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Yonas Alem and Remidius D. Ruhinduka[1]

Saving Africa's Tropical Forests through Energy Transition: A Randomized Controlled Trial in Tanzania

Abstract

The production of charcoal to meet cooking needs of urban households is one of the main causes of deforestation and degradation of Africa's tropical forests, which offer significant carbon sequestration capacity to the global economy. In collaboration with a reputable local microfinance institution, we designed a randomised controlled trial in urban Tanzania and offered LPG stoves through subsidy and on credit to measure their impact on charcoal consumption and the corresponding reduction in deforestation. We also investigate the impact of the stoves on cooking time of women, who are the default cooks of the household. We find that, relative to households in the control group, adoption of LPG stoves reduced charcoal consumption by about 30% in the treatment group 15 months after the intervention. This corresponds to an average reduction in deforestation of 0.04 ha/household/year. However, providing subsidies for stove purchases resulted in a larger reduction in charcoal use (38%) than did providing access on credit (27%) with the corresponding likely reduction in deforestation by 0.05 and 0.03 ha/household/year respectively. A social cost-benefit analysis suggests that the cost of both programs is far below the benefits of the averted carbon dioxide CO2 due to possible reduction in deforestation. A carefully conducted controlled cooking test shows that cooking with LP gas is 50% cheaper than cooking with charcoal and it reduces cooking time by about 44% - welfare effects clearly indicating that LPG is cost-effective to the household as well. We highlight the importance of relaxing households' financial constraints and improving access to credit to encourage urban households to switch to cleaner energy sources and save the remaining forest resources of Africa.

JEL-Code: G21, H31, O10, O13, Q23, Q51

Keywords: Charcoal; deforestation; carbon dioxide; LPG stoves, liquidity constraint, credit

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1 Yonas Alem (Lead Author), University of Gothenburg and RWI Research Network; Remidius D. Ruhinduka, University of Dar es Salaam. - Peter Berck was one of the co-authors and a professor at the Department of Agricultural and Resource Economics, University of California, Berkeley until he passed away on the 10th of August, 2018. He contributed to the inception and the design of the project and provided feedback on the first draft of the paper, which was written based on the findings from the midline survey. As per the recommendations of the Swedish Research Council and the Vancouver authorship guideline, we would like to acknowledge his contributions and dedicate this paper to him in his honor. Alem also gratefully acknowledges Peter's mentorship and academic guidance during his stay as a visiting scholar at the University of California, Berkeley. We also would like to thank Randall Bluffstone, Hakan Eggert, Andrew Foster, Gunnar Köhlin, Mikael Lindahl, Aprajit Mahajan, Edward Miguel, Subhrendu Pattanayak, Mans Söderbom, members of the energy research team of the International Growth Center (IGC) at the London School of Economics (LSE), seminar participants at the University of California, Berkeley, University of California, Davis, University of Gothenburg, Peking University, Renmin University of China, the Indian Statistical Institute, the Indian Institute of Economic Growth, the Rhine-Westphalia Institute for Economic Research (RWI), participants of the 9th EfD annual meeting in Shanghai; and the BERCKnomics conference in memory of Peter Berck, Haas Business School, UC Berkeley for helpful comments and suggestions on earlier versions of the paper. This randomised controlled trial was generously funded by IGC under grant 1-VRE-TZA-VXXXX-89225, which is gratefully acknowledged. Prior to implementation, the randomized control trial was registered in IGC's website and IRB approval was obtained from the University of Dar es Salaam. Part of this research was done while both Alem and Ruhinduka were visiting scholars at Brown University. - All correspondence to: Yonas Alem, University of Gothenburg, Schweden, e-mail: yonas.alem@gu.se

1. Introduction

Charcoal is the main source of cooking energy for households in urban areas of many Sub-Saharan African (SSA) countries (Campbell et al., 2007; WorldBank, 2009, 2014). In the urban parts of Tanzania - our focus in this paper - the proportion of households that use charcoal to meet their main cooking needs increased from 47 percent in 2001 to 71 percent in 2007, and the commercial capital, Dar es Salaam, alone consumes 500,000 tonnes of charcoal, half of the total annual charcoal consumption of the country (WorldBank, 2009). Unsustainable biomass fuel production and consumption has serious environmental and climatic implications. The use of charcoal for cooking in urban areas and firewood in rural areas of SSA has been a prime cause of deforestation and forest degradation (Campbell et al., 2007; Mercer et al., 2011), clearly resulting in loss of irreplaceable biodiversity and degradation of local ecosystems (Allen and Barnes, 1985; Geist and Lambin, 2002; Hofstad et al., 2009; Köhlin et al., 2011). In fact, scientific evidence shows that land use change, mainly driven by deforestation, is the second major contributor of global greenhouse gas emissions after fossil fuel combustion (Jayachandran et al., 2017). Biomass fuel, often burned in inefficient cookstoves, contributes further to climate change through its emission of other harmful greenhouse gases, such as black carbon and methane (Sagar and Kartha, 2007; Kandlikar et al., 2009; Grieshop et al., 2011). In an effort to slow down deforestation and forest degradation in developing countries and improve climate change adaption capacity, international donors, such as the European Union supported different climate action initiatives in the past decade. For example, to support the programs known as Reduce Emissions from Deforestation and forest Degradation (REDD) and REDD+ during 2006-2014 alone, the European Union and its member states spent over 3 billion Euros (EUR) of tax payers funds (EU, 2015).

At the household level, biomass fuelwood use is associated with indoor air pollution, which claims 3.3% of the global burden of disease, especially that of women and children, and causes about 3.8 million premature deaths per year (WHO, 2018). When households burn solid fuel, such as biomass fuels indoors, mostly using inefficient cookstoves, a range of harmful pollutants like PM2.5, small particles are emitted and inhaled deep into the lungs, which eventually lead to disability and death from serious diseases such as pneumonia, chronic obstructive pulmonary disease, stroke ischaemic heart disease and lung cancer (WHO, 2018; Díaz et al., 2007; Clark et al., 2007). Biomass fuel use also puts significant burden on women and children in many developing countries, where they are the main household members responsible for fetching fuel (WorldBank, 2011; Blackden and Wodon, 2006). In a recent experimental work, Alem et al. (2018) show that women in Northern Ethiopia spent about 32.5 hours per month fetching biomass fuel, while men spend only 1.5 hours per month.

Transition to cleaner fuels is therefore crucial to combat the adverse consequences of biomass fuel use, but it is conditional on adoption of appropriate cooking appliances, which can have significant financial implications for poor households, who will have to forgo consumption of other items to acquire them (Edwards and Langpap, 2005; Mobarak et al., 2012; Lewis and Pattanayak, 2012). Using randomised controlled trials, previous studies (Smith-Sivertsen et al., 2009; Miller and Mobarak, 2014; Hanna et al., 2016; Beyene et al., 2015; Alem et al., 2018; Bensch and Peters, 2015; Pattanayak et al., 2019; Mobarak et al., 2012; Beltramo et al., 2015; Levine et al., 2018; Berkouwer and Dean, 2020) have investigated the factors that promote adoption of improved biomass cookstoves and their impact on indoor air quality, health, and fuelwood consumption in rural areas of developing countries.[1] These studies identify affordability, social networks, availability of continuous technical support, cultural factors, technical designs that meet households' expectations and empowerment of women in rural areas as important factors that promote the adoption and continued use of improved biomass cookstoves. They also find that improved cookstoves reduce indoor air pollution, fuel use, and improve health of household members. The few existing studies focusing on adoption of modern (cleaner) cookstoves use observational data (Edwards and Langpap, 2005; Alem et al., 2014) and point out the high start-up cost as the key factor that hinders households from switching to appliances that use cleaner energy sources, such as LP gas and electricity.

The key question is then whether helping urban households relax liquidity constraints can induce them switch to modern cookstoves, or whether dependence on charcoal for cooking is driven by cultural factors that cannot be altered by public policy in the short-run. In this paper, we provide the first rigorous evidence on the causal effects of relaxing households' liquidity constraints to acquire high-cost cooking appliances (LPG stoves) on household welfare and the environment.[2] We collaborated with Tanzania's largest saving and credit cooperative (SACCO), called Women Advancement Trust - WAT SACCOS LTD - and randomly allocated households in Dar es Salaam, the largest city in the country, into a "purchase through subsidy" treatment and "purchase on credit" treatment, which constituted three types of credit repayment schemes (payback daily, payback weekly and payback monthly) repayable in six months. We quantify the impact of the two policy instruments on charcoal consumption and the corresponding reduction in deforestation and emission of carbon dioxide (CO_2). We also perform a social cost-benefit analysis of the two policy instruments and investigate the impact of LPG stoves on cooking times of women, who are the default cooks of the household in the African context. To the best of our knowledge, we are the first to conduct a rigorous randomized controlled trial on the impact of alternative policy instruments to enable households own modern, durable and costly cooking appliances and reduce charcoal consumption, deforestation, CO_2 emission and improve their welfare at the same time.

Our first outcome variable of interest is charcoal consumption and the corresponding reduction in deforestation and averted CO_2. We conduct comprehensive

[1] The only exception to these studies is the study by Pattanayak et al. (2019) who offer both biomass cookstoves and an electric stove to households in the Indian Himalaya.

[2] The two-burner LPG stove we use in this study costs 110 USD at the time of the baseline. The amount was equivalent to about 5 months consumption expenditure of an average urban Tanzanian. Section 2.3 describes the intervention and the stove in detail.

baseline, midline (4 months after the stoves have been distributed), and endline (15 months after the stoves have been distributed) surveys. Our results indicate that LPG stove adoption overall resulted in a significant reduction in total charcoal use by the treatment group. Specifically, intent to treat (ITT) estimates indicate that households in treated communities consumed 29.7% less charcoal compared to the control group 15 months after the stoves have been distributed. This amounted to a reduction in charcoal consumption from about 19.7 kg/week at the baseline to about 15.6 kg/week during the endline follow-up. We find larger reductions in charcoal consumption during the endline (38.2%) by subsidy households compared to credit households, who reduced charcoal consumption by 26.8%.

Almost all charcoal production in Sub-Saharan Africa, and most importantly in Tanzania, takes place through cutting down and burning trees from the natural forest and woodlands in a traditional and highly inefficient process with a conversion efficiency of 8-12 percent (WorldBank, 2009). The reduction in charcoal consumption due to transition to LPG stoves through our credit and subsidy interventions can therefore be translated into reduction in deforestation and net carbon dioxide (CO_2) averted in metric tones (MT), both of which offer significant benefits to the society at large. Liquified Petroleum (LP) gas is highly efficient cooking fuel whose vapor is removed from the atmosphere by natural oxidation in the presence of sunlight or by precipitation, thus it doesn't have an impact on the global climate when emitted in gas form (WAPGA, 2020). However, when burned, LP gas emits equivalent to 34% of the CO_2 emitted from cooking the same meal with charcoal (Johnson, 2009). Thus, accounting for the CO_2 emitted from LPG stoves, the reduction in charcoal consumption by treatment households all together is equivalent to 0.04 ha of forest and 3.91 MT of net CO_2/household/year; 0.03 ha (3.53 MT of CO_2) for the credit treatment group; and 0.05 ha of forest (5.03 MT of CO_2)/household/year for the subsidy treatment group.[3]

We use these figures to conduct a social cost-benefit analysis of the two policy instruments using the Social Cost of Carbon (SCC), which quantifies the monetary value of the benefits of stored CO_2. Results suggest that offering LPG stoves through credit costs USD 41.67 per LPG stove or USD 11.81 per MT of CO_2 averted, while subsidising LPG stoves costs USD 83.33 per LPG stove or USD 16.56 per averted MT of CO_2. Given the SCC of one MT of CO_2 estimated by the US EPA is USD 39 in 2012 prices (Jayachandran et al., 2017), we show that the total SCC value of averted CO_2 due to distribution of LPG stoves sums up to USD 137.66/LPG stove under the credit program and USD 196.21/LPG stove under the subsidy program. The net benefit of the programs would therefore be USD 95.99 and USD 112.88 per LPG stove for the credit and the subsidy programs respectively. It is clearly evident that the social benefit of both interventions is significantly higher than the monetary cost of implementing them.[4]

[3] In order to produce 1 ton of charcoal, 0.13 ha of forest and woodlands must be burned (WorldBank, 2009), and the average carbon stored in a ha of forest in a set-up similar to Tanzania is 153.5 metric tones (MT) (Hansen et al., 2013).

