The Impact of Household Energy Access on Socio-Economic Outcomes in Zambia

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Acknowledgement

Finally, the PhD journey is done. It has been an amazing experience. However, I am grateful to the people who have made this journey memorable. Firstly, I am highly indebted to my supervisor, Professor Edwin Muchapondwa who has been there during the whole journey. His continuous advice and guidance shaped this thesis. Further, his financial support through the scholarship hugely helped complete the PhD studies.

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Despite the support rendered by different individuals toward completion of the thesis, any shortcomings and content of this thesis, I take full responsibility.

Dedication

I dedicate this thesis to my wife, children, and parents.

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Abstract of the Thesis

This thesis focuses on evaluating the impact of household energy access on the socio-economic wellbeing of households in Zambia. The thesis consists of four studies that are interrelated to answer the broader objective. All estimations and descriptive statistics in this thesis use the World Bank/ESMAP dataset collected in 2017/2018 on Zambia.

Consequently, the first study examines the effect of electrification technology on household socio-economic outcomes. The study emphasizes the need to understand the differential impact of household adoption of grid versus off-grid (standalone solar home systems) electricity on non-farm employment, monthly income, and expenditure of the household. Using the Inverse Probability Treatment Weighting estimation strategy, the results reveal heterogeneity in the impacts of the technology used in the electrification programme on household income and expenditure per capita. Therefore, the study observes that, though solar home systems technology offers benefits compared to non-connected, grid electricity offers better effects on household income and expenditure.

The second study ditches restrictive traditional binary evaluation of electricity access on users' welfare in favour of the multitier evaluation framework. The study applies the Generalized Propensity Score approach with continuous multivalued treatment (electricity availability). The study estimates the dose-response function (average treatment effect) of the household's exposure to electricity in a typical day. The results confirm that availability of electricity is key to improving household livelihood. The longer the exposure to the electricity service, the higher the likelihood of reduced expenditure on alternative energy sources; the more time the households allocate to working away from home for pay; and the increased probability of being employed in the non-agriculture sector. However, increasing exposure to electricity within and across Tiers does not always improve livelihood as households may have limited productive use of the electricity service. Generally, the policy implication derived from the results is the importance of the duration of household exposure to electricity in the electrification programmes in developing countries.

The third study estimates WTP for electricity services among non-connected households given the low rate of electricity access in Zambia. The study further estimates changes in WTP for electricity after introducing credit regimes where households are allowed to pay for extended periods of up to one and two years for grid and solar PV, respectively. Contingent valuation approach is applied with single bounded dichotomous responses. The results reveal that the willingness to pay is positive across the payment periods and technology (grid and solar PV). Further, average willingness to pay increases as payment period of the credit facility rises. However, the average willingness to pay for low-capacity standalone PV solar technology falls below market price while for grid electrification and high-capacity standalone PV solar technology, the mean average willingness to pay is positive and above the above market price across the payment periods. The results underscore the need to provide electricity beyond lighting for households to engage in economic activities. To accelerate electricity access among non-connected households, we recommend improving households' access to credit financing or offer subsides for them to pay for connection. Introduction of credit regimes increases households' WTP as it helps to smooth consumption among low-income households.

The fourth study is motivated by how gender affects household access to cooking energy solutions and consists of two parts. The first part compares the gendered effects of decision-making on the choice of, and expenditure on cooking energy solutions at the household level. Probit and Heckman selection models are estimated for the household choice of, and expenditure on, cooking energy solutions, respectively. The results suggest that when women have strong bargaining power, the likelihood of choosing and having increased expenditure on improved cooking solutions is relatively high. Women's employment status and educational attainment positively increase their bargaining power in adopting improved cookstove, likelihood of participating in the market and household expenditure on improved energy fuel. The second part of the study assesses gendered effects of household access to improved cooking energy solution across multi-Tiers. The study adopts the Propensity Score with Regression Adjustment approach to estimate the effects of accessing improved cooking energy solutions. The study results suggest that the probability of experiencing reduced respiratory illness in higher Tiers as exposure to improved cooking solutions improves as opposed to lower Tiers (1 vs 0) where differentiated effects are low.

Gendered results reveal that women experience reduction in respiratory illness of between 3.5% and 5.5% across the Tiers as exposure to quality of cooking energy solutions improves. For the men, the reduction in respiratory illness is only observed in higher Tiers when men tend to participate in cooking as the quality of access to cooking energy solutions improves. Regarding the overall effect on household time allocation to various activities, the results suggest that time saving improves significantly for cooking (between 16.36 and 43.16 minutes) and fuel collection and preparation (between 18 and 23 minutes) as households transition from traditional to improved cooking energy solutions across Tiers. Furthermore, significant increase in time allocated to studying (between 10 and 30 minutes) and income generating activities (between 22 and 44 minutes) is observed as households transition across the Tiers. Gendered results also reveal that women save more time from cooking and fuel collection and preparation in higher Tiers. Therefore, the transitioning process requires identification of users, decision makers and understanding the benefits of being empowered at household level so that policy formulations and training target the right individuals and avoid formulating gender-blind policies.

Effectively, the thesis suggests that Zambia should encourage a mix of grid and off-grid solutions, leverage private energy markets with financing, and empower women for a swift energy transition. Several welfare indicators have been adopted in understanding the effects of electrification technology adoption, availability of electricity services, demand for electricity among non-connected, and gendered access to cooking energy solutions.

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List of Acronyms/ Abbreviations

ADRF	Average Dose Response Function
ATE	Average Treatment Effect
CES	Cooking Energy Solution
CV	Contingent Valuation
DBD	Double Bounded Dichotomous
ERB	Energy Regulation Board
ESCA-UN	Economic and Social Commission for Africa – United Nations
ESMAP	Energy Sector Management Assistance Program
GLM	Generalised Least Model
GPS	Generalised Propensity Score
GRZ	Government of the Republic of Zambia
ICS	Improved Cooking Solution
IEA	International Energy Agency
IPTW	Inverse Probability Treatment Weight
LPG	Liquefied Petroleum Gas
MTF	Multitier Framework
NEP	National Energy Policy
NN-PSM	Near Neighbour- Propensity Score Matching
OLS	Ordinary Least Square
PRSP	Poverty Reduction Strategy Paper
PSM	Propensity Score Matching

QML	Quasi Maximum Likelihood Function
RCT	Randomised Control Trial
REA	Rural Electrification Authority
REMP	Rural Electrification Master Plan
SBD	Single Bounded Dichotomous
SDG	Sustainable Development Goals
SE4ALL	Sustainable Energy 4 All
SHS	Standalone Home Solar PV
SSA	Sub-Saharan Africa
WHO	World Health Organization
WTP	Willingness to Pay
ZESCO	Zambia Electricity Supply Corporation

Chapter One: Introduction

1.1.Background of the Thesis

Household access to electricity/modern energy remains an important aspect in the fight against poverty in Sub-Saharan Africa (SSA) as it positively contributes to improving the socioeconomic status of users and deriving economic growth in developing countries (IEA, 2022). Yet, SSA countries have the lowest levels of access to modern energy which includes electricity across the world. Statistics show that about 600 million individuals lack access to electricity and entirely depend on traditional energy for lighting and other productive activities while 900 million do not have access to clean energy for cooking energy solutions (CES) (IEA, 2020; World Bank, 2018). Literature observes that households who are deprived of electricity/modern energy access experience the negative effect of relying on traditional energy for their livelihood which in turn negatively affects economic development and the environment.

The overreliance on biomass energy limits households' engagement in productivity activities as more time is spent on collecting, preparing, and cooking by users. The women, children, and girls being producers and users of inefficient CES bear much of the negative effects (Crentsil *et al.*, 2019). Further, over reliance on traditional energy sometimes results into premature deaths among users and producers (IEA, 2022; Martin, *et al* 2011). For instance, globally, almost 2 million people die annually from indoor air pollution resulting from traditional cookstoves and fuels (Lim *et al.* 2013) with 490,000 deaths recorded in SSA annually (IEA,2022). To realize the benefits, access to household energy requires conceptualizing it as a continuum of increasing levels of energy attributes as opposed to a single-step transition from lack to access (Bhatia and Angelou, 2015).

Zambia, like any Sub-Saharan African country, continues to rely on several sources of energy for cooking, lighting, and heating purposes at household level. ZamStats (2015) reports that firewood, charcoal, electricity, and LPG remain the main sources of energy for cooking and heating while electricity, kerosene, solar lights, battery torch and candle are the energy sources for lighting. For electricity, the World Bank/ESMAP (2018) estimates that only 32.34% households have access to grid electricity while 5.23% have access to solar photovoltaic (PV) electricity (solar lantern, standalone home solar system-SHS, and solar lights). Majority without access to electricity reside in rural areas were 93% of the households do not have access to grid electricity (Luzi *et al.,* 2019).

The low access levels to electricity among households across various locations in Zambia require strong policy initiatives to ensure that every household has access to affordable improved energy to facilitate poverty reduction and promote household economic activities (GRZ, 2019). Further, households accessing electricity face issues of quality, capacity, reliability, and affordability which limit their usage leading them to fall back on traditional energy sources or to engage in fuel stacking to meet their daily energy needs. National grid electricity provides 91.4% of the electricity produced of which 84.1% is produced through hydro technology thereby creating supply instability during low water levels in drought rainy season due to low water levels experienced during drought rain seasons. For instance, 2015/2016 and 2019/2020 rainy seasons had severe droughts resulting in over 10hours of electricity loadshedding every day (ERB, 2020) in the subsequent years due to overreliance on hydro generated grid electricity.

