)
Number of Durable Goods	1.126***	1.029	1.160***	1.022
	(0.025)	(0.038)	(0.034)	(0.047)
Energy expenditure in last 4 weeks (in Kwacha)[7]	---	1.003***	---	---
		(0.001)		
Log of hygiene expenditure in last four weeks (in Kwacha)	0.988	0.938	1.133	1.133
	(0.109)	(0.155)	(0.128)	(0.276)

[6] One SupaMoto household answered no opinion which artificially inflated the odds ratio. This household was added to the "agree" factor.

[7] Energy expenditure was removed for any model which contained Already User households, as this would have changed after adoption.

Log of all other expenditures in last four weeks (in Kwacha)	1.150 (0.101)	1.082 (0.146)	1.046 (0.123)	1.589* (0.248)
Constant	0.021*** (1.355)	0.138 (1.760)	0.005*** (1.581)	0.004*** (1.922)
Observations	817	467	573	244
Log Likelihood	-495.774	-250.180	-303.744	-147.755
Akaike Information Criterion (AIC)	1,039.548	550.360	655.488	339.509
Bayesian Information Criterion (BIC)	1,152.483	759.909	416.447	654.018
Note:				*p<0.1, **p<0.05, ***p<0.01

Discussion

Our objective was to test the hypothesis that social capital plays a role in improved cookstove adoption Lusaka, Zambia. We operationalized social capital via survey questions as part of a baseline data collection effort by EPPSA and grouped them on a framework popularized by Putnam (2000) and Szreter and Woolcock (2004). Within those groups, as well as other household characteristic variables, yielded several interesting results.

First, with regard to the Trust social capital grouping (Respondent has confidence (or faith) in most people, Respondent can count on their neighbor to send an important letter or message), which was modelled closely after bonding social capital (an individual's closest, horizontal connections), agreeing to one question was found to increase the likelihood of adoption in prospective users as well as in VITALITE compounds.

Specifically, for VITALITE compounds, agreeing to two Trust questions increased likelihood of adoption by 127.6%. This was also the only social capital grouping that impacted adoption, which is interesting because it may suggest that their marketing strategy impacted a more homogenous, individualistic population with strong horizontal connections.

Next, with regard to the Community social capital grouping (Respondent participates in decision making in their community, Respondent feels part of the community), agreeing to one or both questions decreased likelihood of adoption for the prospective user compounds. This is unexpected, because we expected that if there were strong community ties then there would be higher rates of adoption, which is the opposite of this result. This result shows that if a household agreed to both Community questions likelihood of adoption decreased by 36.0%, so strong community ties lead to less adoption in this population.

Taken together with the Trust variable increasing likelihood of adoption, this indicates that there may be an individualistic element at play, where if the respondent has close connections, but does not feel part of the community, then they are more likely to adopt.

Next, for the Full Sample, VITALITE, and SupaMoto models, female headed households were more likely to adopt by 59.9%, 83.3%, and 96.7%, respectively. These results are as expected based on the current cookstove literature which accounts for gender (Lewis and Pattanayak 2012). This is an important finding to take into account when looking to increase adoption because, specifically, VITALITE and SupaMoto could increase adoption by targeting women's groups as part of their marketing strategy. This could include targeting spaces that are primarily

women occupied, for example, women's savings and credit groups. This result may also be indicating that, since women have the most health and time benefits from improved cooking technology, they are aware of this intended benefit.

Finally, with regard to other household characteristic variables, of interest was that for the prospective user compounds, having a primary stove that is electric increased likelihood of adoption by 165.6%. This suggests that people who are already cooking with clean technology understand the economic and health benefits and are likely to continuing to adopt as part of their energy stack. This is an important finding because it further suggests that when users are informed about the intended benefits, adoption has the potential to increase. Owning your home increased likelihood of adoption for the Full Sample, Prospective Users, and SupaMoto compounds, and an increase in the number durable goods increased likelihood of adoption for the Full Sample and VITALITE compounds, which suggests that people who have more economic capital were more likely to adopt. Lastly, for the Prospective User compounds, an increase of energy expenditure increased likelihood of adoption by 0.3%. By combining all of these physical capital variable results, economic barriers to adoption could be at play with this population.

Lastly, an increase of age of the household head increased likelihood of adoption for the Full Sample and VITALITE compounds.