[4] Note that the social cost-benefit analysis results we reported above do not account for other

Africa's tropical forests have significant carbon sequestration capacity but are at greater risk than those in other parts of the world, disappearing three times faster than the world average (Mercer et al., 2011).[5] Our findings have significant implications for policies that aim at promoting transition of households to cleaner energy sources, and saving the remaining forest resources of the continent. Liquified Petroleum (LP) gas is a highly efficient and convenient cooking fuel, and Tanzania and many other SSA countries recently discovered huge stocks of natural gas, which is expected to play a significant role in the countries' economy by transforming the energy sector and boosting gross domestic product (WorldBank, 2017; Fulwood, 2019). The level of on-grid electrification, which could play a greater role in transition to even cleaner cooking sources, is the lowest in SSA compared to many other regions of the world and a massive amount of investment is required in the years to come to improve access to basic services, such as lighting, let alone electricity for cooking (WorldBank, 2019). Consequently, LPG can play a key role in energy transition in Sub-Saharan African countries in the foreseeable future. In fact, a careful four-months-long sample controlled cooking test that we conducted shows that cooking exclusively with LPG gas is almost 50% cheaper than cooking with charcoal. Given that reducing the startup cost of LGP stoves has significant impact on their adoption and consequently on charcoal use, deforestation, and emission of CO_2, governments, international donor agencies and other stakeholders should consider channeling resources to improve accessibility and affordability of LPG stoves to the poor.

The detailed cooking and energy use data we collected from both the treatment and control groups also enables us to identify the impact of adopting LPG stoves on cooking time. Households in developing countries spend a significant amount of time collecting biomass fuels for cooking. Both women and children carry a larger share of the burden of collecting fuelwood, and almost exclusively women do all household cooking, while doing other household work, such as looking after children. Consequently, women and children are the primary victims of health hazards from indoor air pollution due to biomass fuel use (WorldBank, 2011). While improved cookstoves have been shown to reduce cooking time in controlled laboratory cooking tests (Beyene et al., 2015), the empirical findings from the few studies that use randomized controlled trials are mixed. Bensch and Peters (2015) show that improved cookstoves facilitate cooking and allow for temperature regulation, which reduces cooking time in rural Senegal by about 75 minutes per day. Hanna et al. (2016) on the contrary document no significant effect on cooking time in rural India because households had to spend more time repairing their improved stoves. To the best of

benefits of preserving forests, such as, avoidance of other harmful gases (e.g., methane); reduction of indoor air pollution, which claims 3.8 million lives every year; and other ecosystem services of forests and the value of the biodiversity in them. These ecosystem services and benefits are difficult to quantify and beyond the scope of this paper. If these benefits are accounted for, the social benefit of shifting away from charcoal to LPG is likely to increase exponentially.

[5] Mercer et al. (2011) actually documents that 30 million ha of Africa's forest, an area equivalent to the size of Finland, was deforested during 2000-2010, and that 80% of the harvested wood was burned to meet cooking energy needs.

our knowledge, we are the first to investigate and quantify the time-saving impact owning modern cooking appliances.

Results suggest that treatment households reduced the amount of time spent on cooking by about 44 minutes/day at endline, i.e., 15 months after the stoves had been distributed. This corresponds to about a 44% reduction compared to baseline. Decomposition of the ITT effect by treatment type shows that households who adopted the stoves through subsidy used the stoves a bit more often and reduced cooking time by 61% per day, whereas those who acquired the stoves on credit reduced cooking time by 38% per day. The reduction in cooking time is consistent with the efficiency of LPG stoves, which, unlike charcoal stoves, are quick to light up and generate the heat required to cook food much more quickly. The benefits from reduction in cooking time (and possibly from exposure to flame and indoor air pollution) including the reduction in time spent to purchase charcoal daily, largely accrue to women, who can use the saved time for income generating job opportunities and other productive household activities such as child care or even leisure, which either way improves the welfare of women in developing countries.

Finally, the paper contributes to the literature on microcredit in developing countries. Whether micro-credit helps in reducing poverty and improving welfare is a question of great importance. Angelucci et al. (2015) in Mexico, Attanasio et al. (2015) in Mongolia, Augsburg et al. (2015) in Bosnia and Herzogovina, Banerjee et al. (2015) and Tarozzi et al. (2014) in India, Crépon et al. (2015) in Morocco, and Tarozzi et al. (2015) in Ethiopia attempted to study the impact of various types of microcredit interventions on different outcome variables of beneficiaries and document mixed results. We randomly allocate credit households into three different repayment schemes: "payback daily", "payback weekly" and "payback monthly". In addition to investigating the impact of microcredit on adoption of LPG stoves, charcoal consumption, and cooking time, our experimental design therefore enables us to shed light on the question of whether allowing households alternative repayment schedules affects repayment behaviour. The flexibility to pay back credit at different intervals is important for poor households, who often rely on a volatile informal sector for their livelihood and purchase consumption goods, including charcoal, on a daily basis. WAT SACCOS, the micro-finance institution we worked with, conveniently used the local mobile banking service (known as M-Pesa) which operates in Tanzania and neighbouring countries to collect back the instalments through simple mobile transfers.

Our results suggest that, compared to households in the "payback monthly" group - the reference group - households in the "payback daily" treatment group are likely to pay more by the end of the agreed credit period (i.e., six months after the stoves have been distributed). Those who were randomly assigned to the "payback weekly" treatment group also paid back more compared to households in the "payback monthly" group. By the end of the agreed contract period, households in the daily group paid back 88.6% of the credit, while those in the weekly and monthly groups paid only 84% and 76.3% respectively. When we gave an additional 3 months for those who lagged in their repayment, households in the daily group again paid more, with a final repayment rate of 91.12% (i.e., a default rate of only 8.88%), while those in the "payback weekly" and "payback monthly" groups increased their repayment rate to only 90.4% and 86.67% respectively. We argue that behavioural biases, such as procrastination, self-control problems and impatience (Duflo et al., 2011; O'donoghue and Rabin, 1999; Banerjee and Mullainathan, 2010; Thaler and Benartzi, 2004) combined with reliance on unstable source of livelihood likely explain the repayment behaviour of the weekly and monthly groups. The higher repayment success rate of the "payback daily" group can be considered as a practical example of the workings of the "Kaizen" principle, a leadership and goal-setting principle, which motivated us to design the different repayment schemes. The priciple postulates that bigger goals are easier to achieve when decomposed into smaller and manageable actions and goals that build up over time (Bisou, 2015; Imai, 1986; Maurer, 2014).[6] As we anticipated, it appears that it was easier for households to pay 30 daily instalments of 1200 Tanzanian Shillings (USD 0.67) that sum up to 36,000 Tanzanian Shillings (USD 20) over a month, instead of paying the same sum once a month.[7] This finding has important implications for policies that target offering new technologies to liquidity constrained poor households. Policymakers can use flexible repayment options to encourage uptake and utilisation of modern technologies, such as the LPG stoves we consider in this paper, which offer larger benefits to the household and the society at large.

The rest of the paper is structured as follows. The next section describes the experimental design, including the context, sample selection, and the treatments. Section 3 presents descriptive statistics and randomisation checks. Section 4 presents results on the impact of LPG stove adoption on charcoal consumption (consequently on deforestation and CO_2 emission), cooking time, credit repayment behaviour and a detailed cost-benefit analysis of the two policy instruments. Finally, section 5 concludes the paper.

2. Experimental Design

2.1. Context

Our study was conducted in Kinondoni and Temeke, two of the three districts of Dar es Salaam, the largest city of Tanzania. These two districts are located at the two extreme ends of the city, separated by Ilala, a third district. Ilala, which we used for the pilot, is the smallest district both in terms of geographical size and

[6]Kaizen, consisting of two Japanese words; kai (change) and zen (good) to mean "change for better", is a leadership and management principle originally developed in Japan and was popularised by the Toyota company after WWII, which put it into action and managed to achieve significant improvement in its productivity and profitability in a short time (Imai, 1986). The principle states that, instead of aiming for big goals and attempting drastic changes, people are likely to achieve the same goals by taking smaller actions and build on them over time (Bisou, 2015; Maurer, 2014). The principle is also consistent with one of Albert Einstein's famous remarks "compounding is the greatest mathematical discovery of all time" (Blau, 1983).

[7]At the time of the baseline survey, 1 USD = 1800 Tanzanian Shillings (TZS).

population.[8] Dar es Salaam is the most populous region in Tanzania (with nearly 5 million people) and over 70% of its population uses charcoal as their main source of cooking fuel (NBS, 2015). The heavy reliance on charcoal is evident from the open charcoal markets spread throughout the city. Approximately 1 million tonnes of charcoal is consumed for cooking in Tanzania annually and Dar es Salaam alone consumes half of this amount (WorldBank, 2009).

Tanzania has recently discovered huge reserves of natural gas, which is expected to play a significant role in the country's economy by transforming the energy sector and boosting the gross domestic product (WorldBank, 2017). Since 2010, several offshore natural gas discoveries have been made by the BG Group in partnership with Ophir Energy, and Statoil in partnership with Exxon Mobil, reaching around 30 trillion cubic feet of recoverable natural gas reserve. With more discoveries envisaged, a pipeline has been constructed to transport natural gas from Mnazi Bay (the central point of discovery) to Dar es Salaam. These discoveries are expected to significantly reduce the cost of gas and electric energy and create the incentive for households to switch away from charcoal to meet cooking energy needs. However, this transition could be significantly constrained by the relatively high startup cost of modern cooking appliances, especially for poor households. Findings from the baseline survey, which we present in the next sections, support this skepticism. Almost all households we surveyed (99 percent) reported a high level of awareness about LPG stoves and their benefits, but felt constrained not to adopt them, mainly because of the high initial cost.[9]

Our study is conducted at an important time to provide useful and policy relevant evidence on the constraints that households face in adopting modern cookstoves and switching away from charcoal, as well as the roles public policy can play in tackling these constraints. Given the similarities of many Sub-Saharan African countries with Tanzania in terms of access to energy and living conditions, the findings from this study will also have significant relevance to these countries.

2.2. Sample Selection

In order to conduct our experiment, we chose two wards from each of the Temeke and Ilala districts, from a total of 34 and 30 wards respectively.[10] We chose Sandali and Azimio wards from Temeke district, and Manzese and Mwananyamala wards from Kinondoni. The selected wards are home to a majority of the low and middle-income urban households in Dar es Salaam and share similar socioeconomic characteristics, but are located at a distance from each other. The wards benefited reasonably equally

[8] See section 1 of the online appendix for map a of Dar es Salaam city.

[9] Currently, less than 4 percent of households in urban Tanzania own modern cooking stoves such as electric or gas stoves (NBS, 2015).

[10] The randomized controlled trial was reviewed and approved by the energy research program group of the international growth center (IGC) based at the London School of Economics (LSE). The project was registered and posted on IGC's website before implementation. See: https://www.theigc.org/project/liquidity-constraint-lpg-stoves-charcoal-consumption-evidence-randomised-controlled-trial-tanzania

from the Community Infrastructure Upgrading Program (CIUP) implemented by the Dar es Salaam city council between 2005-2010. The program involved improving the quality of roads, footpaths, drainage, sanitation, solid waste, street lighting, public toilets and drinking water (URT, 2004, 2010).

We approached ward secretaries - government officials responsible for administrating wards under districts - to provide us with the list of all sub-wards, the lowest administrative units in urban areas (also known as streets), ranked by the average economic status of resident households. We then selected the top four streets by their rankings in terms of economic status from each ward to participate in our study, which gave us a total of 16 streets. The key argument for selecting households this way is the fact that re-filling LPG gas once the startup gas runs out requires a bulk purchase (as opposed to low cost daily purchase for charcoal, which is common in the city) and, thus, the targeted population should be able to afford such costs. Finally, we asked the 16 sub-ward leaders to prepare a roster of eligible households in their streets, from which we randomly selected a total of 722 households to participate in the baseline survey.[11] Eligibility criteria required that the selected households never owned/used an LPG stove and used charcoal (but not kerosene) as their main source of cooking energy.[12]

In order to minimise contamination (spill-over effects from treatment groups to the control group), we assigned treatments at street (sub-ward) level. The sampled streets are scattered across the districts and are reasonably large by geographical size and demographics, with an average of about 3000 households in each sampled street. Street-level randomization also makes implementation of the program relatively easier as it seems fair from the households' point of view, and is politically acceptable to the ward leaders. It is therefore important to note that our randomization is done at street-level but the outcome variables of interest are measured at the household-level.

We are interested in answering four key research questions: first, we want to identify the impact of LPG stoves (regardless of their mode of acquisition) on charcoal consumption, and the corresponding reduction in deforestation. Second, we are interested in exploring whether the impact on charcoal consumption is different depending on the mode of acquisition (subsidy or credit). Third, we want to assess the impact of LPG stoves on cooking time of women, who take the sole responsibility for cooking including purchasing charcoal from the market. Finally, we are interested in investigating if the repayment scheme affects credit repayment behaviour. We randomly assigned five streets into the credit treatment and four streets into the subsidy treatment; we kept the remaining 8 streets as the control group. As a result, 216 households were potentially assigned to the credit treatment, 209 to the subsidy treatment and 297 to the control group.