Nevertheless, solar PV electricity is increasingly becoming part of the electrification process due to technological advancement and affordability issues. Households unserved by grid electricity especially in rural areas are opting for solar PV as a primary source of electricity in Zambia (World Bank/ESMAP, 2018). Despite the growing interest, literature in developing countries take grid extension as synonymous to electrification programme (Khandker *et al*., 2012; Bonan *et al.*, 2016) such that households accessing solar PV solutions (SHS, solar lanterns, solar lights, and rechargeable solar lights) as primary sources of electricity are sometimes taken as being unelectrified. Supporters of grid electricity extensions as the sole electrification technology that should be adopted in electrification programmes in developing countries question the extent to which solar PV electricity could impact on socioeconomic wellbeing of the users compared to grid electricity.

Given the electricity access/modern energy situation in Zambia and developing countries, the first issue this thesis addresses is the effect of electrification technology[1] on improving the wellbeing of those connected to it. Sievert and Steinbuks (2020) argue that electrification programmes should pay attention to the differences in the quality and capacity of the electrification technologies being adopted. For instance, grid electricity is critical for long term consumption and improvement in education and health institutions due to its sustainability once connected while off-grid electricity

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[1] Electrification technology is defined as the source of electricity services used in the electrification programme. In this thesis electrification technology refers to grid electricity and off-grid solar PV solutions that include standalone solar PV(SHS), solar lanterns, solar lights, and rechargeable solar lights.

(solar PV) offers a reliable and cheap form of electricity for improved lighting and other limited use such as watching TV and phone charging among low-income households (World Bank, 2018). The differences in attributes of the electrification technology may affect the effectiveness and limit the electrification programmes' ability to contribute to wealth generation and poverty reduction among users (Hafner *et al.*, 2018). Hence evaluating the effectiveness of electrification programmes in developing countries like Zambia requires taking into consideration the possible differences that exist across various technologies that may limit the benefits households derive once connected (Khandker *et al*., 2009; Bensch *et al.*, 2011; Daso and Fernandes, 2015). Failure to differentiate the electrification technology may lead to overstating or understating the effect of the electrification programme on household outcomes. Determining how large the differential effect is across various electrification technologies requires further interrogation through evaluation of the extent to which access to off-grid solar electricity differs from grid electricity on household's welfare indicators. Therefore, the first study of the thesis focuses on estimating the differential impact across electrification technology on household economic welfare indicators that include income, non-farm employment and household expenditure defined by annual per capita expenditure and monthly expenditure on alternative energy sources.

Despite, understanding the extent to which electrification technology affects household welfare among connected households, availability of electricity services from these sources may have further implication on the welfare of the user. Long period of absence of electricity services in a typical day limits the usability among those connected to different electrification technologies which in turn has an impact on the quality of livelihood of the users (Torero, 2014). This means that household electricity access goes beyond just getting an elusive connection involving an electric pole in a community, a connection wire, and a bulb in the house. For instance, a gird connected household may decide to discontinue consumption of electricity service due to unaffordability issues and revert to traditional energy sources for lighting and cooking despite having an electric pole and electric connection wire at their house. Sometimes households receive electricity services at odd times (at night) with low voltage and limited hours. Such situations may have little or no effect on the quality of livelihood for the users as they may fail to engage in productive activities (Bhatia and Angelou, 2015).

The World Bank through SE4ALL and Bhatia and Angelou (2015) broadened the definition of access to electricity by classifying electricity services into Tiers starting with no access (Tier 0) to full access (Tier 5). The Tiers are based on seven comprehensive attributes (capacity, availability, reliability, quantity, affordability, legality and health and safety) of measuring households' electricity access regardless of its source (see Bhatia and Angelou, 2015). This broad definition treats electricity access as a spectrum of services offered to a household than a mere binary connection. Studies such as Litzow, Pattanayak and Thinley (2019); Khandker, Barnes and Samad (2009, 2014); Bensch, Kluve and Peters (2011) have all evaluated electrification programmes based on binary approach of access to electricity. The binary approach is deemed a narrow way of understanding the dynamics of electricity access compared to when attributes of multi-Tier approach are adopted (Bhatia and Angelou, 2015).

Henceforth, the second study diverts from the restrictive binary approach and adopts availability attribute of the multi-Tier approach to evaluate the impact on household socio-economic outcomes. Electricity availability is defined as the duration (hours) of electricity service a household receives per day or in the evening (Luzi *et al.,* 2019). The household's duration of exposure to electricity services in a particular day is critical for the users' welfare. The idea of adopting electricity availability provides new insights in literature on the way of evaluating the impact of electrification programmes in developing countries. Assigning households to Tiers based on their electricity availability helps conceptualize access to electricity beyond binary thereby offering a new policy implication to the process of electrification in developing countries. Despite adopting the availability attribute, other attributes such as capacity, affordability, and reliability are critical to explaining access to electricity. Nevertheless, how long a household is exposed to electricity service helps plan its usage and promotes acquiring of electrical appliances thereby improving the welfare of the users.

Further, the observed socioeconomic benefits derived after a household is connected to any source of electrification technology is crucial to understanding whether non-connected household can opt to pay for electricity service in Zambia. This is because nonconnected households to any form of electricity in Zambia remain the largest group accounting for 63% of the total population (Luzi *et al.,*2019). As earlier observed, these individuals rely entirely on traditional energy for cooking, heating, and lighting (Bhatia and Angelou, 2015), thereby limiting economic opportunities derived from being connected. However, the demand for electricity services among non-connected households remains low in Zambia as observed and the major challenge is how to increase accessibility which largely remains unresolved in literature and policy. Abdullah and Jeanty (2011) argue that households wishing to connect to grid electricity face huge costs. For instance, households are required to pay three separate fees including connection, wiring and tariff fees to use the electricity service which is deemed unaffordable to majority of the households and may require subsidizing for low-income earners. The extent to which connection and service fees should be subsided requires understanding demand dynamics for grid electricity service. Furthermore, improvements in technology for off-grid solar PV solutions provide cheaper and reliable alternatives to expensive grid electricity among low-income households. Its ability to provide households with improved lighting and other limited usage such as watching TV, phone charging (Sievert and Steinbuks, 2020; World Bank, 2018) requires promotion as alternative to grid electricity.

However, the socioeconomic status of the households determines whether they can afford to adopt the grid or off-grid solar PV solution or not. For example, in SSA households face income constraints such that electricity service could only be adopted after meeting basic needs such as food, housing, health, and clothing (Sievert and Steinbuks, 2020). Further, Blimpo and Cosgrove-Davies (2019) observe that households' lack of financial liquidity poses a challenge to connect to electricity source. Hence, the third study attempts to elicit household's willingness to pay (WTP) for electricity connection and its determinants across non-connected with a focus on grid vs off-grid solar PV electricity. This is because being connected to any electrification technology has direct and indirect benefits on household productivity resulting in improvement of the user's livelihood (Bhatia and Angelou, 2015). Therefore, these potential benefits should motivate non-connected individuals to adopt any electrification technology as evidenced by better socio-economic outcomes among connected ones.

In addition, the participation of private firms in the provision of electricity is based on whether they can recover the cost of providing that service to households. Hence, the need to understand the market demand for various electrification technology through estimation of the mean WTP. Furthermore, study estimates mean WTP among households after the introduction of the credit facilities given the liquidity constraints faced by majority households. Households are allowed to pay on credit with payment period for connection extended to a year and two years for grid and solar, respectively. Changes in the payment period helps analyse household WTP dynamics for electricity connection given the low rate of access to modern energy in Zambia that include improved cooking solution.

Finally, the fourth study focuses on gendered access to cooking energy solutions (CES) and its effect on welfare indicators in Zambia. Globally, cooking is a fundamental activity conducted by almost every home and forms part of daily life activity. Despite household cooking being a noble activity globally, around 2.8 billion individuals rely entirely on traditional cookstove technology and biomass fuel[2] (IEA, 2021). Majority households that lack access to improved cooking energy and technologies from Sub-Saharan Africa (SSA) estimated at 17% of the population have access to modern energy for cooking (World Bank, 2021). For Zambia, statistics show that households rely mainly on inefficient traditional cooking technology. Over 86.11% of the households rely on biomass and inefficient cooking technology[3] with only 13.89% having access to improved cooking solutions-ICS (World Bank, 2018). The ICS include electricity and LPG stoves as well as improved biomass cookstoves[4]. Majority households adopting ICS as primary stoves and fuels are largely those who have adopted electricity as the primary energy at household level and account for 12.3% of ICS users. However, traditional cookstoves are adopted largely by household as 39.35% use firestoves/3stones stove while 46.73% rely on *Mbaula* cookstove. In rural areas, the situation is worse as 98% of the households depend on biomass and inefficient cooking technologies compared to 67% in urban areas (ZamStats 2015).

Further, statistics show that in Zambia 96.89% of female members of households aged above 15 years participate in cooking meals at household level with 85% cooking every day. However, only 22% of their male counterparts cook meals every day with 41.67% not participating completely in cooking (World Bank/ESMAP, 2018). This shows that access to household cooking energy solutions has a strong gender aspect and women have a heavy presence in the kitchen in Zambia. Despite their heavy presence in the kitchen and its effects on their wellbeing, women lack authority

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[2] The study uses biomass fuel to represent fuel combination of firewood, charcoal, and agriculture refuse.

[3] Inefficient cooking technology encompasses cooking stoves with high emissions and contribute to indoor pollutions as shown by the WHO (2016).

[4] Improved cookstove with biomass fuel is locally referred to as improved *mbaula* and presented in appendix D (figure D4.4). This type of cookstove has less smoke emission and improved efficiency in terms heat resulting into less use of charcoal or firewood.

in making decisions on the type of cooking energy to adopt at households (Dutta *et al.,* 2017). In addition, the negative consequences of relying solely on solid fuel are high among women and girls in SSA countries compared to men and boys respectively as they are producers and users of the CES. Studies such as Morrissey (2017) and WHO (2016) have shown that continuous household exposure to inefficient cooking solutions have negative implications on health leading to loss of lives of children and women due to respiratory illnesses.