With regard to other social capital studies in the cookstove literature, in the rural Northern Peruvian Andes, Adrianzén (2014) also found heterogenous results in their included bonding social capital variable, and concluded that because there is a social learning process present, then these findings are consistent with what should be expected of this process – "it must be stronger in villages with stronger bonding links." With regard to technology adoption more broadly, Bandiera and Radul (2006) studied farmers adopting a new crop (sunflower) in Northern Mozambique and found that farmers were more likely to adopt when some farmers in their network adopted but were then less likely to adopt if many famers adopted. This could account for the Trust and Community grouping results found in this study for the Prospective User compounds.

Conclusion

The intent of this work is to contribute to the literature on improved cookstove (ICS) adoption in urban Lusaka, Zambia. Specifically, the literature on the association between social capital and ICS adoption as well as the association between gender and ICS adoption. The findings presented here suggest that there are many key variables cookstove firms could target to increase the likelihood of adoption that are not dependent on individual household connections or choices.

This study found that within the Prospective User and VITALITE compounds, having increased bonding social capital increased likelihood of adoption. Specifically for the Prospective User households, in addition, having increased community level social capital decreased likelihood of adoption. This means that households who are adopting from this population have strong horizontal ties and weaker community ties, suggesting that they are more individualistic.

With regard to the role of gender and adoption, female headed households were far more likely to adopt than male headed households. This is consistent with what is seen in the current cookstove literature which account for gender. Women have the most to gain from adopting in

terms of health and well-being benefits, so this finding suggests that these women may be well informed of the intended benefits posed.

The results from this population show that VITALITE and SupaMoto probably would not have gained customers from targeting specific people in this community (e.g., doctors, government workers) since this was not a significant variable in this analysis. However, this analysis does show that targeting areas where there is strong bonding social capital (e.g., horizontal connections) would be beneficial for other private sector firms. In addition, marketing to groups and spaces which are women dominated, specifically women decision makers would also be beneficial. An example of these spaces could include women's savings and credit groups. Lastly, similar private sector firms would benefit from targeting households with increased economic capital, as seen by the results of this study where more durable goods, energy expenditure (for prospective users), and owning your home all increased likelihood of adoption, where these were significant.

This study has several limitations. First, this work quantified adoption as only having purchased the respective improved cookstove, not about usage or sustained adoption. For the broader environmental and health implications, adoption is only a small step towards more positive population level outcomes. For those benefits to take place at scale, sustained adoption is needed, which this analysis does not have any findings on. This research could be built on by seeing how social capital relations intervenes in sustained adoption. For example, if having connections that are engaging in long term use influences your household to also have long term use.

Second, social capital was not formally operationalized as specifically as the framework popularized by Putnam (2000) and Szreter and Woolcock (2004) of bridging, bonding, and linking. This work utilized the data available and adapted a framework influenced by these authors, rather than specific questions targeting the bridging, bonding, and linking groupings.

With regard to future research, this work could be built on by looking at any spatial dimension of social capital and ICS adoption. I hypothesize that there could be visible spatial effects to adoption in communities where people have strong horizontal ties to their close neighbors and friends. In addition, an important piece that needs to be studied in the cookstove literature more broadly is not only what impacts adoption, but what impacts sustained usage of the ICS. Whether or not social capital has an impact on sustained adoption would be a novel area of research.

While there are several areas where this work could be built upon, this work does contribute to the large gap regarding social capital and cooking technology adoption in Sub-Saharan generally, but the urban landscape of Zambia specifically. This work bolsters the previous findings in the literature that women are a strong component of adoption, which shows that my population and findings fit in with the findings of the broader improved cookstoves research.

Appendix One – Survey Questions Included in Analysis

From Baseline Survey

Household Characteristics:

- Energy Expenditure (purchased in the last four weeks):
  - charcoal, firewood, electricity, paraffin/kerosene, diesel fuels for genset (for lighting and cooking only), Gas (LPG), any of the following: batteries, light bulbs, lighters, matches, candles, pellets from SupaMoto, pellets/briquettes, and other.
- Hygiene Expenditure (purchased in the last four weeks):
  - bath and handwashing soap, toothpaste, laundry detergent, toilet paper, sanitary towels, and other tissues, cosmetics (lotions, creams, glycerin, make-up, petroleum jellies), hair care (perming, braiding, conditioning, shampooing, haircuts), laundry services (dry cleaning and washing), cleaning agents, and insecticides.
- All other Expenditure (purchased in the last four weeks):
  - salt, spices, and cooking oil, water and sewage charges, home repairs, cable/pay TV (DSTV, My TV, Satellite, ZNBC, etc.), garbage collection (solid waste), public transportation (to and from work, to and from school, other places), private transportation (petrol/diesel/oil, vehicle or motorbike maintenance and repairs, bicycle repairs, other), mobile phones (connection fees, air time, etc.), landline phones (connection fees, prepaid and postpaid), Internet (connection and subscription fees for Internet connection not connected to mobile phones), postal expenses, stationery, typing services, entertainment (cinema, disco, watching soccer/boxing, video hire, visits to entertainment centers), household employee wages, and other.
- Durable goods:
  - functioning radio, functioning TV, functioning VCR/DVD, functioning fan, functioning wall clock, functioning electric kettle, functioning microwave, functioning refrigerator, functioning generator or genset, bed with mattress, sofa/sofa set, table, chair, cupboard, functioning mosquito net(s), functioning telephone (other than mobile), functioning mobile telephone, functioning computer, internet connection other than mobile phone (ie dongle/Mifi), functioning sewing machine, functioning cassette player, functioning bicycle, functioning motorcycle/scooter, and functioning car/truck.
- On what basis does your household occupy the dwelling you live in? Is it… (owner occupied, rented from government, rented from private person, provided by employer, family home that you live in, other – specify)[8]
- Men usually make decisions on purchasing of cooking devices in my household. (disagree, agree, no opinion)
- Which stove was used the most during the last 30 days? (tradional three stone (mafuwa), improved fuelwood stove, traditional metal charcoal stove/brazier (mbaula) (stove of only metal with holes on sides), improved metal charcoal brazier (mbaula) (ie unpunctured metal with clay insert), paraffin/kerosene stove, gas cooker, electric cooker with an oven, electric cooker without an oven, ethanol/methanol stove, other – specify)[9]

Household Head Characteristics:

- Is [NAME] male or female?
- How old is [NAME] now?
- School questions combined into one variable:[10]

[8] Later merged into binary code for rent or own the dwelling

[9] Later merged into binary variable: primary stove is electric (with or without oven), primary stove is not electric

[10] Later merged into four level categorical variable: no education, some primary or completed, some secondary or completed, more than secondary

    - What grade/level of education is [NAME] currently attending?
    - Has [NAME] ever attended school?
    - What was the highest grade [NAME] attained?
- How long has this person lived in the CITY of Lusaka for? (Years)[11]

Social Capital:[12]

- Among your current acquaintances and relative, are there any who… (Yes/No)
    - Are doctors/nurses, or who work in hospitals and clinics?
    - Are teachers, school officials, or anybody who works in a school?
    - Are in government service? [other than doctors, teachers, above]
    - Works for an improved stove and/or fuel company
- I have confidence (or faith) in most people. (strongly disagree, disagree, strongly agree, agree)
- I can count on my neighbour to send an important letter/message. (strongly disagree, disagree, strongly agree, agree)
- My life is determined by my own actions. (strongly disagree, disagree, strongly agree, agree)
- I can make important decisions that can change my life. (strongly disagree, disagree, strongly agree, agree)
- I participate in decision making in my community. (strongly disagree, disagree, strongly agree, agree)
- I feel part of the community. (strongly disagree, disagree, strongly agree, agree)
- I have close friends or relatives I can talk to. (strongly disagree, disagree, strongly agree, agree)
- I participate in financial decision within my own household. (strongly disagree, disagree, strongly agree, agree)

<u>From Rapid Survey[13]</u>

- Were you or anyone in your household contacted by VITALITE/SupaMoto trying to sell you an EcoZoom/Mimimoto?
- Did your household purchase a EcoZoom/Mimimoto stove?

[11] Later merged into binary variable: <= 5years=0, >5 years=1

[12] All strongly agree, agree, strongly disagree, disagree questions were merged into a binary: disagree=0, agree=1

[13] These questions were combined to form the dependent variable

Appendix Two – Social Capital Groups

Linkages

- Among your current acquaintances and relative, are there any who… (Yes/No)[14]
    - Are doctors/nurses, or who work in hospitals and clinics?
    - Are teachers, school officials, or anybody who works in a school?
    - Are in government service? [other than doctors, teachers, above]
    - Works for an improved stove and/or fuel company

Trust (Bonding Social Capital)

- I have confidence (or faith) in most people. (0/1)
- I can count on my neighbour to send an important letter/message. (0/1)