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[11] We specifically divided the total number of households in each sub-ward by the proposed sample size of households in the ward to get a number, say x. Then we pick every x^{th} household from the roster.

[12] The proportion of households that use kerosene gas in Dar es Salaam is only about 7.8% (NBS, 2015).

2.3. Treatments and Timeline of the Experiment

We obtained a research permit for this project from the office of Dar es Salaam Regional and Districts Administrative Secretaries, and implemented a fact-finding survey of 40 urban households during October-November 2014. The aim of this survey was to document both qualitative and quantitative background information about knowledge, adoption and usage (and non-usage) of both LPG and charcoal stoves in all districts, important information that we later use to design our interventions. We designed a short questionnaire and conducted a few focus group discussion sessions that allowed us to obtain informative responses. At this stage, we also included a set of questions on households' maximum willingness to pay for an LPG stove package. We found encouraging responses from households regarding knowledge and willingness to adopt LPG stoves. We also found out that the high start-up cost of LPG stoves seemed to be the main factor that hindered households from acquiring the stove.

We conducted a comprehensive baseline survey during March-April 2015, covering all 722 sampled households in the 16 sub-wards. In the baseline, we included questions on demographic and other socioeconomic characteristics, cooking habits, charcoal consumption, stove use, and awareness and willingness to pay for LPG stoves. This was important information given that the cost of acquiring the stove package is reasonably high and it is natural that some households may not be willing to buy it either on credit or through a subsidy. In addition to household-level information, we collected community-level information such as distance to the nearest charcoal market, access to roads, etc.[13]

In early May 2015, we conducted a pre-intervention survey to check whether the households who were assigned to the treatment group were available. During this time, we informed the treatment group that their household was one of the households randomly selected to receive an LPG stove through a subsidy or credit and that the stoves were planned to be delivered approximately 1-2 weeks after the pre-intervention survey. The households were then asked whether they would like to be a part of the program. Out of the 425 households who were randomly chosen to participate in the program, 292 agreed to purchase the stoves, and the remaining 133 households (31%) declined to participate (72 in the credit treatment group, and 61 in the subsidy treatment group). The treatment effects we compute in the results section account for the households who did not take up the stoves.

We implemented the LPG stove program in collaboration with a Saving and Credit Cooperative (SACCO) named "Women Advancement Trust, Saving and Credit Cooperative Society Limited" (WAT SACCOS LTD), which helped us with handling the delivery of the stoves and collection of repayment installments for the credit treatment households. WAT SACCOS is one of the fast-growing saving and credit cooperatives that are working to provide access to micro-finance for the urban poor. It has gained a good reputation and credibility in disbursement and handling of different types of loans, including micro-credit to finance the purchase of household

[13] See section 3.1 of the online appendix for the baseline questionnaire.

durables.[14] In order to make the loan credible and minimize the default rate, we followed all procedures for getting such loans as per the rules of WAT SACCOS, but with a few modifications to suit the objectives of this study. For example, we did not require households to present any physical asset other than the stove itself as collateral. They were also required to provide a letter of guarantee from their local government offices, which in a Tanzanian context offers a credible commitment device.

The intervention was implemented in late May 2015. We purchased the full LPG package from Oryx Energies, the largest distributer of fuels, LPG and lubricants in Tanzania and other East African countries.[15] All households selected for the treatments were invited for an information and training meeting by Oryx Energies before they were handed the LPG stove in its full package. The training included instructions on how to safely use, clean, maintain and re-fill the LPG stoves once the startup gas runs out.[16] Households in the subsidy treatment received the stove at 75 percent subsidy, i.e., they paid only 25 percent of the full cost. At the time of delivery, the full cost of a two-burner LPG stove (including a 15 liter cylinder filled with gas) was 200,000 TZS (about USD 110). We decided to subsidize 75 percent of the cost of the LPG stoves because the average reported willingness-to-pay for the stoves during the baseline was about 65,000 TZS, which was slightly lower than a third of the market price of the stoves.[17]

The credit treatment included three randomly determined repayment schemes: payback daily, payback weekly and payback monthly. When designing these repayment schemes, we were inspired by the "Kaizen" principle, a leadership and goal-setting principle, which postulates that bigger goals are easier to achieve when decomposed into smaller and manageable actions and goals that build up over time. Moreover, a large proportion of households in urban Tanzania (75% of our sample of households) purchase charcoal on a daily or weekly basis, which makes charcoal use convenient. The three types of credit repayment schemes therefore mimic charcoal purchase habits of our sample of households as well. All credit treatment households were required to pay TZS 20,000 (i.e., 10% of the total loan) upfront as their initial re-payment on the day of stove delivery. They were also provided with extra instruc-

[14]See "http://watsaccos.co.tz" for more information about WAT SACCOS Limited.

[15]We purchased the LPG stoves through the University of Dar es Salaam following its full purchasing regulations. Sealed bids were collected from several suppliers and Oryx Energies won the bid by offering the same quality LPG stoves and cylinders as offered by other suppliers at the lowest price.

[16]See section 2 of the online appendix for pictures taken during training sessions and home visits.

[17]A more informative approach would have been to implement different levels of subsidy arms and determine the optimal level of subsidy based on uptake data. Unfortunately, we were not able to do so due to the high-cost nature of the interventions. The project costed around USD 172,000 of which USD 148,00 was generously offered by the International Growth Center (IGC) of the London School of Economics (LSE), and USD 24,000 was contributed by the Environment for Development (EfD) initiative of the University of Gothenburg. In the results section, we conduct a cost-benefit analysis of the two policy instruments and argue that subsidising LPG stoves at a 75% subsidy rate will still offer net benefits to society in terms of saving forest resources and averting emission of CO_2.

tions regarding their specific credit scheme, including how to fill in the application forms and how the repayments would be collected, etc. All participants were allowed to ask as many questions as they wished and answers were given by the survey team. To minimize the associated transaction costs and inconvenience, we required credit households to transfer the repayment installments to a given mobile phone account managed by WAT SACCOS using the mobile phone banking system known in the region as M-Pesa. The transfers were set to be made during the working hours of either each working day of the week, every Monday or every 30^{th} day of the month, depending on the treatment type. The complete loan repayment period was set to be six months after delivery of the stove, with repayment rates of either TZS 1,200 per day, TZS 8,350 per week or TZS 33,350 per month, depending on the treatment type. We did not charge any interest on the loans, but required beneficiary households to cover minor transaction fees charged by M-Pesa operators during loan repayment. This can be considered as an implicit interest rate on the loan. Finally, the control group was offered to buy the complete LPG package at the full market price.

We then conducted a midline follow-up survey at the end of September 2015 - approximately four months after the stoves were distributed - to collect information on key outcome variables of interest, including charcoal consumption, LPG stove use, compliance with treatment, and satisfaction with the stoves.[18],[19]

Finally, in order to assess the longer term impact of our interventions, we conducted a comprehensive end-line follow up survey during August, 2016, i.e., 15 months after the interventions. We documented detailed information on household and community characteristics, cookstove use, energy use and consumption, cooking habits, and LPG stove use and satisfaction.[20]

3. Descriptives, Randomization Checks and Attrition

Table 1 presents descriptive statistics of key household socioeconomic characteristics, cooking pattern, charcoal use and reported demand for LPG stoves at the baseline. Panel A shows that the average age of the household head is about 48 years, the majority of whom (70%) are male, and the average education is 7.5 years of schooling, which is slightly higher than the standard primary school level in Tanzania (7 years). About half of the sample households live in privately owned households, but only 41% have access to a separate private kitchen, the remainder either cooking in their corridors or sharing a kitchen with other households. Consistent with our expectation, the majority of our sample households are low-income urban dwellers with average reported mean annual income of TZS 309,000 (about USD 172). We notice, however that the reported average daily expenditure on basic consumption items is

[18] See section 3.2 of the online appendix for the midline questionnaire.

[19] We initially planned to conduct the mid-line survey six months after the stoves were distributed. However, the 2015 Tanzania National Election was scheduled in October 2015. In order to avoid interference in our survey due to election related activities, we instead decided to conduct the mid-line survey in September 2015, four months after the intervention.

[20] See section 3.3 of the online appendix for the endline questionnaire.

TZS 9,600, which, on an annual basis is nearly eleven times larger than the reported income. This overwhelming difference provides additional evidence that, compared to consumption expenditure, income in developing countries is significantly under-reported (Deaton, 1997; Deaton and Grosh, 2000). In our subsequent analysis, we rely on consumption expenditure to control for economic status of households in regressions.

Table 1 about here

There is a large dependence on charcoal to meet cooking energy needs by households in urban Tanzania (Panel B). The average household cooked using charcoal for about 23 years and consumes about 19.18 kg of charcoal per week, which costs about 11,200 TZS. Our sample of 722 households therefore consume 13,848 kg or about 13.85 tonnes or charcoal per week, which translates to about 59.5 tonnes per month. We use insights from WorldBank (2009) to shed light on the devastating consequences of charcoal use. It requires 0.125 hectares of woodland forest to produce 1 tonne of charcoal in Tanzania. Our sample of 722 households therefore deplete an equivalent of 7.44 ha of forest every month. When it comes to the intra-household decision on the choice of cook stoves, only 44 percent reported that the head is the main decision maker about the type of stoves to be used by the household. This suggests that, on average, spouses (wives) have fairly strong decision-making power when it comes to acquisition of kitchen appliances. The type of meals cooked by the household could influence the amount and type of fuel used due to the cooking time and taste of food. During the fact finding survey, a few respondents argued that, while rice tastes better when cooked on a charcoal stove, it takes significantly longer to boil beans (the main ingredient for the complementary sauce) on the stove. Our baseline data suggests that nearly half of the sample cook rice very often, with about 19 meals cooked per week.

The low adoption of LPG stoves in Dar es Salaam seems to be mainly driven by liquidity constraint. Panel C of Table 1 reports that 99 percent of the sample households knew about LPG stoves and 80 percent know someone within their close network who uses the stove. However, 93 percent of the the sample households reported the high startup cost of the stove package as the main constraint to their adoption. Difference in taste of food cooked using LPG stoves does not seem to be an important reason for not owning LPG stoves for almost the entire sample. Only 2 percent reported it as the main reason for not owning an LPG stove. This could be partly because none of the households in our sample used an LPG stove previously so they did not experience the taste of food cooked using the stove. Later in the results section, we show that treatment households are highly satisfied by all features of the LPG stove, including stove quality, stove functioning, food taste and stove convenience. When asked if they wish to have an LPG stove in the future in case their economic status improves, a staggering 96% of our sample households replied “yes” but their reported average willingness-to-pay for the stove package is only TZS 63,420, which is only 32% of the market price (200,000 TZS) of the stove package in Dar es Salaam.

Randomisation of treatment should ensure that on average treatment and control groups have similar baseline characteristics. In order to check this, in Table 2, we present means of several key characteristics of households in both groups, as well as test results for the null hypothesis that the difference in means is statistically significantly not different from zero. For nearly all the variables presented, the difference in means is not statistically different from zero. The exceptions are that there is a statistically significant difference in the means of the variable "household size" between the control and the credit treatment groups (at 10%); in the variable "wish to own an LPG stove in the future" between the control and credit treatment groups (at 5%); and in the reported "maximum willingness-to-pay" between the control and subsidy groups (at 5%). Although these differences are unfortunate, we don't think they will bias our results because, the magnitude of these differences is not large, and we will re-estimate our treatment effects after controlling for them in the regressions.

Moreover, as described in Section 2.3, around 31% of households who were assigned to the treatments (72 households in the credit treatment group and 61 households in the subsidy treatment group) declined to uptake the stove. We ran a simple OLS regression on uptake as a function of the treatments and baseline covariates and report the results in Table 3. The regression results suggest that households did not self-select themselves based on the type of treatment, i.e., uptake did not vary by treatment. No household in the control group acquired the LPG stove at the market price. This is expected, because the descriptive statistics reported in Table 1 indicate that 99% of the households know about LPG stoves and the high market price of the appliances is the key reason for not owning one.

Table 2 about here

Table 3 about here

During the midline survey, which we conducted about 4 months after the intervention, the proportion of households who changed their residence and we could not track was only 3%. However, the proportion increased to about 27% during the endline survey, which we conducted 15 months after the intervention. It is common to encounter a larger rate of attrition in urban areas than in rural areas of developing countries (Bandiera et al., 2015). As shown in Table 1, during baseline, about half of our sample of households lived in rented residential places. By the time of the endline survey, several households had moved to rented apartments in other parts of the city. While the survey team managed to track some of them using their cell phone numbers, others could not be tracked, and, thus, we could not document endline information for these households.