Further, the use of inefficient cooking solutions significantly contributes to loss of time thereby preventing users such as women and girls from being productive as they spend reasonable amounts of time collecting firewood and preparing meals. This loss in productive labour hours by women contributes to gender inequalities in both education and labour markets (Crentsil *et al.*, 2019; Rahul *et al.,*2014). Hence, improving access to either improved biomass or electric cookstove or biodigester has the possibility of reducing pre-mature death and respiratory illness (Bensch and Peters, 2015) justify in relation with gender. It can also reduce the time women spend gathering and cooking with firewood daily (Krishnapriya *et al.,*2021) as well as allow women to spend more time on education (Jeuland *et al.,* 2020), and improve their employment possibilities (Dinkelman, 2011) and civic engagement (IEA, 2022). Therefore, if achieving the SDG 7 objective and gaining the benefits of access to ICS is possible, inclusion of women in decision making, increasing annual investment, and remodelling the way of accessing ICS are key (Jagas *et al.,*2020).

To mitigate the negative effect, households need to transition from traditional energy sources to ICS and women empowerment through decision making is essential. Hence, the final study of the thesis undertakes a comparison analysis of gendered decision making on choice and expenditure of CES at household level. This arises due to gender differences in preferences on expenditure and choice on ICS across adult members of the households. The heavy involvement of women in cooking relative to men does not entail decision making toward fuel expenditure and choice of cookstoves. The study further assesses the impact when a household has access to multitier CES on gender outcomes. Each household is assigned to an overall Tier (0-5) based on the multitier framework (MTF) attributes of the CES with the aim of estimating the gendered differential effects as household transition across the six Tiers.

Hence, the thesis situates its analysis of the impact of household's energy access on socioeconomic welfare on four distinct but interrelated themes. These four themes comprehensively examine the household's energy access in developing countries taking Zambia as a case study. The first three focus on electricity access and its impact on household socio-economic welfare while the final theme diverts to cooking energy solutions (CES). Section 1.1.1. below presents the broad objectives.

1.1.1. Broad objectives of the Thesis

To understand the impact of household energy access on socio-economic outcomes in Zambia, the thesis situates its analysis on the following broad objectives:

i. To examine the impact of electrification technology on household socio-economic welfare indicators in Zambia
ii. To evaluate the impact of electricity availability on household socio-economic indicators
iii. To estimate WTP, its determinants and credit constraint effect among non-connected households in Zambia.
iv. To analyse gendered cooking energy choice, expenditure, and its welfare effects among households.

1.1.2. Contribution of the Thesis

The Thesis is relevant to both literature and policy as it provides empirical evidence about the impact of household energy access on socio-economic outcome in a developing country. The overall contributions of the thesis to literature are; to provide empirical evidence of the effects of electrification technology on socioeconomic outcomes of the users; provide empirical evidence of the impact of electricity availability among connected households on their welfare; contribute to debate on demand for electricity connection among non-connected households in developing countries with financial access constraint; and provide evidence on gendered decision making effects on expenditure and choice of cooking energy solutions and the welfare outcomes for adopting multitier cooking energy solutions.

Hence, the first two objectives of the thesis highlight the importance of accessing electricity on household welfare. The first objective focuses on the effect of electrification technology on household welfare. We disaggregate the data into two electrification technology that include grid and SHS electricity. The second objective focused on the effect of electricity service availability provided by the electrification technology on household welfare. Therefore, objectives one and two make a case that electrification is important for welfare improvement among Zambian people, and everyone should be electrified. However, relying on government progress alone will take a lot of time for everyone to be connected. This is why there is need to see whether the private market can come in and provide access. And for the private sector to enter the market the willingness to pay (WTP) for electricity connection should match the cost of connecting. Hence, the third objective focuses on understanding why non-connected households would connect or not by estimating their WTP and its determinants across electrification technologies considered in the first two objectives. This is because majority of the household in Zambia (63%) have no access to electricity and understanding what determines their willingness to connect is a step to determining whether private markets can participate in the provision of the electricity service so as to increase access to electricity in Zambia.

The fourth objective completes the understanding/examining the effects of energy access on household welfare outcomes in transition economies like Zambia. The first three objectives have established that electrification is beneficial to household and private market participation can complement government efforts in enhancing access to electricity. However, these initiatives have inertial and may take time for individuals to feel the impacts. This is why there are smaller paths to the problem of cooking energy access that can be tackled, especially that cooking takes the largest part of the electricity consumption at household level in Zambia. Therefore, we look at gendered cooking energy solution category separately, highlighting what access to electricity together with other sources of energy can to do to improve users' welfare and how different players in the market can influence the transition to modern energy.

Further contribution of the Thesis is from the adoption of multitier framework (MTF) when evaluating the impact of household energy access which provides new standpoints in literature as it is beyond the restrictive binary approach adopted by most studies.

1.2.Multitier Framework Data

The entire thesis utilises data collected by World Bank/ESMAP in 2017/2018 on household access to energy. The survey represents the standard household energy dataset developed by ESMAP under SE4ALL initiative following the adoption of the SDGs. The purpose of the survey is to monitor and evaluate energy access beyond the binary approach by introducing multidimensional approach (MTF) at national level. Further, the MTF survey generates global baseline data for energy access and use for benchmarking the SDGs (Krishinapriya *et al*., 2021; World Bank/ESMAP, 2018) to target universal access to modern energy.

The dataset includes detailed intra-household characteristics relating to energy access using the MTF. The MTF data categorises households into Tiers based on the attributes of energy access. For electricity access[5] there are basically six Tiers and seven attributes. The least Tier is 0 presenting no access to electricity while Tier 5 is the highest level of access to electricity (Bhatia and Angelou, 2015). The Tiers are defined by seven attributes which include electricity capacity, availability, reliability, affordability, quality, formality and health and safety. Further, the dataset also provides different forms of electricity technology sources apart from grid electricity that include Solar PV such as solar lantern, SHS, solar lights and off-grid solutions (mini-hydro and mini-solar grids) and other sources of electricity such as diesel generators. However, no one from the sample reported using electricity from mini grids (either solar or hydro). Similarly, cooking energy solutions[6] has basically six Tiers (0 to 5) defined by six attributes; exposure, efficiency, availability, affordability, safety, and convenience (Luzi *et al.,* 2019). The attributes consider both the fuel, cookstove and affordability issues of the energy adopted at household level.

Further, each attribute rates a household access level. The lowest Tier among all the attributes determines the overall access to cooking Tier or electricity Tiers for the household (Bhatia and Angelou, 2015). Households in Tier zero have no access to either improved cooking energy or electricity and entirely depend on inefficient sources of energy for lighting and cooking. Those in Tier one for electricity access, have at least four hours of available electricity services per day and at least an hour per night with the capacity to power multiple lighting bulbs, charge phone and/or radio (Krishinapriya *et al.*, 2021).

The MTF dataset for Zambia covers the entire country with the sample size designed to capture enough estimates per Tier at national level. The interview targeted 3658 households drawn from 260 enumeration areas (EAs) where each contributed 14 households. The stratification random sampling strategy was employed at two different stages. The first stage of stratification involved the urban-rural strata where EAs were stratified into rural and urban areas and were picked based on sample size for each province. The second stratification was to determine the electrification

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[5] In the appendix the table 1A present MTF for measuring access to electricity at household level

[6] In the appendix the table 1B present MTF for measuring access to modern energy cooking solutions

status of the EAs in the study population. An EA was considered electrified if at least 3% of the households in that area were connected to the national grid electricity while less than 3% households connected to grid electricity qualified an EA as a non-electrification status (World Bank/ ESMAP, 2018). A total of 3612 households were interviewed with 50% of respondents being from rural areas while the other 50% were from the urban areas of the ten provinces. To reduce sampling error and maximise the sample size the prevalence rate used to calculate sample size was 50% as a conservative choice and to achieve minimum marginal error.[7] The survey was administered using a uniform survey instrument (questionnaire).

Furthermore, the dataset was inspected before using it for estimations. We established that the dataset is credible for use in the estimation of the four studies of the thesis. This is because the data did not require imputation of variables or throwing out some observations. It did not have many missing variables and odd observations after inspecting dataset to affect inferences estimations. However, new variables were generated from existing variables to fit the requirements of each study. The description of the data extracted from the MTF dataset for each study is discussed in each study methodology under data section.

Nevertheless, the dataset had limitation that constrained the thesis from undertaking certain estimations and analysis. For instance, the sample size (3612 households) is relatively small such that disaggregating the dataset into subsamples such as rural-urban and electrification technology (SHS and grid electricity) failed in certain circumstances as described in each study. This has limited the extent of the analysis and estimation of the studies. Further, the dataset collected by the World Bank/ESMAP (2018) is nationally represented. This entails that uniform questionnaire was administered with same questions for every individual in the sample size regardless of the location. The failure to account for location left out salient features unique to each location. The differences in economic characteristics and energy access level across location (urban and rural areas) entails different questions are supposed to be administered. Additional limitations of the dataset have been discussed in each study. Each study has highlighted the dataset limitations that has resulted in the failure to conduct subsample analysis in certain sections of the thesis.

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[7] For further understanding of the sampling strategy see https://doi.org/10.48529/b2ds-j290

1.3.Organization of the thesis

The thesis comprises of six chapters with the first chapter being the introduction of the thesis. It introduces the context of the thesis, broad objectives, and MTF dataset used in the entire thesis. The next four chapters present the four substantive studies which analyse the four different aspects of household energy access and its impact on socio-economic welfare indicators in Zambia. The first study presented in Chapter 2 examines the impact of electrification technology on household welfare indicators while the second study presented in Chapter 3 analyses the impact of electricity availability on households' welfare indicators. The study diverts from the traditional binary approach to impact evaluation to focus on multitier framework where attributes of electricity access are used as treatment to electricity access. In Chapter 4 the thesis presents the third study which estimates the WTP for electricity connection (grid vs SHS) among non-connected households. The fourth study is presented in Chapter 5 which focuses on analysing the gendered effect of choices and expenditure of cooking energy solutions and how that affect the welfare indicators of the users. The final chapter is Chapter 6 which synthesises the four chapters in order to consolidate the policy implications and provide a conclusion to the thesis.