Personal

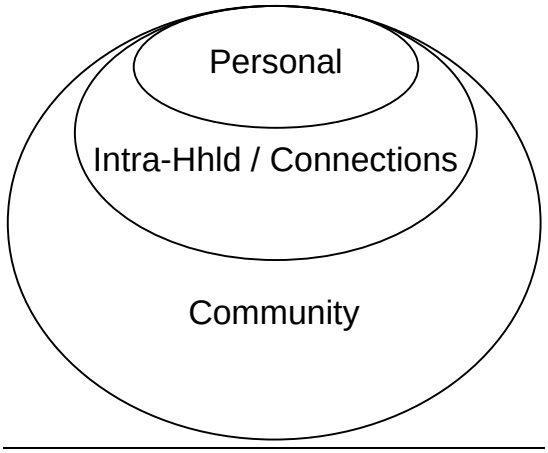
- My life is determined by my own actions. (0/1)
- I can make important decisions that can change my life. (0/1)

Intra-Household / Connections

- I have close friends or relatives I can talk to. (0/1)
- I participate in financial decision within my own household. (0/1)

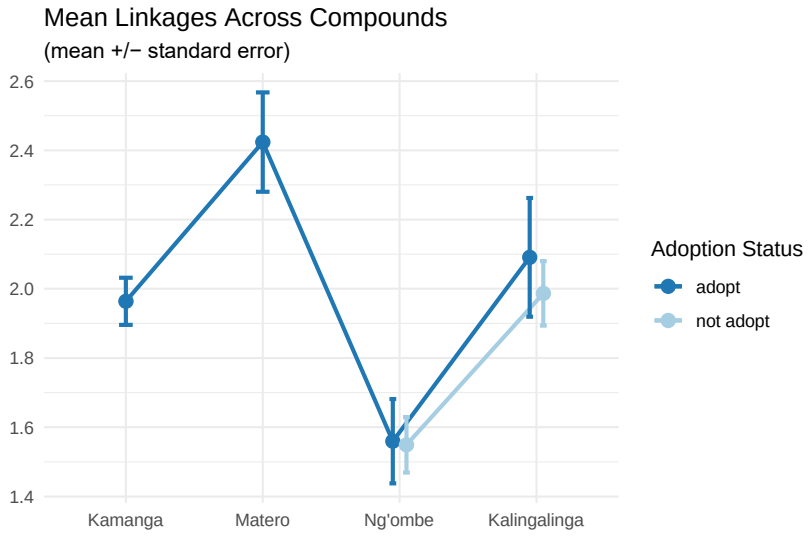
Community

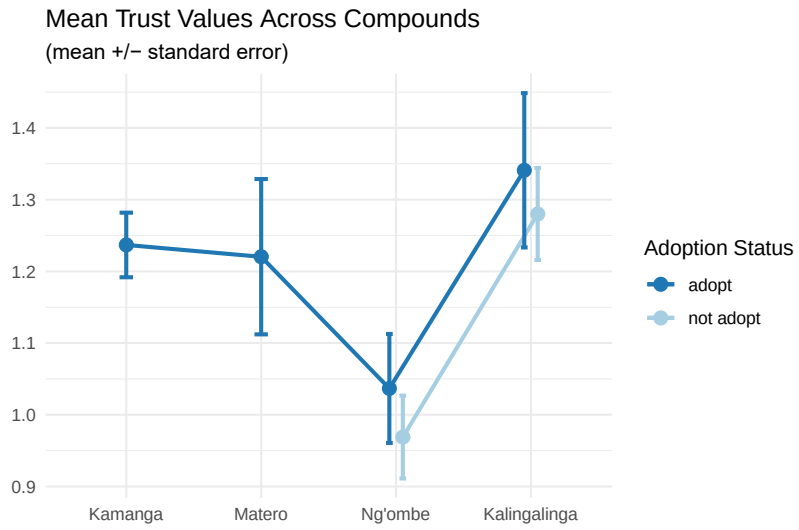
- I participate in decision making in my community. (0/1)
- I feel part of the community. (0/1)