In order to check if attrition in our sample has been systematic, we run an OLS regression for the correlates of attrition and report the results in Table 4. The dependent variable is a dummy equal to one if the household could not be tracked by endline. Column 1 controls for being treated (LPG acquisition either on credit or through subsidy). Column 2 differentiates the correlates of attrition by the type of intervention. Column 3 controls for other baseline characteristics in addition to the type of treatment. Results in all columns suggest that none of our interventions are statistically significant in predicting attrition. Column 3 however, shows households living in their own residential property are less likely to leave and the correlation is statistically significant at the one percent level. In the results section, we compute treatment effects, which account for attrition.

Table 4 about here

4. Results

4.1. Specification

Given the randomised nature of our design, we can identify the impact of adoption of LPG stoves on charcoal consumption and cooking time from the single mean differences between treatment and control groups in an OLS regression. As participation in our interventions (both credit and subsidy) are voluntary, not all households who have been assigned to the interventions take-up the offer. Consequently, we focus on intent-to-treat (ITT) impacts. Given the random assignment of sub-wards to treatment, we can estimate the ITT impact of the LPG credit and subsidy programs using the following OLS specifications.

$$y_{ijt} = \alpha + \gamma treat_j + \beta X_{ij0} + \varepsilon_{ijt} \tag{1}$$

and

$$y_{ijt} = \alpha + \eta credit_j + \theta subsidy_j + \beta X_{ij0} + \varepsilon_{ijt} \tag{2}$$

where y_{ijt} represent our key outcome variables of interest, charcoal consumption and cooking time by household i in sub-ward j at 4 months ($t = 1$) and 15 months ($t = 2$), *treat* is a binary indicator for either credit or subsidy treatment, *credit* and *subsidy* refer to binary indicators of treatment type, X_{ij0} are control variables at the baseline, and ε_{ijt} is a random error term that we allow to be clustered by sub-ward. γ, η and θ are the coefficients of interest, which measure the ITT impact of our credit and subsidy interventions, and β is the vector of the coefficient of control variables.

In order to minimise measurement error in the key outcome variable of interest - charcoal used for cooking - during all the three surveys, households were asked to keep a record of the quantity of charcoal used during the most recent week using the local measurement units. We visited four charcoal markets in each ward and constructed average conversion factors to standard units by measuring each available local unit using a digital scale. We then converted all local units reported by households into standard units using these conversion factors.

4.2. Charcoal Consumption

We begin with results from the simple mean comparison of charcoal consumption between the treatment and control groups during the baseline, mid-line (4 months after the interventions) and endline (15 months after the interventions). Figure 1 reports weekly charcoal consumption by both treatment and control groups. While the control and treatment groups reported almost similar amounts of charcoal consumption per week during the baseline (19.73 kg and 18.79 kg respectively), treated households consumed 4.35 kg less (20.11kg - 15.76kg) compared to the control households during the midline, and 4.42 kg less (20.03kg -15.61kg) during the endline. Both these effects translate into a large reduction in charcoal use which is statistically significant at the one percent level.

Figure 1 about here

Table 5 provides formal empirical estimation of intent to treat (ITT) from an OLS estimator. Columns (1) & (2) present the results for the impact of adoption of LPG, regardless of the treatment type at the midline. In columns (3) & (4), we extend the analysis by controlling for the type of treatment (subsidy and credit), and for key covariates and cluster (sub-ward) fixed effects. This is very important from a public policy point of view given the ongoing debate about the idea that people tend to value and use goods less when they receive them at a lower price (Hoffmann, 2009; Hoffmann et al., 2009; Cohen and Dupas, 2010). Consistent with the observation in the mean comparison presented in the previous table, column 1 of Table 5 suggests that, compared to the treatment group, LPG adoption reduced charcoal consumption by about 37.6 percent per week four months after the interventions. Controlling for baseline covariates and sub-ward fixed effects increases the impact to 62.8 percent. When we assess the impact by the treatment type controlling for baseline covariates and sub-ward fixed effects, results in column 4 suggest a larger impact (66.5 percent) for the households who acquired LPG stoves through credit compared to the control group, than those who purchased the stoves through subsidy (53.8 percent).

Table 5 about here

In columns (5) - (8), we investigate the impact of adoption of LPG stoves at endline - 15 months after the stoves have been distributed. This is important given the recent finding on improved stoves that, after stoves have been adopted, households might not continue using them for several reasons (Hanna et al., 2016). Results remain quite robust 15 months after the intervention, although the magnitude of the treatment effects declined compared to the midline. On average, LPG adoption reduced charcoal consumption by 29.7 percent (column 6), acquiring the stoves through subsidy resulted in a 38.2 percent reduction in charcoal use, and acquiring them on credit led to a 26.8 percent reduction in charcoal use (column 8). The ITT effects reported in both columns control for baseline covariates and sub-ward fixed effects and the standard errors are clustered at the sub-ward level.

It is evident from column (4) of Table 5 that, during the midline, credit households reduced charcoal consumption by a larger magnitude (12.7 percentage points more) than the subsidy treatment group. During the endline, however, subsidy households reduced charcoal consumption by 11.4 percentage points more than credit households (column 8). The difference in charcoal consumption at endline is consistent with the difference in stove use and gas refill behaviour between subsidy and credit households which we discuss in section 4.4 in detail. Households in the subsidy treatment group used the stove and refilled LP gas more often than the credit treatment group and, consequently, reduced charcoal consumption by a larger magnitude. The main reason for such a difference is likely to be liquidity constraint. Households in the subsidy group acquired the stove at a much cheaper cost (with only 25% of the full cost of the stove) than credit households who had to pay the full price of the stove, albeit in 6-9 months period of time. Thus, it is plausible that subsidy households could better afford paying for the LP gas than credit households, and consequently use it more often and reduce charcoal consumption at a larger magnitude. However, we note that, in all ITT regressions that estimate the impact based on treatment types, the difference in the credit and subsidy treatments is not statistically significant. We will discuss the implications of this in the section 4.6.

The large reduction in charcoal consumption due to the use of LPG stoves can easily be translated to reduction in deforestation and averted carbon dioxide (CO_2). According to WorldBank (2009), all charcoal consumed in Tanzania is harvested unsustainably from dry woodlands located up to 200 kilometers away from urban areas. Charcoal production takes place using a traditional and highly inefficient process with a conversion efficiency of 8-12 percent. In order to produce the 1 million tonnes of charcoal consumed annually in the country, nearly 125,000 hectares of forest is destroyed. This is equivalent to 0.13 ha of forest to produce 1 tonne of charcoal. The average household in our sample consumed 19.18 kg of charcoal/week, 82.2 kg/month or 986 kg (approximately 1 tonne) per year at baseline, which translates to 0.13 ha of forest per year. Multiplying by the number of households in the sample, i.e., 722, yields charcoal consumption of 13,848 kg/week, 59,348 kg/month, or 711,892 kg (approx. 712 tonnes) per year, which translates to 92.6 ha of forest. Introduction of LPG stoves on average reduced charcoal consumption by 29.7% 15 months after the intervention. This implies saving 0.04 ha of forest per household or 27.50 ha of forests for the entire sample of households per year. The average carbon stored per hectare of forest cover in a similar set-up as Tanzania is 153.5 metric tones (MT) (Hansen et al., 2013). Introduction of LPG stoves therefore averts emission of approximately 5.93 MT of CO_2 per household per year from forests. This implies averting emission of 4,282 MT of CO_2 from forests for the entire sample of households per year. Decomposing the treatment effects by treatment type implies averting 0.03 ha (5.35 MT of CO_2) and 0.05 ha (7.62 MT of CO_2) of forest per household per year through the credit and subsidy treatments respectively.

Despite being highly efficient and relatively clean, LP gas is still fossil fuel and, when burned, it emits CO_2. Thus, some of the averted CO_2 through saving deforestation and charcoal burning will be compensated (emitted) by cooking with LPG stoves. Research shows that cooking with LPG emits CO_2 equivalent to only 34% of the CO_2 emitted when cooking with charcoal (Johnson, 2009).[21] It is therefore reasonable to assume that the net averted CO_2 is 3.91 MT/household/year for the treatment group in general, and 5.03 MT and 3.53 MT/household/year for the subsidy and credit treatment groups respectively. In section 4.6, we conduct a cost-benefit analysis of the interventions in terms of the monetary value of the forest saved and the corresponding averted CO_2, and compare with the cost of the interventions.

[21] Johnson (2009) uses emission data from 300 grilling sessions using charcoal and LPG grill systems (150 sessions for each systems) and shows that grilling with charcoal emits 6.7 kg CO_2e per grilling session, while grilling with LPG emits only 2.3 kg CO_2e.

4.3. Cooking Time

Figure 2 presents a simple mean comparison of daily cooking time between treatment and control groups during the baseline and endline.[22] Panel A shows that, at baseline, there is no statistically significant difference between treatment and control groups, with the former spending about 101 minutes, and the latter about 102 minutes/day on cooking. However, 15 months after the LPG stoves have been distributed, treatment households spent only 59 minutes per day on cooking, compared to control households, who still spend about 103 minutes, comparable to the baseline amount. This implies around a 42% reduction in cooking time, a significant impact of owning a modern and efficient cookstove, which makes it convenient and quick to heat up and cook on two burners at the same time.

Figure 2 about here

We present intent-to-treat estimates of the impact of adopting LPG stoves on cooking time in Table 6. Column (1) & (2) report ITT effects of LPG adoption on cooking time regardless of the type of treatment at endline. Columns (3) & (4) extend the analysis by controlling for the type of treatment (subsidy and credit), baseline controls and sub-ward fixed effects respectively. Consistent with the results in the mean comparison presented in figure 2, column 2 of Table 6 suggests that compared to the treatment group, LPG adoption reduced cooking time by about 44% per day 15 months after the interventions. Assessing the impact of LPG stove ownership by treatment type (column 4) again reveals relatively larger impacts (60.9% reduction) for the subsidy treatment group than the credit treatment group (38.3% reduction).

Table 6 about here

The overall reduction in cooking time has significant implications on household production, and female and children's empowerment. The majority of fuelwood fetching and household cooking in developing countries (almost 100% in our sample) is done by women, who also endure the hazards from cooking and very often are multi-tasking, e.g., looking after children while cooking (WorldBank, 2011; WHO, 2018). In addition to all its adverse environmental, climatic and health impacts, charcoal takes time to light up and get ready for cooking. Moreover, cooking an additional meal at the same time requires an additional charcoal stove. It is all these adverse consequences that are tackled by using a modern and efficient cookstove, such as the type of two-burner LPG stove we offered to treatment households in urban Tanzania. Although we did not collect detailed information on time use of mothers due to the limited scope of our study, it is plausible to expect that the extra time saved is often used to engage in extra income earning activities, child care, and leisure, all of which have significant welfare-enhancing impacts on household members in general and women in particular.

[22] Unfortunately information on cooking time was not collected during mid-line.

4.4. LPG Stove use and satisfaction

In addition to identifying the impact of LPG stove adoption on charcoal use and cooking time, it would be insightful to investigate how often adopter households use the stoves and whether the intensity of use differs across treatments. One could anticipate that provision of LPG stoves would encourage households to switch from charcoal to LPG. However, existing empirical evidence (Masera et al., 2000; Heltberg, 2005) suggests that households may continue to use the charcoal stove in combination with the LPG stove, a phenomenon known as "fuel stacking". To shed light on this, we collected information on weekly stove use both at midline and endline for the two treatment groups and report the descriptive results in panel (a) of Figure 3. The results suggest that credit and subsidy households used the stove 12.21 and 11.69 times per week respectively during midline with no statistically significant difference in use. At endline, however, credit households used the stoves 8.03 times per week, while subsidy households used them 9.83 times per week, and the difference is statistically significant at the 10 percent level.

Figure 3 about here

In Panel A of Table 7, we use regressions to explore if stove use and intensity are correlated with the type of treatment assigned to households both at the midline and endline. Results reported in columns 1-4 suggest that the number of times the stove is put to use is not correlated with the treatment type in a statistically significant manner. These results are robust to controlling for other covariates. During endline (column 4), the credit treatment group used the stove 1.9 times less than the subsidy treatment group, but the effect is not statistically significant at conventional levels. The observed statistically significant difference in stove use between the two groups reported in the simple mean comparison test in Figure 3 is not supported by the regression results likely due to the reduction in the sample size to stove adopter households only. Among the control variables we included in the regressions, education and economic status measured by the log of household expenditure are both positively correlated with using the stove more often. Most likely indicating habit formation, households who used charcoal stoves for a longer period of time used LPG stoves less frequently at endline, and the coefficient is statistically significant at the 1 percent level.