Chapter Two
Electrification Technology and its Effect on Household Socio-Economic Welfare

Abstract

The study evaluates the effectiveness of electrification technologies on households economic outcomes; non-farm employment, income and expenditure in Zambia. Grid and off-grid solar PV electricity are identified as electrification technology. This is premised on the fact that electrification programmes in developing countries are implemented with the aim of improving the users' livelihoods and understanding the differential impact of household adoption of grid versus off-grid (standalone solar home systems) electricity on socioeconomic outcomes is essential. The study adopts the Inverse Probability Treatment Weighting estimation strategy. The results of the study reveal heterogeneity in the impacts of the technology used in the electrification programme on non-farm employment, household monthly income, household monthly expenditure on alternative energy and annual expenditure per capita. While standalone solar home systems offer benefits, grid electricity offers better effects on household income and expenditure than standalone solar systems. Given the benefits derived from electricity adoption (grid vs solar PV), the study raises the issue of viability of SHS as a mode of electrification technology and its impact on household welfare outcomes. This requires policymakers to understand the limitation of the electrification technology in improving the livelihood of the users.

2.1.Introduction

2.1.1. Background to the Study

Literature shows that household and community access to electricity services in developing countries contributes to users' ability to improve their livelihood. It enables users engage in income generating activities such as running grocery shops, hair salons, barbershops and sewing (Khandker *et al.,* 2009; Bensch *et al.,* 2011; Daso and Fernades, 2015) once connected. It further reduces exposure to indoor pollution as reliance on traditional fuels for lighting and cooking (Khandker *et al.,* 2012; Bonan *et al*., 2016) reduces and is further linked to increased time and years children spend studying (Litzow *et al.*, 2019; Julio and Aguirre, 2014). In addition, electricity access improves household access to information as individuals acquire mobile phones and appliances such as radios, and TV that use electricity (Bensch, *et al*., 2011).

Considering possible benefits, countries in the global south implementing electrification programmes should aim at enabling users improve socio-economic livelihood and economic development (Torero, 2014). In short, policy efforts should ensure users of the electricity services from a given electrification technology[8] experience improvement in their socio-economic outcomes. This is because a host of electricity sources and/or technology may supply electricity services with different capacity and quality thereby limiting the benefits derived by users. For instance, the extent to which a household receiving grid electricity, off-grid-standalone solar electricity and/ or solar lantern derive their socio-economic benefits may differ due to differing appliances connected. Additionally, inadequate access to electricity from an electricity system and/or technology may result in users implementing coping strategies. The copying strategies may significantly cost the users' health, safety, social and gender aspects, and economic status (Bhatia and Angelou, 2015).

Since 2002, successive governments in Zambia have implemented various policies that include Vision 2030; Rural Electrification Master Plan (2008-2030); National Development Plans (2005-2022); and National Energy Policies (2007; 2019). The emphasis in these policy documents is to increase household access to electricity services through grid and off-grid electricity. Therefore, to increase electricity access, the government promotes mainly grid extension and off-grid solar

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[8] In this study electrification technology refer to sources of electricity services sources. From the data, the study has identified two sources of electricity services adopted in the electrification program that include, grid electricity and off-grid solutions defined by standalone solar PV (solar lanterns, solar lights, solar home systems).

PV connection among households. However, the electricity service is expected to be reliable and affordable to facilitate poverty reduction and promote household business expansion (NEP, 2019). For instance, off-grid electricity (PV solar) offers a reliable and cheap form of electricity for improved lighting and other limited use such as watching TV, phone charging among low-income households (Sievert and Steinbuks, 2020; World Bank, 2018) especially for those residing in rural areas far away from the grid. Nevertheless, continuously connecting households to grid electricity is critical for long term improvement in household livelihood. Grid electricity offers sustainable electricity that may improve income generation, education attainment, and health of users which are central to overcoming household poverty.

Therefore, the attributes of the electricity supplied are important catalysts in wealth generation and poverty reduction among users (Hafner *et al.*, 2018). This is because the benefits derived from the electricity supplied by the electrification technology tend to be incremental in levels starting with meeting basic human needs (lighting, aiding communication, education, and health); productive uses (hair saloon, barbershop, grocery shop, pumping water for agriculture purposes) and modern society needs (heating and cooling) (Sokona *et al*., 2012). In short, the differential effect may exist across various electrification technologies that limit users' benefits to a certain level and to what extent requires further investigation. Failure to differentiate the electricity technology may led to either overstating or understating the impact of electrification on household outcomes. Hence, the study estimates the differential effect of adopting various technologies in the electrification programme on households' employment, income, and expenditure outcomes.

2.1.2. Study Objective

Literature has pointed out that electrification technology adopted at household level should facilitate poverty reduction and livelihood improvement through income generation ventures and non-farm employment. The study objective therefore is to evaluate the effectiveness of electrification technologies on households' economic outcomes; non-farm employment, income, and expenditure in Zambia.

2.1.3. Household Electrification Programme in Zambia

Following the formulation and adoption of the Poverty Reduction Strategy Paper (PRSP) in 2002, government identified the electrification programme as a vehicle to poverty reduction by improving households' livelihood and stimulating economic growth (REMP, 2007). The programme needed to accelerate access to improved energy, promote use of energy efficient devices and alternative clean fuels at household level. The targets included increased electrification in the medium term (by 2010) from 2% to 15% in rural areas while in urban areas increasing to 50% translating to 35% at national level from 20% in 2002 (PRSP, 2002). The commitments were amplified by the formulation and implementation of various policies that included the Fifth National Development Plan (2006-2010) and Vision 2030 in 2005 and 2006, respectively. The policies led to designing and adoption of programmes for rural electrification involving mainly grid extension connections across the country. In 2003, a law was enacted that led to the establishment of the Rural Electrification Authority (REA) in 2006 and in 2007 the Rural Electrification Master Plan (REMP) was drafted and adopted.

Despite the medium goals, the electrification programme's long-term objective is to ensure that over 51% of the rural household's transition to using electricity by 2030 from 2% in 2002 while in urban areas 90% are connected to grid electricity. Achieving the long-term objectives help households connected to electricity initiate economic activities and/or improve productivity. Thus, central government committed through REA to spending $50 million annually for 22 years (2008 to 2030) to electrify rural areas through grid extension. The funds were sourced from the 3% monthly sales tax on household electricity consumption (REMP, 2007). In addition, successive governments have continued reviewing the policy priority regarding increasing the number of households connected to electricity both in rural and urban areas. For instance, the Zambia National Energy Policy (NEP) of 2019 recognised the need to increase electricity access among households through implementation of integrated electrification pathways to achieve universal access to improved energy (NEP, 2019) while in the Zambian Vision 2030 and National Development Plan (2006-2010), the government committed itself to reducing the share of wood fuel at the household level from 80% in 2006 to 40% by 2030 through increasing access to clean, affordable and reliable cooking energy solutions at the household level.

At inception stage, the electrification programme concentrated on grid electricity extension with little attention paid to off-grid solutions. The electricity mix shows that grid electricity accounts for 91.4%; hydroelectricity (81.5%) and coal (9.9%) while off-grid electricity accounts for 8.6%; solar PV (2.7%), diesel (2.6%) and heavy fuels (3.3%) (ERB, 2021). Despite taking a huge share in the electricity mix, grid extension concentrates on connecting government institutions (schools, health, agriculture, and administrative offices) and public places (chief palaces, markets). The government institutions and public places given priority are connected at no cost while households are required to pay connection fees. Connection fees range between $69.7 and $74 for rural areas (REA, 2019) while in urban areas fees range between $240 to $400 plus wiring costs as of 2017 (Luzi, 2019). In addition to connection fees, wiring fees, house structure quality, high household poverty levels (at 76.6% in rural areas and 23.4% in urban areas), and high usage tariffs have made it impossible to increase electricity connectivity among households (ZamStats, 2015).

However, the electrification programme is slowly integrating off-grid solutions to capture unserved households. The off-grid electrification technology including mini-grid (solar PV and hydroelectricity) are being implemented by REA in collaboration with partners and the private sector to target households currently unserved by grid electricity. For instance, in 2021, REA undertook 7 solar mini grid projects out of 18 projects for rural electrification (ERB, 2021). Further, solar lanterns and standalone home solar PV technologies are sold in markets for unserved populations in rural areas (NEP, 2019) and in urban areas standalone home solar PV are adopted by households as backup measures due to unreliability and unavailability of grid electricity for lighting and few appliances. Grid electricity capacity and cost, poor economic conditions of rural households, improved off-grid technology and/or the suitability[9] of rural areas are key drivers of increased adoption of off-grid electricity.

The standard connection requirements for grid electricity that are applied to mini-grid electricity (mini-solar and mini-hydro); usage tariff structures, wiring and connection fees discourage household uptake of the electricity services (ERB, 2021). Instead, households opt to connect to the standalone solar system; solar home system, solar lantern, solar rechargeable batteries, and solar lighting system due to affordability among low-income households, ease of connection and operation despite their usage limitations (Bhatia and Angelou, 2015). Therefore, just like grid extension, the off-grid solutions (mini-grid solar and hydro) being implemented through the electrification programme are failing to increase the number of households accessing electricity to achieve the 2030 target.

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[9] Suitability factors such as enough water, sun, or wind to establish a min grid for hydro, solar or wind electricity.