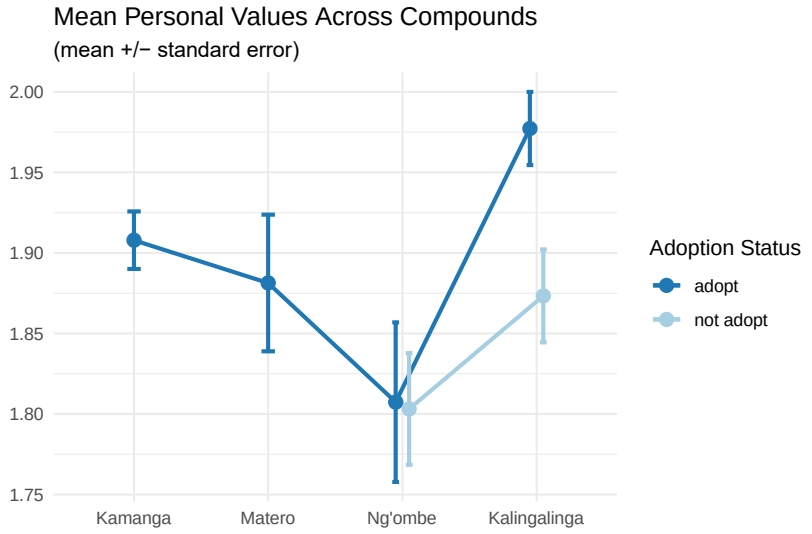


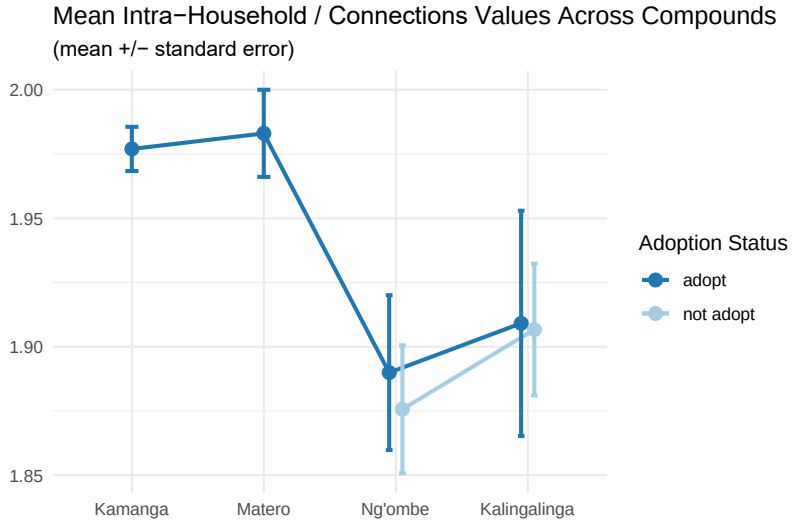
[14] Now a count variable 0-4; 0 being all "No"s, 4 being all "Yes"s

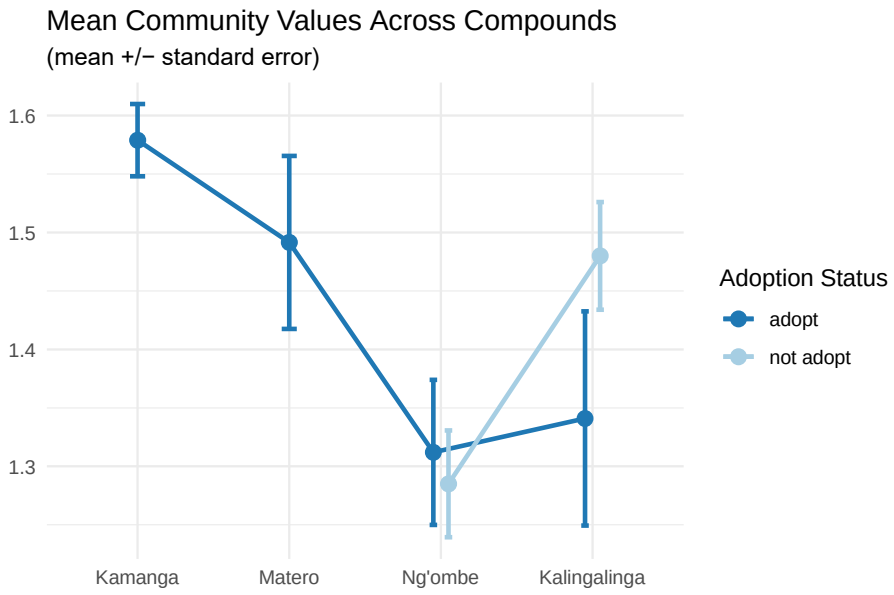
Appendix Three – Plotting Social Capital Variables










Mean Community Values Across Compounds
(mean +/− standard error)
1.6
1.5
1.4
1.3
Kamanga
Matero
Ng'ombe
Kalingalinga
Adoption Status
adopt
not adopt

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