Table 7 about here

An important question related to stove use, which sheds light on the sustained utilization and reduction of charcoal, is whether and how frequently treatment households refilled their LPG stoves. Overall, treatment households refilled LPG gas 2.25 times on average during the 15 month time period after receiving the stove.[23] Panel (b) of Figure 3 decomposes the frequency of refill by treatment type. We note that the credit treatment group refilled LPG gas 1.89 times, while the subsidy group refilled 2.61 times during the 15 month period after the intervention. The difference in

[23] The LPG stoves distributed to both the credit and subsidy treatment groups were filled with 15 liters (3.96 gallons) of gas at the time of delivery. Thus, households start refilling when the original gas delivered with the stove runs out after a few weeks.

the frequency of LPG refill between the two groups is statistically significant at the 5 percent level. We further explore LPG gas refill behaviour using regressions and report the results in Panel B of table 7. Column 6 suggests that the credit treatment group refilled gas about 0.68 times less than subsidy households, but the effect is not statistically significant, probably due to the relatively small sample. The finding that the subsidy treatment group reduced charcoal more than the credit treatment group, which we documented in the preceding section, is consistent with the fact that the subsidy group refilled the gas and used the stove more often. The key reason is likely liquidity constraint by the credit treatment group as they were required to pay the full cost of the stove in 6 months time, while the subsidy group acquired the stoves at 75 percent subsidy, which probably enabled them to refill the gas and use the stove more often than the credit treatment group.

We finally explore the extent to which treatment households are satisfied with the different attributes of the LPG stoves. Figure 4 shows the distribution of responses to the questions on satisfaction with the stoves. The majority of the households who received the LPG stoves seem to be satisfied with all features of the stove, including stove quality (80 percent), stove functioning (79 percent), gas cost (77 percent), food taste (73 percent) and cooking convenience (80 percent). These results indicate that the type of LPG stoves we distributed have a reasonably high level of acceptance by households in urban Tanzania.

Figure 4 about here

In order to explore the correlates of reported levels of satisfaction with the different attributes of LPG stoves, we run simple OLS regressions of satisfaction and report the results in Table 8. Two variables appear to be consistently important correlates of satisfaction with LPG stoves: economic status measured by the log of consumption expenditure and years of schooling. Households with better economic status tend to be satisfied by the taste of food, affordability of the LPG gas and the convenience of the stoves, whereas those headed by educated individuals are satisfied with the functioning, food taste and convenience of the stoves. We do not, however, find any evidence suggesting that satisfaction with stove attributes is correlated with the type of treatment, as indicated by the coefficient of the credit treatment variable, which is statistically insignificant.

Table 8 about here

4.5. Credit Repayment

Finally, we investigate the impact of alternative credit repayment arrangements on the amount of credit paid back. Households in the credit treatment were randomly allocated into three credit repayment schemes (payback daily, payback weekly and payback monthly) to be completed in six months. On December 31^{st}, 2015, the credit repayment period ended. WAT SACCOS, the micro-finance institution we worked with, began sending reminders and warnings to all credit households who did not pay back their credit until March 31^{st}, 2016 and attempted to collect the remaining credit amount. With the intention of avoiding uncooperative behaviour in the endline survey, we decided to discontinue pressuring households to pay back the remaining amount and declared the amount not collected by March 31^{st}, as uncollectible.

Table 9 presents descriptive statistics on the mean amount paid back by the three treatment groups, both as of the last date of the contractually agreed credit repayment period (Dec. 31^{st}, 2015) and at the end of the three months extension (March 31^{st}, 2016). One can see that credit households who were randomly assigned to the payback daily treatment group paid on average 177,250 TZS of the 200,000 TZS, i.e., 88.6% of the credit by the end of the official credit period. However, the figures for the weekly and monthly treatment groups are 168,127 (84.06%) and 152,608.3 (76.3%) respectively. The mean difference between the daily and the monthly groups is statistically significant at the five percent level. After several reminders and warnings by the micro-finance association, by March 31^{st}, 2016, the mean repaid amount increased for all treatment groups, with the largest increase in the monthly treatment group. However, the mean differences, understandably, are not statistically significant any longer for any of the groups by the end of the extended repayment period. WAT SACCOS sent the warnings to all credit households with outstanding balance stating that it would take away the stoves as per the contract, and households in all the treatment groups responded to the threat by paying back some amount, with no statistically significant differences in mean payments.

Table 9 about here

Table 10 presents OLS regression results on the log amount of credit repaid regressed on the credit repayment treatments. Columns 1 and 2 show regressions as of Dec. 31^{st}, 2015, the end of the agreed credit period, and columns 3 and 4 present regression results as of March 31^{st} 2016, the end of the three months extension. The results conform to the findings from the mean comparison tests presented in the preceding figure. Regression results in column 2, which control for baseline variables, suggest that, compared to households in the monthly group, households in the daily and the weekly treatment groups paid back 22% more than the monthly group by the end of the agreed credit period. The effect is statistically significant at the five percent level. The regression results in column 4 also suggest that households in both the daily and the weekly treatment groups paid back more compared to the monthly group by March 31^{st}, i.e., after reminders and warnings, but the effects are not statistically significant at conventional levels.

Table 10 about here

The finding that households in the payback daily treatment group paid more than those in the payback weekly and payback monthly treatment groups has important implications for policies that aim at helping poor households acquire household durables, such as costly cooking appliances that can reduce the pressure on forest resources.[24] Over 90% of our sample of households depend on the informal sector for their livelihood, which does not offer predictable income. In fact, official

[24] Due to the expensive nature of our RCT, we only had a total of 150 households and 3 streets (clusters) in the three credit repayment treatment groups. This could raise the issue of statistical power when it comes to generalising to the Tanzanian urban population. Consequently, our results have to be interpreted with a bit of caution.

statistics indicate that 78.1% of the total labor force of Tanzania is self-employed and 11.4% are contributing family workers, both groups depending on the informal sector (Eurofound, 2012). One possible key reason for the high repayment rate - which we hypothesised before the intervention - is the practice of buying charcoal on a daily basis due to liquidity constraint. Due to lack of cash, around 74% percent of our households at baseline bought charcoal on a daily basis, although it is much cheaper to buy it at bulk on a monthly basis. It is this aspect of charcoal purchase we attempted to mimic in the payback daily treatment. If provision of access to credit which allows paying back the debt using mobile banking technology results in the maximum amount of repayment (consequently the least amount of default), policymakers should consider this option to promote adoption of LPG stoves and energy transition.

Of course, it is also possible that other factors incentivised households in the payback daily option to pay more. For example, research shows that individuals in general, and those in developing countries in particular, have behavioural biases such as procrastination, poor self-control, impatience, present bias and myopic behaviours (Duflo et al., 2011; O'donoghue and Rabin, 1999; Banerjee and Mullainathan, 2010; Thaler and Benartzi, 2004). Thus, having the option to settle their debt right after they earned their daily income most likely encouraged them to pay back more and honour the credit agreement. We also would like to argue that the "Kaizen" principle, a leadership and goal-setting principle that motivated us to design the different repayment schemes explains the high success rate of the payback daily group. The central idea of the principle is, that bigger goals are easier to achieve when broken down into smaller and manageable actions and goals that build up over time (Bisou, 2015; Imai, 1986; Maurer, 2014). Our results clearly show that it was easier for households to pay 30 daily instalments of 1200 Tanzanian Shillings (USD 0.67) that sum up to 36,000 Tanzanian Shillings (USD 20) over a month, instead of paying the same sum once a month.

4.6. Cost-benefit Analysis

In this sub-section, we present a simple cost-benefit analysis of the two policy instruments we considered in our study - subsidy and credit. Since we did not find a statistically significant difference in the impact of the two policy instruments on charcoal consumption, policymakers' choice to encourage urban households to switch to LPG will depend on the net social benefit of the policy instruments. At the time of the baseline survey (April 2015), a complete two-burner LPG stove including the cylinder costs TZS 200,000 (USD110). If the government aims to implement a 75% subsidy initiative to encourage adoption, the per unit cost of an LPG stove would therefore be TZS 150,000 or USD 83.33. Consider offering LPG stoves on credit; three months after the end of the credit period or 9 months after the stove distribution (i.e., on March 31st 2016), credit households on average paid back around 90% of the total amount of the loan. This results in a 10% default rate (TZS 20,000) per LPG stove. In addition, it costs TZS 55,000/LPG stove to process and collect back credit from treatment households through WAT SACCOS. The total per LPG stove cost of the credit treatment to the government would therefore be TZS 75,000 or USD 41.67 maximum. Considering the economies of scale associated with a larger number of stove adopters, the unit cost of distributing LPG stoves on both subsidy and credit is likely to drop significantly.

We can calculate the monetary value of the the averted CO_2 due to the reduction in charcoal consumption and trees cut down following our interventions, and compare the benefit to the cost of the interventions. Table 11 presents the details of the cost-benefit analysis. In section 4.2, we showed that, after accounting for emission of CO_2 through cooking with LP gas, adoption of LPG stoves on average reduced 0.04 ha of forest (3.91 MT of CO_2)/household/year, subsidy reduced 0.05 ha of forest (5,03 MT of CO_2)/household/year and credit reduced 0.03 ha of forest (3.53 MT of CO_2)/household/year.[25] Given the average per LPG stove cost of the subsidy and credit interventions calculated above, i.e., USD 83.33 and USD 41.67 respectively, it is straightforward to show that the programs cost USD 16.56 and USD 11.81 respectively to avert emission of one MT of CO_2. This shows that, in terms of cost per MT of CO_2 averted, offering LPG stoves through the type of micro credit we implemented is about 29% cheaper than subsidizing.

The cost of implementing the subsidy and credit interventions can be compared with the benefits of averting emission of CO_2 using the social cost of carbon (SCC). The United States Environmental Protection Agency (US EPA) estimates the SCC of one MT of averted CO_2 to be USD 39 in 2012 USD (Jayachandran et al., 2017). The total SCC value of averted CO_2 sums up to be USD 196.21 per LPG stove under the subsidy and USD 137.66 per LPG under the credit program. The net benefit of the programs per LPG stove would therefore be USD 112.88 and USD 95.99 for the subsidy and the credit programs respectively.

Table 11 about here

It is evident that the social benefit of both interventions is much higher than the monetary cost of implementing them. However, on a per MT of CO_2 averted basis, the 75% subsidy scheme is about 29% more costly than the credit scheme, i.e., USD 16.56 vs USD 11.81. Moreover, despite previous studies (e.g., Cohen and Dupas, 2010; Dupas, 2014; Kremer and Miguel, 2007) point out subsidies as the most effective ways to boost inefficiently low adoption rates of new technologies in developing countries, from a public policy point of view, such a high rate of subsidy is likely to be unpopular among government decision-makers who often have to allocate limited resources among competing needs. Equivalent levels of reduction in deforestation and aversion of CO_2 can be achieved using the micro-finance options that take the repayment preference of households into account, which is one of the key messages of our analysis.

Unsustainable production of charcoal in Africa and its consumption to meet cook-

[25] Note that without accounting for CO_2 emitted by cooking with LPG stoves, the amount of CO_2 averted due to reduction in deforestation following reduction in charcoal consumption is 5.93 MT for the whole treatment group, 7.62 MT for the subsidy treatment group and 5.35 MT for the credit treatment group.

ing needs of households have other significant negative impacts. Charcoal production is one of the key causes of deforestation and forest degradation, which directly results in permanent loss of biodiversity and disturbance of local ecosystems (Campbell et al., 2007; Mercer et al., 2011; Allen and Barnes, 1985; Geist and Lambin, 2002; Hofstad et al., 2009; Köhlin et al., 2011). Burning of charcoal also emits other harmful greenhouse gasses, such as methane - the second major greenhouse gas next to CO_2 in terms of volume emitted, which contributes to global warming 21 times more by trapping heat in the atmosphere (vanDam, 2017; USEPA, 2012), and black carbon emitted when burned in inefficient cookstoves (Sagar and Kartha, 2007; Kandlikar et al., 2009; Grieshop et al., 2011), which absorbs light and reduces the reflectivity of snow and ice (vanDam, 2017). Charcoal and other solid biomass fuels burned often in inefficient cookstoves result in premature death of 3.8 million people in developing countries due to indoor air pollution (IEA, 2017; WHO, 2018). These are major additional negative aspects of charcoal consumption in Africa, which we didn't incorporate in the cost-benefit analysis we conducted above because they are difficult to quantify and beyond the scope of the paper. Thus, the social benefit of reducing charcoal use through acquiring modern cooking appliances, such as the LPG stove we offered to households in urban Tanzania, extends far beyond reducing emission of CO_2.