2.1.4. Statement of Contribution of the Study

Although universal access to electricity may not sufficiently achieve development and fully eradicate poverty, it is a central catalyst to achieving improvement in the socio-economic being of the users (Sokona *et al.,* 2012). However, what is unclear is how effective the different electrification technologies (grid vs solar electricity) adopted in the electrification process are in changing the livelihood of users. This is because of the differences in the attributes (capacity, quality, availability, and reliability) of the two-electrification technologies which potentially limit the benefits derived once connected. Therefore, the study adds to literature debate by comparing the effectiveness of electrification technologies on household welfare indicators. This is because several studies evaluating the impact of electrification programmes in developing countries neglect the differential effect of multiple electrification and instead focus on single electrification technology despite the programmes adopting mixed technology. For instance, the decrease in the cost of renewable energy sources that include Solar PV entails households will independently take up standalone solar PV as the primary sources of energy. Thus, understanding the benefits households derive from connecting to standalone solar PV versus grid electricity and non-connected households is central to the electrification programme leading to possible policy recommendation for a rollout programme of solar PV to meet universal electrification in Zambia. To the knowledge of the researcher, this study is among the first of its kind to comprehensively study the differential effect of electrification technology adopted in the electrification programme on household welfare indicators in Zambia.

2.1.5. Organization of the Study

The study is organised into six sections with the introduction of the study being the first section. Literature review is divided into two sections that include the theory of change and empirical review of the study. The third section presents the study methodology, detailing the process of estimation, data description, descriptive statistics that include control variables and outcomes variables. The section further presents sensitivity analysis of the GPS estimation. The firth section presents empirical results and discussion, and the final section provides the conclusion and policy implications of the study.

2.2.Literature Review

This section reviews literature both empirical and theoretical. The section begins with the theory of change and household adoption of electricity. Thereafter, the section presents the empirical review and finally the synthesis of the literature.

2.2.1. Household Adoption of Electricity and Theory of Change

In theory, the change in user's welfare is depicted by causal pathways that lead to specific outcomes once a household is electrified. The change mechanism only starts after a household is electrified (Karumba and Muchapondwa, 2018) with direction and period (short, medium, and long term) of the observed impacts differing among household members. Furthermore, the pathways to achieving a given outcome once electrified differ depending on the source of electricity services. Figure 2.1 below depicts pathways for two (grid and off-grid solutions) sources of electricity services adopted in the electrification programme. The standard grid electricity involves a synchronised electricity system with its sources which include hydro, coal, diesel, or heavy fuel oils and solar in the case of Zambia (ERB, 2021). However, off-grid solutions in this study include standalone solar PV home system, lanterns, and rechargeable solar lights. These are generally referred to as standalone home solar system (SHS) and are defined by the capacity of 3W to 500W.

The pathways by standard grid electricity service differ from standalone home solar systems due to differences in attributes. Heavy appliances: electric stoves, welding and saloon appliances are best suited for grid electricity services due to high capacity and stability. On the other hand, SHS system, electricity services supplied from SHS technologies vary according to the capacity of the gadget acquired. For instance, the SHS with capacity between 3W-50W are limited to lighting and a few home appliances such as radio, phone charging while those with capacity higher than 50W have the capacity to power small capacity appliances such as a TV, radio, domestic water pump and irrigation electric pumps (Luzi *et al.*, 2019).

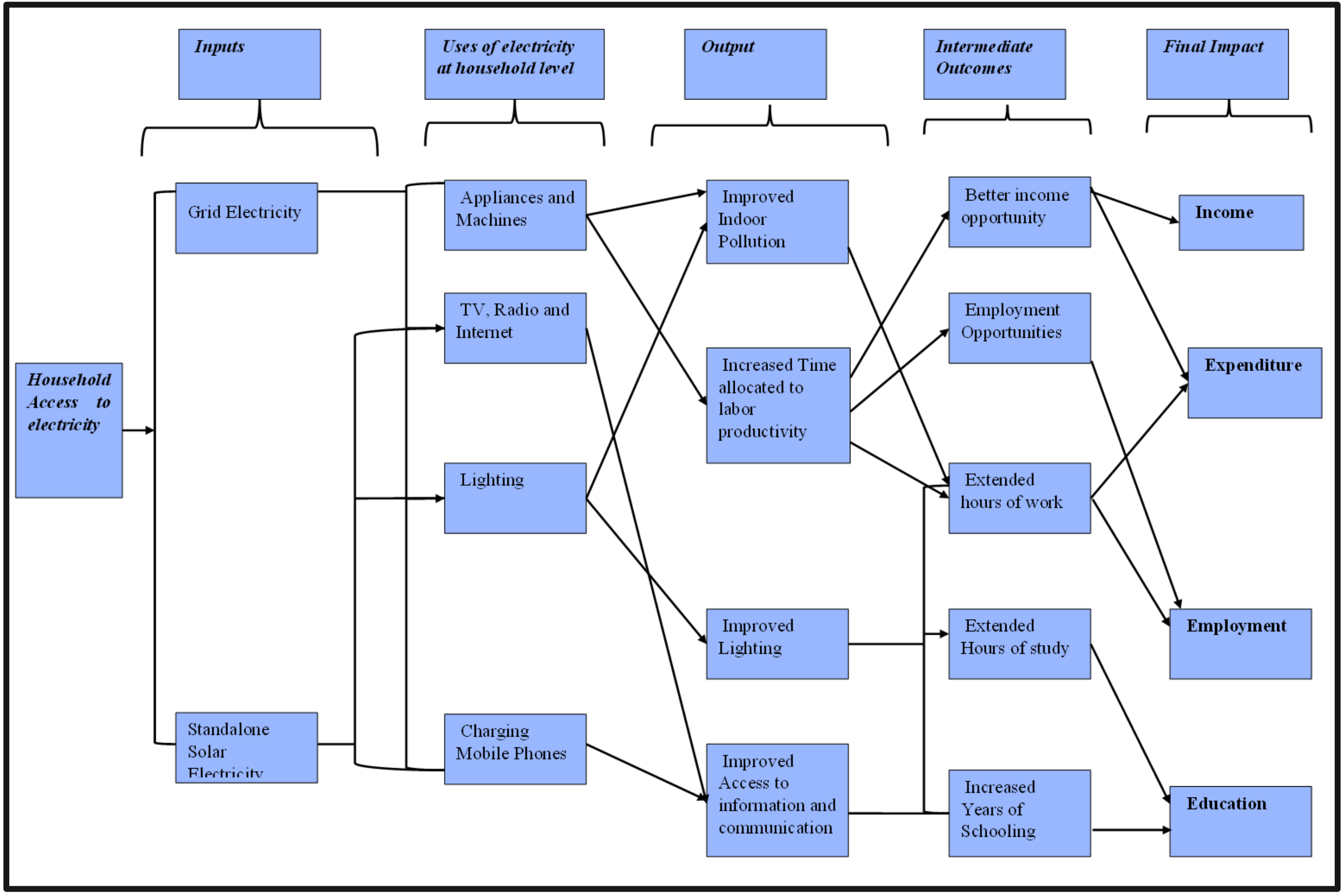
Despite differences in electricity service attributes provided, there are several pathways in which a household welfare is improved. Figure 2.1 shows that the first visible outcome is improvement in the quality of lighting at household level. This translates into reduced use of dirty fuels like kerosene, candle, and diesel for lighting. Studies (Karumba and Muchapondwa, 2018; van de Walle *et al*., 2013; Bensch *et al*., 2011) show that users expect reduced indoor pollutions due to improved quality of lighting and reduction in expenditure on dirty fuels for lighting. Hence, the reduced indoor pollution will improve the health of users (possibility of reduced respiratory illness) and further expenditure on other goods and services. Furthermore, improved lighting leads to the possibility of increased time children spend on studying. Khandker *et al.* (2012) and Litzow *et al.* (2019) show that time children spent studying increases leading to more years completed in school with boys spending more time studying relative to girls (Bonan *et al.*, 2017).

The second pathway involves the use of electric appliances and/or machines following the household adoption of electricity. Adoption of electric appliances at household level results in saved time, which is reallocated to other productive activities (Khandker *et al*. 2012; Bonan *et al.*, 2017). For instance, time allocated to cooking reduces significantly once households adopt electricity. The time allocated to collecting, preparing firewood, and cooking by women in rural areas is shortened and transferred to other economic activities that improve the household's income (Dinkelman *et al*. 2011). The time allocation substitution results in more people being employed and work beyond normal working hours in a day. After acquiring electric appliances, households further invest in businesses such as grocery shops, barbershops, hair salons and tailoring due to availability of electricity services. This impacts positively on employment, income, and wages thereby affecting labour supply (Dasso and Fernades, 2015).

The third pathway is the use of radios, TV and mobile phones that improve household access to information and communication. Households are motivated to acquire mobile phones due to availability of electricity for charging. Improved access to information through acquiring phones and TV has a bearing on the quality of businesses households engage in and is linked to improved income (Bensch *et al.*, 2011).

Therefore, the extent of the impact in change mechanism of household access to electricity is affected by source of electricity technology (either grid or solar electricity) as alluded to earlier. Jimenez (2017) argues that quality, availability and reliability of the electricity service will operate through the type of electricity technology and follow the same channels. For instance, poor quality, unavailability, and unreliability of the electricity services from a given technological source (grid or SHS) limits the extent of the impact and its period (short, medium, or long term). This is why this study focuses on understanding the extent to which electrification technology impacts on household welfare indicators once a household is connected.

Figure 2.1: Causal Pathways for Household Electrification Technology



Source: Author generated

2.2.2. Household Electrification and Socio-economic Outcomes- Empirical Review

This section presents empirical review of the impact of the electrification programme on household socio-economic outcomes. The justification for evaluating impact of electrification among scholars rely on the benefits and transformation effects of household's access to electricity. Although access to electricity alone is not an end to achieving economic growth and poverty reduction (IEA, 2014), electricity service accompanied by other infrastructure is treated as an essential need to catalyse economic activities. In theory access to electricity improves socio-economic conditions of communities and households by influencing components of their livelihood such as education, health and productive environment thereby reducing poverty (Torero, 2015).