Finally, an important finding we document in our study is on the possible household-level welfare effects of cooking with LPG rather than charcoal. Our sample of households at baseline, which on average had 5.83 household members, consumed 19.18 kg of charcoal per week, which costs 11,189 TZS (USD 6.23). The reported median price paid by households to refill the 15 kg LPG cylinder was about 45,000 (USD 25). In order to clearly understand how long a household can use the 15 kg gas if they cooked exclusively with LPG, we conducted a controlled cooking test with the household of one of the co-authors. The household (comprising three adults and three children) resides in a newly-constructed apartment, in which cooking with biomass fuel is not allowed. All three meals of the day for all members were cooked exclusively using LPG for 4 months. This household was able to cook with the LPG cylinder for six weeks on average. The comparable six-week cost of charcoal would be 67,134 TZS (USD 37.30). It is clear that charcoal is almost 50% more expensive to the household than LPG and households could save money significantly by switching to LPG once they get access to the stove.

5. Conclusions

Charcoal production to meet the cooking energy needs of households in urban areas of Sub-Saharan Africa, has been documented to be one of the main causes of deforestation and forest degradation in the region. Clearing of the natural forest for charcoal production using unsustainable production methods results in loss of invaluable biodiversity, destruction of local ecosystems and emission of harmful greenhouse gases that exacerbate the problem of climate change. One important factor that hinders transition of households from biomass energy to clean energy sources is the high start-up cost of modern cooking appliances. In order to test this hypothesis, we collaborated with one of Tanzania's largest micro-finance institutions, WAT SACCOS, and implemented a liquified petroleum gas (LPG) stove program in a randomised controlled trial setup. The program involved provision of a durable and high-quality two-burner LPG stove package through subsidy and on credit, which included different repayment arrangements. We conduct a midline survey 4 months after the interventions, and an endline survey 15 months after the interventions. We measure the impact of the LPG stoves on charcoal consumption, our key outcome variable of interest, and the corresponding possible reduction in deforestation and averting of carbon dioxide ($\mathrm{CO_2}$). We then conduct a social cost-benefit analysis, which compares the cost of the two policy instruments to the social cost of carbon, which is the monetary value of the benefits of sequestered CO_2. Our design also allows us to investigate the reduction in household cooking time and the impact of different credit repayment schemes on household credit repayment behaviour. We therefore offer rigorous evidence on the causal impact of relaxing households' financial constraints through alternative policy instruments on charcoal consumption and the resulting significant benefits that accrue to households and the society at large.

The LPG stoves we offered had a high uptake rate by urban households in Tanzania, with 69 percent adoption rate by those who were randomly assigned to the two treatments. The adoption rate in the control group which was offered the stoves at the market price is zero. These findings clearly indicate that the key reason which hinders households' transition to cleaner energy sources is liquidity constraint. Our results also indicate that, overall, adoption of LPG stoves reduced charcoal consumption by about 29.7 percent per week compared to the control group 15 months after the stoves have been distributed. This is equivalent to saving 0.04 ha of forest, which translates to net aversion of 3.91 MT of CO_2/household/year after accounting for the CO_2 emitted from cooking with LP gas. When we assess the impact by the treatment type, estimates suggest that, compared to the control group, those who adopted the stoves through a subsidised price reduced charcoal consumption by 38.2 percent, while those who adopted the stoves on credit reduced charcoal consumption by 26.8 percent. The corresponding reduction in deforestation and CO_2 emitted is 0.03 ha of forest and 3.53 MT of CO_2 for the credit treatment group, and 0.05 ha of forest and 5.03 MT of CO_2/household/year for the subsidy treatment group. Social cost-benefit analysis conducted using the social cost (benefit) of carbon estimated by the US EPA (USD 39/MT CO_2 in 2012 prices) shows that distribution of LPG stoves with subsidy and credit offers a net benefit of USD 112.88 and USD 95.99 per stove respectively. Using a carefully conducted four-month-long controlled cooking test, we show that cooking with LPG gas is 50% cheaper than cooking with charcoal. This finding, together with the 44% reduction in cooking time by treatment households, clearly shows that transition to cooking with LPG is highly beneficial even to households.

We also investigated the impact of micro-credit on acquisition of LPG stoves, and whether the repayment schedule affects credit repayment, by randomly assigning households into three repayment types: payback daily, payback weekly and payback monthly. The micro-finance institution we collaborated with used a convenient and popular mobile money transfer platform used in the region called "M-Pesa" to collect the credit repayments. At the end of the originally agreed credit period (i.e., six months after the stoves had been distributed), credit households on average paid back 88.6% of the credit amount, but those in the payback daily group paid more than the other two groups, and those in the payback weekly group paid more than the payback monthly group. We argue that reliance on unstable income from the informal sector combined with behavioural biases, such as self-control issues and procrastination in a set-up characterised by liquidity constraint, explain why the payback daily group paid more on average than the other two groups. Most households earn income on a daily basis and find it easy to pay back their debt right away, just like the way they buy charcoal on a daily basis. Consistent with the Kaizen goal-setting and accomplishment principle (Bisou, 2015; Imai, 1986; Maurer, 2014), which motivated us to design the repayment schemes, the results also suggest that small and frequent payments result in a higher repayment rate than larger and less frequent repayments. Our finding therefore highlights the scope for efficient and tailored micro-finance services in promoting acquisition of costly household durables in general, and cooking appliances in particular, that speed up energy transition in developing countries.

Millions of hectares of Africa's forests are destroyed for production of charcoal and firewood each year. Given the documented high carbon sequestration potential of Tanzania's forests, targeting reduction of charcoal production is likely to provide substantial external benefits to society at large. The findings from our study provide useful insights on how to reduce charcoal consumption in urban areas of Africa. Both the descriptive statistics and results from our randomised controlled trial demonstrate that the high start-up cost of modern cooking appliances such as LPG stoves is the main factor that prohibits households from switching to modern and relatively environmentally-friendly energy sources. In view of this, simple policy interventions, such as reducing the import duty on LPG stoves, could increase adoption and use of LPG stoves and consequently reduce charcoal consumption. Currently, the Tanzanian government levies a 25% import duty on LPG stoves and 10% on the cylinders. Reducing these duties and making LPG stoves affordable would likely result in a larger rate of uptake of the stoves. This is the key message of our study, which should be picked up by policymakers, donors, and other stakeholders who are interested in saving the remaining forest resources of Africa and tackling emission of harmful greenhouse gases that exacerbate the problem of climate change.

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Table 1: Descriptive statistics of variables at baseline

	Mean
Panel A: Socioeconomic Characteristics	
Head's age	47.46
	(12.54)
Male head	0.695
	(0.461)
Household size	5.834
	(2.190)
Annual income (TZS)	329181.4
	(279851.0)
Head's years of schooling	7.510
	(2.972)
Average daily expenditure	9479.9
	(9154.2)
Separate kitchen	0.406
	(0.491)
House privately owned	0.493
	(0.500)
Panel B: Cooking Pattern and Charcoal Use	
Number of years using charcoal stove	23.14
	(10.93)
Head decides on acquisition of stove	0.440
	(0.497)
Walking distance to the nearest charcoal market (in min.)	4.452
	(4.333)
Number of meals cooked last week	19.22
	(3.334)
Rice, main staple for the household	0.507
	(0.500)
Amount of charcoal used last week (in Kg.)	19.18
	(10.20)
Expenditure on charcoal last week (in TZS)	11189.8
	(6168.2)
Cooking time of a meal using charcoal (in min.)	101.8
	(39.08)
Panel C: Demand for LPG stove	
Knows about LPG stoves	0.985
	(0.123)
Knows someone using LPG stove	0.803
	(0.398)
LPG requires high start up cost	0.934
	(0.249)
Food tastes different when cooked with LPG	0.0235
	(0.152)
Wishes to own LPG stove in the future	0.961
	(0.193)
Maximum willingness to pay for an LPG stove (in TZS)	63419.7
	(38548.5)
Affords gas refilling cost	0.882
	(0.323)
Observations	722

Notes: This table presents descriptive statistics (means and standard deviations) of key variables collected from both treatment and control groups at baseline. Standard deviations are reported in parentheses under means.

Table 2: Mean comparisons: treatment and control groups.

	(1) Control	(2) Credit	(3) Subsidy	(4) Cont.- Cred.	(5) Cont.- Subs.	(6) Cred.- Subs.
Panel A: Socioeconomic Characteristics						
Head's age	47.53	47.77	47.03	-0.237	0.498	0.735
	(12.82)	(12.72)	(11.99)	(-0.21)	(0.44)	(0.61)
Male head	0.724	0.694	0.656	0.0295	0.0684	0.0389
	(0.448)	(0.462)	(0.476)	(0.73)	(1.65)	(0.86)
Household size	5.997	5.644	5.799	0.353*	0.198	-0.156
	(2.258)	(2.039)	(2.236)	(1.82)	(0.97)	(-0.75)
Annual income (TZS)	328111.1	337064.8	322555.0	-8953.7	5556.1	14509.8
	(220083.3)	(282883.4)	(346001.5)	(-0.40)	(0.22)	(0.47)
Head's years of schooling	7.404	7.602	7.565	-0.198	-0.161	0.0373
	(2.711)	(3.261)	(3.022)	(-0.75)	(-0.63)	(0.12)
Average daily expenditure	9168.4	8877.3	10545.5	291.0	-1377.1	-1668.1
	(6438.1)	(5968.3)	(13892.9)	(0.52)	(-1.50)	(-1.62)
Separate kitchen	0.421	0.421	0.368	-0.000421	0.0525	0.0529
	(0.495)	(0.495)	(0.484)	(-0.01)	(1.19)	(1.11)
House privately owned	0.515	0.472	0.483	0.0429	0.0319	-0.0110
	(0.501)	(0.500)	(0.501)	(0.96)	(0.71)	(-0.23)
Panel B: Cooking Pattern and Charcoal Use						
Number of years using charcoal stove	22.99	23.74	22.74	-0.750	0.250	0.999
	(10.81)	(11.17)	(10.86)	(-0.76)	(0.26)	(0.93)
Head decides on acquisition of stove	0.421	0.472	0.435	-0.0513	-0.0145	0.0368
	(0.495)	(0.500)	(0.497)	(-1.16)	(-0.32)	(0.76)
Distance to the nearest charcoal market (min.)	4.236	4.512	4.696	-0.276	-0.460	-0.185
	(4.752)	(4.125)	(3.902)	(-0.69)	(-1.15)	(-0.47)
Number of meals cooked last week	19.12	19.22	19.36	-0.101	-0.242	-0.141
	(3.492)	(3.105)	(3.344)	(-0.34)	(-0.78)	(-0.45)
Rice, main staple for the household	0.488	0.537	0.502	-0.0488	-0.0142	0.0346
	(0.501)	(0.500)	(0.501)	(-1.09)	(-0.31)	(0.71)
Amount of charcoal used last week (in Kg.)	19.73	19.09	18.48	0.646	1.252	0.606
	(11.73)	(8.921)	(9.043)	(0.68)	(1.30)	(0.70)
Expenditure on charcoal last week (in TZS)	11498.9	11137.4	10804.5	361.4	694.4	332.9
	(7474.9)	(5191.6)	(4921.6)	(0.61)	(1.18)	(0.68)
Cooking time of a meal using charcoal (min.)	102.0	101.0	102.2	0.994	-0.159	-1.153
	(38.65)	(38.03)	(40.89)	(0.29)	(-0.04)	(-0.30)
Panel C: Demand for LPG stove						
Knows about LPG stoves	0.983	0.981	0.990	0.00168	-0.00727	-0.00895
	(0.129)	(0.135)	(0.0976)	(0.14)	(-0.69)	(-0.78)
Knows someone using LPG stove	0.791	0.819	0.804	-0.0282	-0.0126	0.0156
	(0.407)	(0.386)	(0.398)	(-0.79)	(-0.35)	(0.41)
LPG requires high start up cost	0.936	0.949	0.914	-0.0130	0.0222	0.0352
	(0.245)	(0.220)	(0.281)	(-0.62)	(0.94)	(1.44)
Food tastes different when cooked with LPG	0.0202	0.0370	0.0144	-0.0168	0.00585	0.0227
	(0.141)	(0.189)	(0.119)	(-1.15)	(0.49)	(1.47)
Wishes to own LPG stove in the future	0.939	0.981	0.971	-0.0421**	-0.0319*	0.0102
	(0.239)	(0.135)	(0.167)	(-2.33)	(-1.66)	(0.69)
Maximum WTP for an LPG stove (in TZS)	60148.1	64199.1	67263.2	-4050.9	-7115.0**	-3064.1
	(40281.4)	(37458.2)	(36888.8)	(-1.16)	(-2.02)	(-0.85)
Affords gas refilling cost	0.862	0.889	0.904	-0.0269	-0.0424	-0.0154
	(0.346)	(0.315)	(0.295)	(-0.90)	(-1.44)	(-0.52)
Observations	297	216	209			

Notes: This table presents summary statistics of variables at baseline for the control group, credit treatment group, and subsidy treatment group, and the corresponding statistical t-test results on mean differences. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 3: Correlates of LPG uptake