Therefore, several studies using different methodologies have estimated the impact of electrification on several socio-economic outcomes. The first visible service after adopting electricity is improved lighting at household level which immediately replaces the use of other sources of energies for lighting such as kerosene, batteries, and candles. This immediately impacts on fuel expenditure at household level and general energy expenditure. However, results from various studies indicate mixed results on the impact of electricity on fuel expenditure at household level. Studies such as Bensch *et al.* (2011); Khandker *et al*. (2012); van de Walle *et al.* (2013); and Chakravorty *et al*. (2016) report a significant rise in the fuel expenditure at household level while Arriaz and Calero (2014); Samad *et al*. (2013); Grimm *et al*. (2016); Karumba and Muchapondwa (2018) and Litzow *et al.* (2019) found a decrease in the fuel expenditure and consumption among household connected to electricity compared to non-connected.

Statistically, significant increase in energy expenditure at household level after being connected is based on the grid electricity service. For instance, Bensch *et al.* (2011) applying a propensity score matching identification strategy found a higher and significant rise in the energy expenditure among connected households in Rwanda. The study argued that rise in expenditure is due to increased consumption of electricity as households acquire more electric appliances such as TVs, fridges and stoves that are beyond lighting. Furthermore, Khandker *et al.* (2012) in a study conducted in rural India found that failure to account for effect of reliability and availability of grid electricity among connected households contributes to rising general energy expenditure. However, in another study conducted in Bangladesh, Khandker *et al*., (2009) argue that a reduction in expenditure can only be seen if electricity supplied from a given technology is reliable. The study contends that unreliable and unavailable electricity leads to households maintaining a huge expenditure on batteries, kerosene, and candles. Thus, the total energy expenditure rises when households acquire additional appliances while the expenditure on alternative energy (candle, kerosene, diesel) reduces only if the grid electricity services are reliable and available most of the time during the day (Bhatia and Anglomeu, 2015).

However, Karumba and Muchapondwa (2018) applying a PSM estimation strategy to treated and non-treated households under off-grid; mini-grid electricity services in Kenya, found a statistically significant reduction on household expenditure on kerosene consumption per month among those connected compared to non-connected. These results were similar to Dinkelman (2011) in South Africa who empirically found that household in rural areas following grid electrification reduced expenditure on dirty fuel such as kerosene and fuelwood in preference for electric cooking and lighting in the six-year period (1996-2001) in Kwazulu Natal Province. Furthermore, Bonan *et al.* (2017) noted that off-grid solutions such as standalone solar home system offer opportunities to lower further or eliminate household's expenditure on traditional fuels like kerosene (Arriaz and Calero, 2014; Samad *et al*., 2013) compared to unreliable grid electricity connection (Litzow *et al.,* 2019; Barron and Torero, 2015). Households once connected to off-grid solutions immediately reduce consumption of non-electricity lighting thereby experiencing a reduction on household's expenditure on kerosene, candles, and batteries. The changes from off-grid and grid connections, nevertheless, do not affect cooking fuels expenditure as households prefer to maintain firewood and charcoal. The high cost (tariffs) of maintaining grid electricity and limited capacity of off-grid solutions leads to households-short-run coping costs increasing (Barron and Torero, 2015; Karumba and Muchapondwa, 2018; Litzow *et al*., 2019).

Further, several studies conducted show that the impact of electrification on labour outcomes are robust despite not being definitive (Bonan *et al.,* 2017). The labour outcomes defined by different measures include employment, hours of work, wages and earning among adult working age. However, the impact of household electrification on employment has a gender bias where female employment rises significantly compared to males. For example, Arriaz and Calero (2014) found statistically significant rise in the employment level and supply of labour among females in Peru away from agriculture activities. Also, Grogen and Sadanand (2013) conducting an evaluation of the impact of rural electrification on employment in poor countries found improved employment in rural areas in Nicaragua. The study showed that female's ability to work outside rose by 23% compared to males with no change due to electrification. In South Africa, Dinkelman (2011) applying an IV strategy to estimate the impact of rural electrification in KwaZulu Natal Province found employment level rising among females by 9 to 9.5% translating into almost 1% female labour participation increase. Female employment rose during the period 1996 to 2001 when electrification was undertaken; electrification led to reduction in home productivity as more women engaged in microenterprises away from their homes. The study, however, found a statistically insignificant impact on male employment among communities electrified. This was also supported by Arriaz and Calero (2014) who found no impact on male employment due to rural electrification.

Despite the positive impact on female employment due to the presence of electricity at home, their earnings or wages tend be lower than males. Dinkelman (2011) applying a fixed effect estimation strategy found that increased supply of labour among female leads to a drop in wages compared to men. This is supported by Khandker *et al.,* (2013) who found significant increase in household income generated from non-agricultural activities but no effect in general on households' wage among working age groups, especially females. However, Arriaz and Calero (2014) found a significant rise in female earnings compared to males in rural areas because of the implementation of the electrification programme in Peru. Their study contended that households which adopted electricity as a source of income-generation through establishing business ventures that use electricity, witnessed a rise in income significantly (Bensch *et al.,*2011). However, the improvement in income is on condition that there is better supply of electricity as it acts as an input in their production (Chakravorty *et al.,* 2014).

2.2.3. Gap in the Literature

The literature discussion shows that the electrification programme among households has mixed impact on various socio-economic outcomes. However, majority of the studies cited in the literature take grid extension as the electrification programme neglecting those connected to off-grid solutions. This creates a gap in literature as studies fail to control for different electricity technology sources. Hence, the study aims to fill this gap by estimating the effect of electrification technology adopted on household employment, expenditure per capital, expenditure on alternative energy and income in developing countries by considering the electrification technology adopted by households as the primary source of energy.

2.3. Methodology

The section describes estimation procedure of the objective. The section begins by defining the experiment treatment. Thereafter it describes the estimation procedures. Finally, the section describes the household socio-economic outcome variables used in the study.

2.3.1. Defining the Treatment (Household Access to Electricity) of the Experiment

The aim of the study is to estimate average treatment effect (ATE) of being treated (electrification) on household socio-economic outcomes. Equation 2.1 is the starting point in the estimation process of the ATE.

$$\boldsymbol{Y_i = \alpha + \delta T_i + \beta X_i + \varepsilon_i} \qquad 2.1$$

where Y_i is the observed outcome variable under a given treatment, T_i is the treatment individual i receives, X_i is a vector of covariates and ε_i is the error term. Defining T_i as an integer value entails it ranges from 0 $to\ K$; $T_i = \{0, 1, \dots K\}$ as opposed to binary treatment (0,1). Therefore, equation 2.2 below defines the experiment treatment (access to electricity):

$$T_i = \begin{cases} 0 & not\ connected \\ 1 & connected\ to\ grid \\ 2 & connected\ to\ SHS \end{cases} \qquad 2.2$$

The experiment treatment (T_i) in equation 2.2 shows that individual households are either treated to grid electricity ($k = 1$) or standalone solar home system electricity ($k = 2$). The households who are untreated ($k = 0$) are those with no access to electricity and entirely depend on traditional forms of energy for both lighting and cooking. Having $n(T_i) = 3$, defines treatment as a multiple/multivalued treatment effect (Feng *et al*., 2019), and each category is independent. The treatment defined as either grid or SHS is based on household dominant or primary source of electricity used for lighting and other electrical appliances. Therefore, evaluation approach involves estimating the pairwise differential impact of electrification technologies adopted on household socio-economic outcomes. Table 2.1 shows distribution of the whole sample of 3,612 households across the treatments (different forms of electricity access) and subsamples for rural-urban areas.

Table 2.1: Categorical Treatment to Household Access to Electricity

	Overall Treatment		**Urban**		**Rural**	
Source of Electricity	**Obs.**	**Percentage**	**Obs.**	**Percentage**	**Obs.**	**Percentage**
Not Connected (NC)	2, 169	61.8	664	37.8	1, 505	86.0
Grid Electricity (GE)	1,151	32.8	1,008	57.3	143	8.2
Standalone Solar Electricity (SHS)	189	5.4	86	4.9	103	5.8
Total	***3,509***	***100***	***1, 758***	***100***	***1,751***	***100***

Source: World Bank/ESMAP (2018)

From Table 2.1, majority (61.8%) of the households in Zambia are not connected to any source of electricity (NC) while 32.8% of the households use grid electricity as the primary source of electricity and only 5.4% of the total household depend on solar as primary of electricity. As earlier alluded, SHS include standalone solar PV, solar lanterns, and rechargeable solar lights. Despite various types of SHS majority of the households in Zambia have not adopted solar appliances as sources of electricity. However, for the rural urban subsample, Table 2.1 show that around 60% of the households have access to electricity in urban areas compared to less than 14% in rural areas from different sources of electricity. Majority rural households have no access to any form of electricity (86%) compared to about 40% in urban areas.

2.3.2. Multiple Treatment of Household Access to Electricity Service: Application of the Propensity Score Approach

Randomization[10] of electrification programmes in developing countries is impossible as programmes are designed and implemented based on investment viability or government priority. The lack of randomization in the assignment to treatment leads to difficulties in constructing a counterfactual; a scenario that would have happened if those connected to electricity did not connect (Khandker *et al.,*2009). Thus, estimators may be biased as treatment indicators and covariates are not independent (Imben and Woodridge, 2009). However, the challenge of randomization of the electrification programmes has led to several studies relying on non-experimental or observational data to evaluate the impact of electrification programmes. Applying specific assumptions on the identification of counterfactual group, non-experimental data can avoid issues of endogeneity and selection bias thereby producing unbiased estimates (Bonan *et al.*, 2017).

Rosenbaum and Rubin (1983) proposed the use of propensity score technique that requires adjusting for differences in pre-treatment variables (Feng *et al.*, 2019). The propensity score shows the conditional probability of receiving a treatment given the pre-treatment variables (Imbens, 2000). Various methods such as weighting (Robbin *et al.*, 2000), matching (Dehijia and Wahba, 2000), sub-classification (Rosenbaum and Rubin, 1983) and imputation (Gutman and Rubin, 2015) have utilised propensity score technique to balance across the different groups whereas treated and non-treated groups are exposed to different pre-treatment variables (Lopez and Gutman, 2017).

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[10] Randomised experiments in impact evaluation of programs are taken as gold standard due to its ability to construct the counterfactual through the random assignment of individuals to control group (Lopez and Gutman, 2017, Imben and Woodridge, 2009).

Several studies such as Khandker *et al.*, (2009); Samad *et al.*, (2013); Litzow *et al.*, (2019) have utilised propensity score matching technique to evaluate the impact of electrification programmes with observational data. These studies base their design on a binary scenario as designed by Rosenbaum and Rubin (1983) where a household is either connected or not to a given source of electricity. However, in this study the treatment is defined beyond binary approach. The household treatment to electricity access is a multiple treatment with $T > 2$. In this case, propensity score weighting technique (IPTW) is adopted due to its ability to reduce estimation bias (Leite *et al.*, 2019).

2.3.3. Multiple Treatment (Categorical) and Application of Inverse Probability Treatment Weighting (IPTW)

The objective of the study is to estimate the average treatment effect of electrification technology on household socio-economic outcomes. The study relies on Imbens (2000) extension of Rosenbaum and Rubin (1983) framework of binary treatment analysis to accommodate multiple/multivalued treatments under the propensity score analysis. The extension referred to as generalised propensity score (GPS) made it possible to estimate unbiased casual inferences under the assumption of weak unconfoundedness. Theoretically, GPS assumes that selection into a given programme is random and conditional on a set of pre-treatment covariates. Imbens (2000) define GPS for multiple treatment as defined in equation 2.3 below.

$$r(k,x) \equiv \Pr(T = k|X = x) = E(T(k)|X = x) \qquad 2.3$$

where $r(k,x)$ is the GPS which is equivalent to the conditional probability of an individual belonging to treatment k given the pre-treatment variables X. The GPS in multiple treatment framework accommodates unordered categorical treatment as given in this study. Moreover, to define potential outcomes and estimate unbiased average treatment effects under multiple treatment framework, two basic assumptions of weakly unconfoundedness and area of common support should hold for every treatment (Lopez and Gutman, 2017). The first assumption of weakly unconfoundedness assumption given by equation 2.4.

$$I(k) \perp Y(k)|X \qquad 2.4$$

where $I(k) = \begin{cases} 1 & if \;\; T = k \\ 0 & otherwise \end{cases}$ is the indicator of receiving treatment k while $Y(k)$ is outcome variable.

Equation 2.4 shows that a potential outcome should be independent of the assignment to a level of treatment given that all effects and interactions of true confounders are included in the estimation of the propensity score. Imbens (2000) demonstrated that if assignment to treatment is weakly unconfounded given the pre-treatment variables, then the assignment to treatment will be weakly unconfounded given the GPS as shown in equation 2.5:

$$I(k) \perp Y(k) | r(k, X) \qquad 2.5$$

Equation 2.5 shows that assignment to treatment is independent of the outcome thereby eliminating systematic selection of individuals into a given treatment (Leite *et al.,* 2019). The inclusion of several household and community characteristics (control variables) helps reduce systematic selection of individuals in a given category.

The second assumption is the overlap assumption or area of common support which shows that the probability of receiving the treatment should be positive for all households in all levels of the treatments given the pre-treatment variables (Catteneo *et al*, 2013).

$$0 < p(T_i = k|x) < 1 \text{ for all k and i} \qquad 2.6$$

The assumption in equation 2.6 is tested using a kernel density plot. The absence of an overlap in the distribution of the observed pre-treatment variables between groups receiving different treatments implies difficulties in making comparisons across the ATEs (McCaffrey *et al.,* 2013).

2.3.3.1. Estimating Generalised Propensity Score (GPS)

The estimation process of the ATE starts with the estimation of GPS where the first step involves deciding on covariates to include in the model. Baseline characteristics that are close to both the treatment and potential outcomes are considered. Caliendo and Kopeinig (2008) argue that including variables only related to treatment increases sampling variance of the treatment while leaving relevant variables lead to hidden bias which affects balancing between treatment groups and further leads to errors in the estimation of treatment effects. Furthermore, adding only statistically significant covariates as suggested by Heckman *et al*., (1998) and Smith and Todd (1998) to estimation of GPS defeats the practical importance of establishing optimal balance between treatment comparisons (Marcus *et al.,* 2004). Therefore, all baseline characteristics that are close to both the outcome and the treatment should be included to in order to reduce or eliminate bias and/or self-selection. The second stage involves estimating the GPS through multinomial logit estimation approach following Imbens (2000); Imai and Van Dyk (2004); Lopez and Gutman (2017) approach. Multinomial logit is appropriate because electrification technology is taken as unordered categorical variable with three categories (Yan *et al.*, 2019). The GPS is predicted post multinomial logit estimation for each treatment group as a conditional probability of being assigned to a treatment group $(0, \dots\dots, k)$ given the covariates (Li, 2019).

The predicted GPS for each treatment from the multinomial logit is plotted using the Kernel Density to investigate whether the overlap assumption holds for different treatments. Determining the credibility of the overlap assumption gives key ingredient for estimating the ATEs. This is because the assumption shows the range of distribution of treatment where there are individuals with comparable probabilities of receiving a given treatment for each group (Flores and Mitnik, 2009). Hence, inadequate overlap of the GPS distribution limits generalization of the treatment effects as inferences cannot be made for the individual outside the areas of common support (Leite *et al.*, 2019).

2.3.3.2.Application of Inverse Probability Treatment Weighting (IPTW) to ATE Estimation

As earlier stated, the interest is to estimate and compare the causal effect of being treated to either grid electricity or solar system on socio-economic welfare indicators of the households. McCaffrey *et al.* (2013) argues that the estimands among individuals receiving treatment can be biased or inconsistent if there are confounding issues. Therefore, if the two assumptions (weak unconfoundedness and overlap) are met then the problem of confoundedness is solved such that it is possible to reweight the treatment sample for the distribution of the covariates to match that of the other treatment group (ibid). In such a scenario, application of inverse probability treatment weighting (IPTW) with propensity scores helps estimate causal inferences. The IPTW approach has been applied by various studies such as Imbens (2000); McCaffrey *et al*., (2013); Feng *et al.* (2011) and Lopez and Gutman (2017). The rationale behind the IPTW approach with multiple treatment is to allow construction of a pseudo population for the treatments through weighting the subject in the observed group $\boldsymbol{k}$. The weighting process creates a sample in which covariates are balanced across all treatment groups. Thereafter, the expected outcome for those units with treatment $\boldsymbol{T_i = k}$ are calculated with weights normalized to add up to one in each treatment group in expectation (Flores and Mitnik, 2009; Feng *et al,* 2011).

Given that we have three treatments (0,1 and 2), the study implements IPTW for each ATE of the sample by weighting the outcome (Feng *et al*., 2011; Imbens, 2000).

$$E(Y_i(k_0)) = \left(\sum_{i=1}^{n} \frac{D(T_i=k_0)Y_i}{r(k_0,X_i)}\right)\left(\sum_{i=1}^{n} \frac{D(T_i=k_0)}{r(k_0,X_i)}\right)^{-1} \qquad 2.7$$

$$E(Y_i(k_1)) = \left(\sum_{i=1}^{n} \frac{D(T_i=k_1)Y_i}{r(k_1,X_i)}\right)\left(\sum_{i=1}^{n} \frac{D(T_i=k_1)}{r(k_1,X_i)}\right)^{-1} \qquad 2.8$$

$$E(Y_i(k_2)) = \left(\sum_{i=1}^{n} \frac{D(T_i=k_2)Y_i}{r(k_2,X_i)}\right)\left(\sum_{i=1}^{n} \frac{D(T_i=k_2)}{r(k_2,X_i)}\right)^{-1} \qquad 2.9$$

The individual ATEs obtained after implementing the IPTW are used to estimate the three pairwise ATEs across the three treatments with each treatment having $T(T-1) = 2$ individual pairwise.

$$ATE_{\ k1,k2} = E[Y_i(k_1)] - E[Y_i(k_2)] \qquad 2.10$$

The pairwise ATE given by equation 2.10 shows the average effect of a household receiving treatment 1 instead of treatment 2. And the ATE estimated in equation 2.10 is the interest of the study.

2.4.Data and Descriptive Statistics

2.4.1. Data Description

This study relies on data from World Bank/ESMAP (2018) on household access to energy in Zambia as discussed in Chapter One. The entire dataset of 3,509 households is utilized in this study as observed in Table 2.1. Households indicated their primary sources of electricity with two electrification technology (grid and SHS) identified from the dataset with third category comprising those non-connected (control group) households. The dataset did not record any household accessing electricity services from mini-grid hydro and mini-grid solar. However, the SHS category consist of all solar related technology except min-grid solar technology. Further, the dataset includes set of outcomes and several control variables for households such as social and economic factors that are used in the estimation process. Section 2.4.2 and 2.4.3 below present descriptive statistics for household characteristics and socioeconomic outcomes.

2.4.2. Household Characteristics

The first stage in the impact evaluation using the propensity scores approach involves identification of the control variables (Dehejia and Wahba, 2002). Table A1.1 in the appendix shows descriptive statistics for identified covariates used to estimate the GPS. The descriptive statistics show means and standard deviations across the three groups of the treatment (NC, GE and SHS). The inclusion of selected control variables in the estimation of the GPS is informed by Garrido *et al.* (2014) and Bensch *et al*. (2011). These studies argue that variables included should influence both the treatment and outcome variables and should exclude those that affect only the treatment (Karumba and Muchapondwa, 2018). Thus, household head characteristics (education, gender, age); household characteristics (number of mobile phones owned, household size, access to financial services); quality of the house (number of rooms, floor, and walls); community characteristics (area price of candle, location) are all included as control variables.