	(1)	(2)
Credit	-0.0429	-0.0939
	(-0.48)	(-0.61)
Head's age		-0.00120
		(-0.61)
Male head		-0.0737
		(-1.46)
Household size		-0.00414
		(-0.53)
Head's years of schooling		0.0139
		(1.35)
LN_exp		0.105*
		(2.22)
Separate kitchen		-0.00224
		(-0.06)
House privately owned		-0.0439
		(-1.27)
Number of years using charcoal stove		0.00549**
		(2.52)
Head decides on acquisition of stove		-0.0538
		(-1.03)
Walking distance to the nearest charcoal market (in min.)		0.0107
		(1.34)
Number of meals cooked last week		-0.000899
		(-0.11)
Rice, main staple for the household		-0.0590
		(-1.56)
Knows someone using LPG stove		0.0172
		(0.36)
Constant	0.710***	-0.360
	(12.35)	(-0.92)
R-squared	0.002	0.12
Observations	426	426

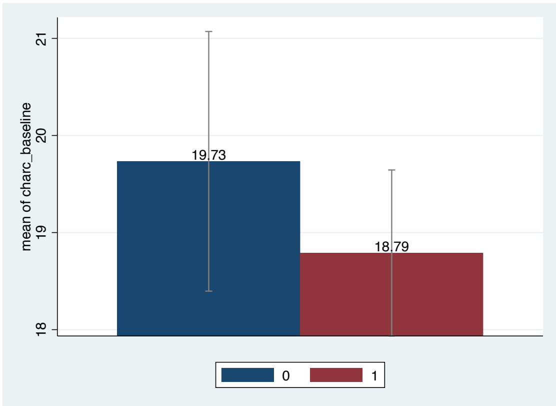
Notes: This table reports OLS regression results on correlates of uptake. Column 1 controls for treatment type. Column 2 controls for treatment type, baseline covariates and sub-ward fixed effects. Standard errors reported in parentheses are clustered at the sub-ward level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 4: Correlates of attrition, Baseline - Endline: OLS Regression Results

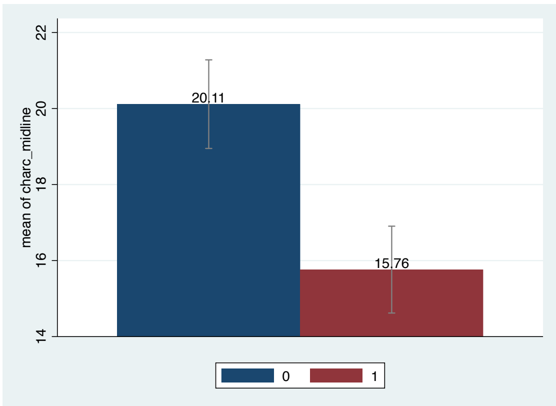
	(1)	(2)	(3)
Treated	-0.115		
	(0.100)		
Credit		-0.065	-0.051
		(0.096)	(0.099)
Subsidy		-0.259	-0.247
		(0.186)	(0.204)
Head's age			0.001
			(0.001)
Male head			-0.042
			(0.038)
Household size			0.003
			(0.009)
Head's years of schooling			-0.005
			(0.008)
LN_exp			0.047
			(0.040)
Separate kitchen			0.000
			(0.034)
House privately owned			-0.113***
			(0.028)
Number of years using charcoal stove			-0.002
			(0.002)
Head decides on acquisition of stove			-0.052
			(0.045)
Walking distance to the nearest charcoal market (in min.)			-0.003
			(0.003)
Number of meals cooked last week			-0.001
			(0.005)
Rice, main staple for the household			-0.019
			(0.030)
Knows someone using LPG stove			-0.003
			(0.044)
R-squared	0.05	0.05	0.08
Observations	722	722	722

Notes: This table reports OLS regressions for the correlates of attrition. The dependent variable is a dummy equal to one if the household is lost to attrition by endline. Column 1 controls for being treated (LPG acquisition either on credit or through subsidy). Column 2 differentiates the correlates of attrition by the type of treatment. Column 3 controls for the type of treatment, other baseline socioeconomic variables, and sub-ward fixed effects. Standard errors reported in parentheses are clustered at the sub-ward level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

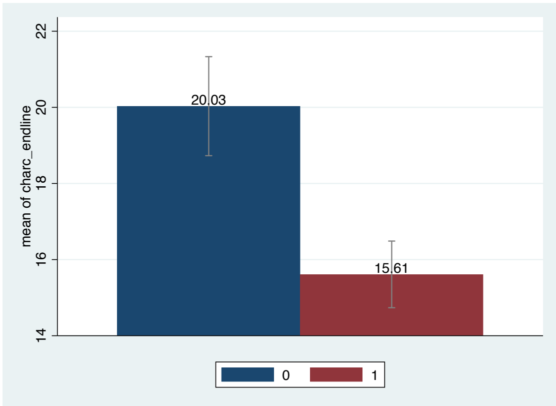
Figure 1: Weekly Charcoal Consumption: Baseline, Midline and Endline



(a) Baseline



(b) Midline



(c) Endline

Table 5: The impact of LPG stoves on charcoal consumption - ITT effects

	Midline				Endline			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treated	-0.376***	-0.628**			-0.296***	-0.297**		
	(0.079)	(0.240)			(0.088)	(0.102)		
WC P-value	[0.000]	[0.071]			[0.005]	[0.055]		
Credit			-0.387***	-0.665***			-0.254**	-0.268**
			(0.094)	(0.213)			(0.091)	(0.125)
WC P-value			[0.000]	[0.072]			[0.023]	[0.231]
Subsidy			-0.366***	-0.538*			-0.341**	-0.382**
			(0.098)	(0.292)			(0.120)	(0.139)
WC P-value			[0.033]	[0.090]			[0.091]	[0.081]
Credit Vs Subsidy			[0.852]	[0.487]			[0.475]	[0.416]
Controls	No	Yes	No	Yes	No	Yes	No	Yes
R-squared	0.058	0.115	0.058	0.116	0.045	0.177	0.047	0.177
Observations	695	695	695	695	540	540	540	540

Notes: This table reports intent-to-treat (ITT) effects of LPG stove ownership on charcoal consumption at midline and endline. Columns 1 and 5 show ITT effects of LPG ownership at midline and endline respectively. Columns 2 and 6 report ITT effects of LPG ownership controlling for baseline covariates and sub-ward fixed effects at midline and endline respectively. Columns 3 and 7 report ITT effects of LPG ownership by treatment type at midline and endline respectively. Columns 4 and 8 report ITT effects by treatment type controlling for baseline covariates and sub-ward fixed effects at midline and endline respectively. Standard errors reported in parentheses are clustered at the sub-ward level. Wild cluster bootstrap-t p-values of treatment effects are reported in square brackets. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Figure 2: Cooking Time Per Week: Baseline and Endline

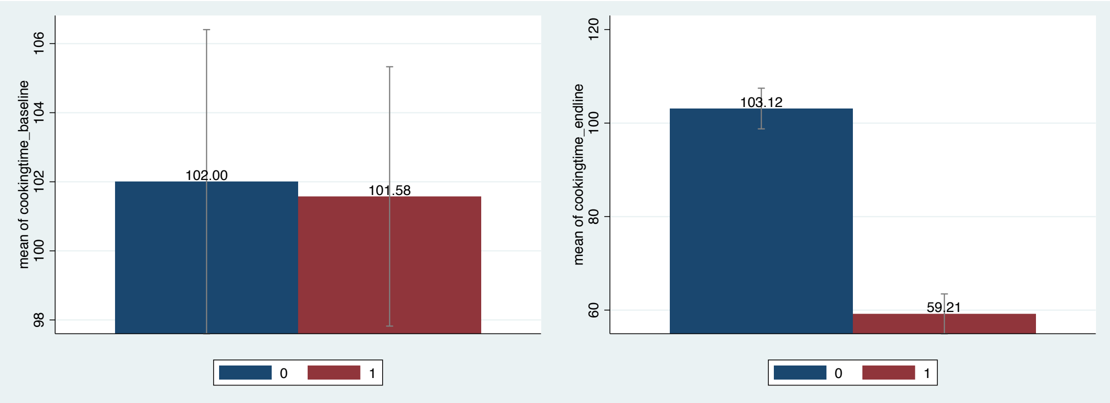
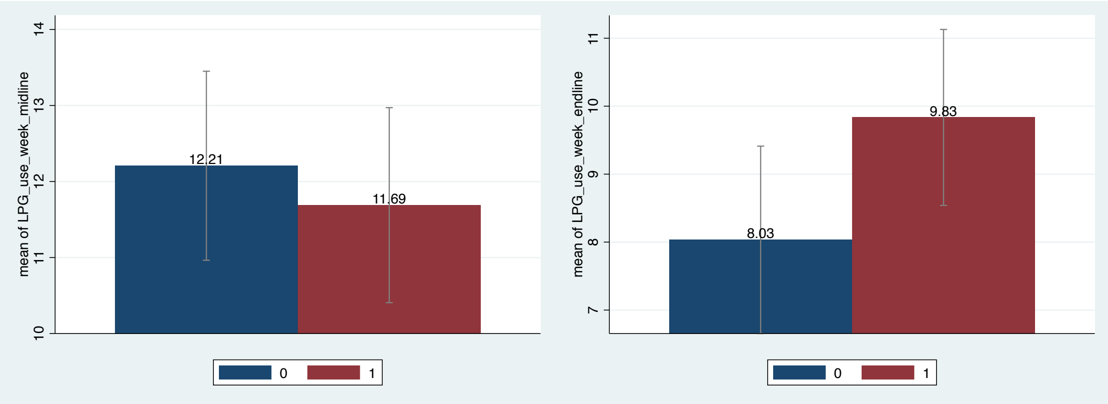


Table 6: The impact of LPG stoves on cooking time: ITT effects

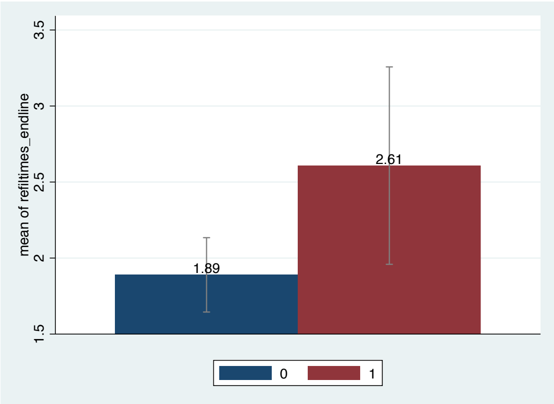
	(1)	(2)	(3)	(4)
Treated	-0.693***	-0.441***		
	(0.063)	(0.095)		
WC P-value	[0.000]	[0.036]		
Credit			-0.607***	-0.383***
			(0.080)	(0.087)
WC P-value			[0.000]	[0.050]
Subsidy			-0.786***	-0.609**
			(0.060)	(0.221)
WC P-value			[0.000]	[0.069]
Credit Vs Subsidy			[0.058]	[0.387]
Controls	No	Yes	No	Yes
R-squared	0.058	0.115	0.058	0.116
Observations	540	540	540	540

Notes: This table reports intent-to-treat (ITT) effects of LPG stove ownership on cooking time at endline. The dependent variable is the log of cooking time per day in minutes. Column 1 reports ITT effects of LPG ownership on cooking time. Column 2 reports ITT effects of LPG ownership controlling for baseline covariates and sub-ward fixed effects. Column 3 presents ITT effects by treatment type. Column 4 reports ITT effects by treatment type controlling for baseline covariates and sub-ward fixed effects. Standard errors reported in parentheses are clustered at the sub-ward level. Wild cluster bootstrap-t p-values of treatment effects are reported in square brackets. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Figure 3: LPG Stove Use and Refill: Baseline, Midline and Endline



(a) LPG Use: Midline and Endline



(b) LPG Gas Refill: Endline

Table 7: Correlates of LPG stove use and refill

	Panel A LPG Use				Panel B LPG Gas Refill	
	Midline		Endline		Endline	
	(1)	(2)	(3)	(4)	(5)	(6)
Credit	0.681	0.588	-1.653	-1.882	-0.688	-0.683
	(1.069)	(1.177)	(1.427)	(1.509)	(0.422)	(0.460)
WC P-value	[0.547]	[0.646]	[0.331]	[0.296]	[0.177]	[0.225]
Head's age		0.074		0.020		-0.002
		(0.041)		(0.037)		(0.007)
Male head		-0.504		1.818		-0.077
		(0.911)		(1.219)		(0.310)
Household size		0.090		-0.090		-0.007
		(0.279)		(0.229)		(0.087)
Head's years of schooling		0.304		0.298**		0.027
		(0.189)		(0.126)		(0.026)
LN_exp		1.854***		2.085*		0.430**
		(0.579)		(1.086)		(0.164)
Separate kitchen		-1.337*		-1.088		-0.033
		(0.634)		(0.857)		(0.291)
House privately owned		-1.280		0.803		-0.239
		(1.085)		(0.971)		(0.235)
Number of years using charcoal stove		-0.076		-0.126***		-0.018**
		(0.049)		(0.038)		(0.007)
Head decides on acquisition of stove		1.851		2.445*		-0.152
		(1.403)		(1.332)		(0.355)
Rice, main staple for the household		-0.794		-0.922		0.037
		(0.843)		(0.549)		(0.287)
R-squared	.002	0.07	0.02	0.11	0.02	0.03
Observations	293	293	241	241	293	293

Notes: This table reports OLS regression results on the correlates of LPG use at midline and endline, and LPG gas refill at endline. The dependent variable in Panel A is the number of times the LPG stove has been put to use in the past week. The dependent variable in Panel B is the number of times the household refilled LPG gas since the intervention, i.e., in the past 15 months. Columns 1 and 3 report regressions for LPG use at midline and endline, controlling for the treatment type only. Columns 2, and 4 report the same regressions controlling for key baseline covariates. Column 5 reports OLS regression for LPG gas refill controlling for the type of treatment only. Column 6 reports the same regression controlling for key baseline covariates. Standard errors reported in parentheses are clustered at the sub-ward level. Wild cluster bootstrap-t p-values of treatment effects are reported in square brackets. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Figure 4: Satisfaction with Different Attributes of LPG Stoves

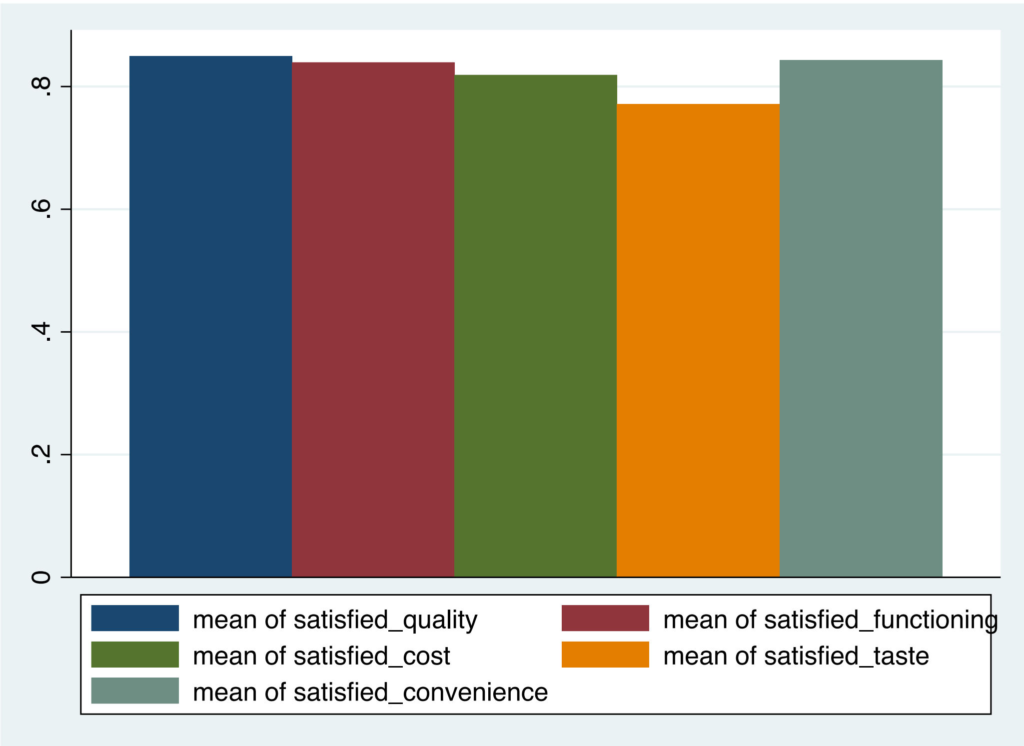


Table 8: Correlates of satisfaction with different LPG stove attributes

	(1) Quality	(2) Functioning	(3) Food Taste	(4) Gas Cost	(5) Convenience
Credit	0.042	0.019	0.042	0.018	0.044
	(0.034)	(0.043)	(0.042)	(0.037)	(0.044)
Head's age	0.001	0.003*	0.003	0.005***	0.003*
	(0.001)	(0.001)	(0.003)	(0.001)	(0.001)
Male head	-0.022	-0.049	-0.058	-0.071	-0.069
	(0.057)	(0.072)	(0.075)	(0.076)	(0.069)
Household size	0.005	0.001	0.015	-0.001	0.007
	(0.006)	(0.007)	(0.013)	(0.007)	(0.006)
Head's years of schooling	0.010	0.015*	0.024***	0.014	0.012*
	(0.006)	(0.007)	(0.007)	(0.009)	(0.006)
LN_exp	-0.009	0.038	0.068**	0.076**	0.058*
	(0.030)	(0.040)	(0.028)	(0.026)	(0.029)
Separate kitchen	0.015	0.006	0.010	0.034	0.011
	(0.046)	(0.053)	(0.043)	(0.064)	(0.042)
House privately owned	-0.008	-0.042	-0.038	-0.064	-0.039
	(0.028)	(0.056)	(0.057)	(0.055)	(0.052)
Number of years using charcoal stove	-0.001	-0.001	-0.004	-0.002	-0.003
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
Head decides on acquisition of stove	0.052	0.033	0.080	0.020	0.039
	(0.085)	(0.090)	(0.082)	(0.095)	(0.085)
Rice, main staple for the household	-0.013	-0.007	-0.022	-0.022	0.011
	(0.042)	(0.051)	(0.045)	(0.037)	(0.039)
R-squared	0.02	0.03	0.06	0.05	0.04
Observations	293	293	293	293	293

Notes: This table reports OLS regression results on the correlates of satisfaction with the different attributes of the LPG stove. The dependent variable is a binary variable coding 1 if the household reported satisfaction with the respective attribute of the stove, and 0 otherwise. Standard errors reported in parentheses are clustered at the sub-ward level. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 9: Final credit repayments by repayment scheme

	Summary Statistics			Mean Differences		
	(1)	(2)	(3)	(4)	(5)	(6)
	Daily	Weekly	Monthly	Daily - Weekly	Daily - Monthly	Weekly - Monthly
Dec. 2015	177250	168127.7	152608.3	9122.3	24641.7**	15519.3
	(37658.4)	(45126.1)	(52686.2)	(1.00)	(2.50)	(1.61)
Percent Paid Back	88.63	84.06	76.30			
March 2016	182236.8	180808.5	173333.3	1428.3	8903.5	7475.2
	(36017.6)	(39572.4)	(46227.8)	(0.17)	(1.01)	(0.88)
Percent Paid Back	91.12	90.4	86.67			
Observations	38	47	60	-	-	-

Notes: This table presents summary statistics of the amount of credit repayment in TZS by the three credit treatment types at the end of the agreed repayment deadline (December 31^{st} 2015) and at the extended repayment deadline (March 31^{st}, 2016) with the corresponding statistical t-test results on mean differences. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 10: The impact of credit repayment scheme on repayment behaviour

	Dec.2015		March 2016	
	(1)	(2)	(3)	(4)
Daily	0.228**	0.267***	0.093	0.150
	(0.087)	(0.100)	(0.076)	(0.094)
Weekly	0.148	0.181*	0.067	0.120
	(0.095)	(0.103)	(0.084)	(0.097)
Controls	No	Yes	No	Yes
R-squared	0.04	0.11	0.01	0.10
Observations	145	145	145	145

Notes: This table reports intent-to-treat (ITT) effects of the credit repayment type on the repayment amount. The dependent variable is the log of the amount of credit paid back as of December 31^{st}, 2015 and March 31^{st}, 2016 respectively. Columns 1 and 3 report ITT effects controlling for the treatment types only. Columns 2 and 4 report ITT effects controlling for baseline covariates as well. Robust standard errors reported in parentheses. ***, ** and * denote significance at the 1, 5 and 10% levels, respectively.

Table 11: Cost-Benefit Analysis of Subsidy and Credit Policy Instruments

	(1) Subsidy	(2) Credit	(3) All
Reduction in charcoal consumption per LPG Stove (%)	0.38	0.27	0.30
Reduction in deforestation per LPG stove/Year in ha	0.05	0.03	0.04
Gross CO_2 averted in MT (153.5 MT per ha)	7.62	5.35	5.93
CO_2 emitted from cooking with LPG in MT (eq. to 34%)	2.59	1.82	2.02
Net CO_2 averted	5.03	3.53	3.91
Social Cost of Carbon (SCC) in saved forest (USD 39/MT CO_2)	196.21	137.66	152.55
Average cost of program per unit of LPG in USD	83.33	41.67	62.50
Average cost of program per MT of CO_2 Averted	16.56	11.81	15.98
Average net benefit per LPG	112.88	95.99	90.05

Notes: This table reports social cost-benefit analysis of the subsidy and credit treatments. Column 1 presents reduction in charcoal consumption and deforestation, the amount of CO_2 averted including its cost and benefit to society due to subsidising 75% of the cost of LPG stoves. Columns 2 and 3 report the same information for the credit treatment group and both treatment groups combined respectively.

Saving Africa's Tropical Forests through Energy Transition: A Randomized Controlled Trial in Tanzania

Appendix for Online Publication

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November 9, 2020

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Figure 1: Map of Dar es Salaam

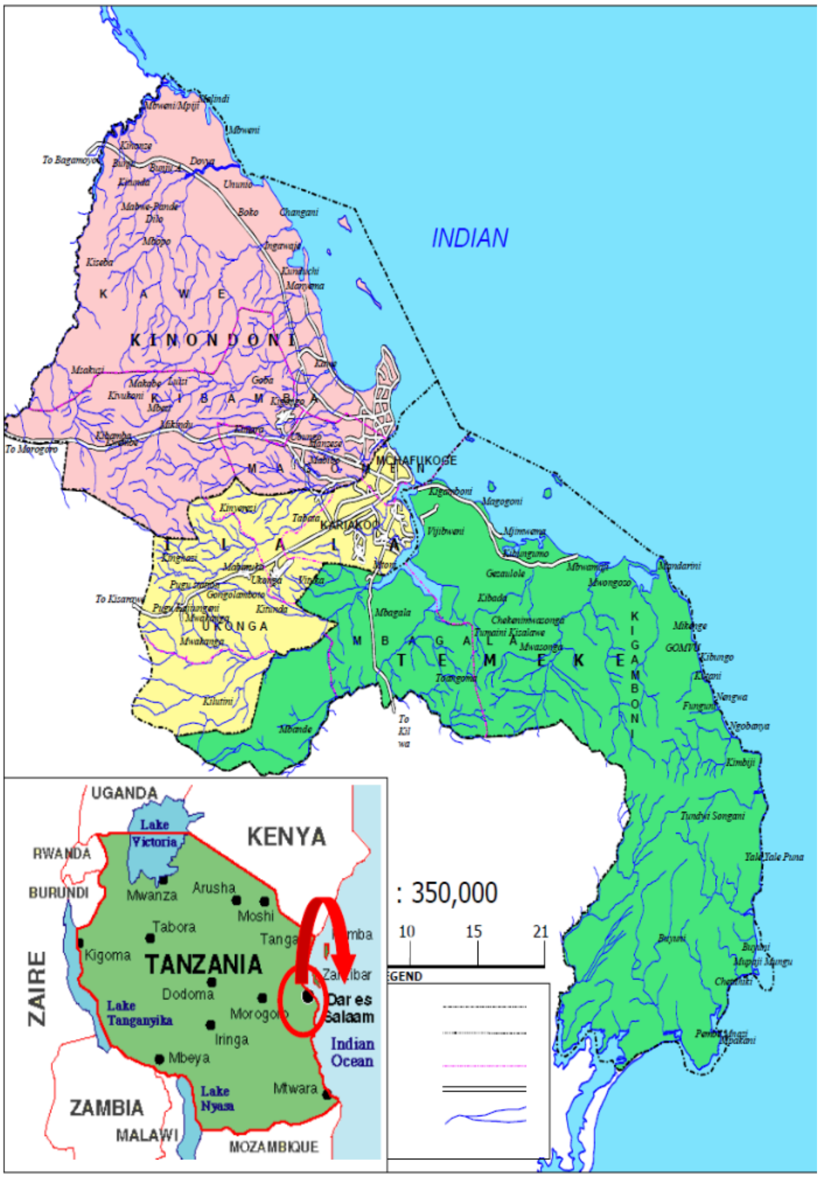

Figure 2: Training on the Use of LPG Stoves

(a) Midline

Figure 3: Home Visits: Treatment Group