Notably from Table A1.1 in the appendix is the average years household heads spent studying across those connected to GE is 10.2 (senior secondary) while 8.4 (Junior secondary) among those connected to SHS and 6.2 (primary school) among non-connected. This indicates that those connected to grid electricity are those with senior secondary education on average. Further, household members connected to grid electricity and SHS PV own an average of two mobile phones whereas non-connected own an average of 1. The presence of electricity at the household level contributes to majority household members owning a mobile phone as the cost of charging reduces. Furthermore, access to financial services is important regarding the type of household energy and their expenditure. Households connected to grid electricity have at least access to a mobile money account with a few having a bank account (2.35) compared to those without electricity where majority have no access to financial services (1.22). And on average more men are household heads across all the three categories on average (NC= 0.74; GE=0.76; SHS=0.76).

However, these naïve observed differences in the means of the covariates in the three groups are less informative about causal effect of electricity access and cannot solely be attributed to the impact of having access to electricity. Thus, the need to undertake an impact evaluation across the three treatments to ascertain extent of the differential impact on household socio-economic outcomes.

2.4.3. Household Socioeconomic Outcomes

Following the literature review, the study adopts three sets of household socioeconomic outcomes. These include non-farm employment, household monthly income and expenditure. The household expenditure outcome is defined into two categories; annual per capita expenditure and expenditure on alternative energy sources. Like descriptive statistics for household characteristics, the mean and standard errors are estimated for household socioeconomic outcomes. Therefore, Table A1.2 in the appendix presents the descriptive statistics for the selected socio-economic outcomes. Regarding employment, Table A1.2 shows that 54% are employed in non-farm given that they reside in an electrified area. Segregating the household into electrification technology; 89% accessing grid are employed while 53% accessing SHS electricity are employed. However, only 34% of those without electricity work in non-farm employment. Majority employed are in self-employment while others are under government, or private organisations. In terms of monthly income, the overall average income across households is K2,123 (US$212.30[11]). Households connected to grid electricity have an average income of K3,144.3 (US$314.43) per month while the average income among households accessing SHS electricity K2,580 (US$258) and K1,538 (US$153.8) for non-connected households.

As earlier alluded, the study considers household expenditure of two forms; first, annual per capita expenditure and second, expenditure on alternative sources of energy. The alternative energy sources included kerosene, charcoal, and firewood both collected and bought. From Table A1.2, households connected to the grid spend an average of K86.8 (US$8.66) per month on alternative energy sources while those using SHS spend K85. 61 (US$8.56) compared with K69.40 (US$6.94) for non-connected households. The household expenditure on charcoal contributes more to the total expenditure on alternative energy among those connected to grid compared to non-connected individuals who depend on firewood collected by the household members. However, the expectation is that once a household is connected to electricity services, the expenditure on alternative energy sources reduces. Furthermore, the annual per capita expenditure includes all household annual expenditure on goods and services divided by household size. Household accessing grid electricity spend on average K8,670 (US$ 867) per capital while those connected to SHS have an average expenditure per capita of K6,165 (US$ 616.5). The average per capita expenditure for the two categories is higher compared to those households who are not connected with K2,646 (US$264.6) while the overall average of the annual expenditure per capita is K4,722 (US$ 472.2).

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[11] The exchange rate is K10=US$1 in 2018.

Despite the differences in the averages across the three treatment categories observed in Table A1.2, it is difficult to entirely attribute these differences among households to the category they fall in without undertaking an impact evaluation. There is a possibility that the source of electricity may influence those outcomes, but the extent can only be determined through impact evaluation after controlling for other household characteristics. Therefore, the purpose of undertaking this study.

2.4.4. GPS Estimation and Overlap Assumption

After covariates are identified, the study's second stage involves estimating multinomial logit with treatment (NC, GE and SHS) as dependent variable while identified covariates as independent variables. The GPS is predicted post multinomial logit estimation. The predicted set of propensity scores show conditional probability of a household belonging to a given treatment category. Table 2.2 below shows the mean distribution of GPS across the three treatments.

Table 2.2: Mean Values for Estimated GPS (Categorical Treatment)

Estimated GPS	**Treatment Level (Access to Electricity)**		
	Not treated (0)	**Grid Electricity (1)**	**Solar Home System (2)**
Phat (0)	0.808 (0.232)	0.278 (0.229)	0.512 (0.339)
Phat (1)	0.147 (0.221)	0.660 (0.222)	0.373 (0.341)
Phat (2)	0.043 (0.051)	0.061 (0.060)	0.114 (0.098)
No. Observations	***2, 169***	***1, 151***	***189***

Note: standard deviations in parenthesis

From Table 2.2, it is difficult to deduce whether the overlap assumption is met and to what extent it is fulfilled. However, the study estimates the Kernel Density Graph to see whether the area of common supports (overlap assumption) for the GPS across the three treatments. Figure 1.1A in the appendix shows three Kernel Density Graphs showing conditional densities of the probability of the three-treatment levels (NC=0, GE=1 and SHS=2). There is an indication that the area of common support is satisfied in all three categories of the treatment. Although the overlap is not fully satisfied, there is enough area of common support across the three categories to enable us to estimate the pairwise ATE. The key observation across the three categories is that households' probability falls within certain range that enables us to estimate the ATE for each category. Further, the overlap assumption test was conducted for the three treatments under each subsample: rural and urban regions. Similarly, the kernel density is used to test the area of overlap. The kernel density graphs are presented in figure A1.2 for rural areas and A1.3 for urban areas under appendix A. The overlap in both cases has been met though not fully due to sample data challenges across subsamples and treatment categories which affects comparable probabilities and results in low propensity scores. For instance, the SHS electricity (treatment=2), the density falls to almost zero for all the three categories; full sample (figure A1.1- third Panel); Rural areas (Figure A1.2- Panel 2); and Urban areas (Figure A1.3- Panel 3). The challenge is low variability across the samples due to sample size after controlling for household and community characteristics. Despite this challenge, the overlap assumption has been met allowing us to procced with estimating the ATE.

Following multinomial logit estimation, the study present results of the average marginal effect (AMF) in Table A1.3 in the appendix for the full model[12]. The results from AMF show factors affecting the probability of a household getting a connection. Factors such as household location, quality of the household dwelling represented by house walls and floor, household size and number of phones owned by household members are all statistically significant across the three treatment categories with expected signs. However, household head years of schooling, access to financial services and number of rooms are only statistically significant in two categories. Thus, the probability of a household being connected to GE increases by 0.0046 while for not being connected reduces by 0.0059 on average as the number of years a head of household spent in school increases by 1. Access to financial service is important to households in GE and NE categories. The probability of connecting to grid electricity increases by 0.154 if a household owns a bank account compared to those without access to any financial services on average. While the probability of not being connected reduces on average by 0.151 if a household holds a bank account compared to when they have no access to any financial services. A household probability of connecting to GE rises by 0.316 on average if the house floor has tiles compared to mud/dung floor while the probability of not being connected any form of electricity reduces by 0.282 on average if the house floor has floor tiles compared to mud/dung floor. The quality of the floor indicates how well the family is to afford either to connect to grid or SHS.

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[12] Subsample multinomial results (rural and urban areas) have not been presented in this study but only for full sample model.

The study included household assets; house ownership and farmland ownership for the household to connect to either grid or SHS electricity. The results show that households who own their dwelling especially those in rural areas are likely not connect to any source of electricity compared to those who do not. Similarly, those who own dwelling are less likely to connect to grid electricity. Their probability reduces while those who own their dwelling, their probability increases compared to those who do not. Majority households who own their dwelling are in rural areas such that very few could connect to any sources of energy instead rely on traditional energy. Moreover, households in urban areas usually rent the dwelling and will opt for a house with electricity than not.

Farmand ownership is considered in two ways; as a dummy (yes or no) and as number of hectares owned by a household. The results show that farmland ownership contribute less to grid connection and more being unconnected. The probability increases of not being connected compared to those without farmland while the likelihood reduces of connecting to grid if a household owns a farmland. Similarly, dwelling ownership, majority of the households who own farmland are in rural areas compared to urban areas. However, considering farmland ownership in the number of hectares, we observe that as the number of hectares owned by the household increases, the probability of not being connected reduces while probability of being connected to SHS electricity increases. This shows that acquiring more hectares of land for farming activities is sign of improvement in the economic welfare of the household. Finally, the area prices of candle, marital status, age, and gender of the household head are only statistically significant in one category. However, all these variables possess the expected sign in the respective categories. For instance, the area prices of candles as a substitute to any form of electricity for lighting is statistically significant in SHS category. It shows that the probability of switching to SHS increases on average if there is a unit increase in price of candle in the area. Therefore, several selected covariates determine household decision to connect to either grid or SHS electricity or not connect to any form of electricity technology available to them.

2.5.Empirical Results and Discussion

2.5.1. Pairwise ATE Estimation Using IPTW Approach – Full Model.

Table 2.3 represents estimated pairwise ATE across the three outcomes (household income, employment, and household expenditure). The estimated ATE for each outcome is estimated for every treatment by weighting the outcome with the inverse of the GPS, thereafter, the ATE is obtained by pairwise difference.

Table 2.3: Results of the Pairwise ATE from IPTW Estimation

Outcome Variables		**Pairwise Average Treatment Effect**		
		GE vs NC	**SHS vs NC**	**GE vs SHS**
Household[13] income	Monthly income (US$)	**160.59*****	**104.5*****	**56.23****
		(9.23)	(24.28)	(24.66)
Employment	Household head employment in non-agriculture sector	**0.15*****	*0.05*	0.11
		(0.04)	(0.06)	(0.09)
Household Expenditure	Annual household expenditure per capita (log)	**0.43****	*0.12*	***0.34******
		(0.07)	(0.27)	(0.12)
	Household Monthly Expenditure on Alternative Energy (US$)	**-1.72*****	**-1.69****	-0.10
		(0.29)	(0.72)	(0.84)

Note: ***, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent Robust Standard Error

Starting with employment opportunities in non-agriculture sectors for household heads residing in electrified communities, results in Table 2.3 show positive and statistically significant impact under GE vs NC category. The results show the likelihood of a household head getting employed in a non-agriculture sector increases by 15% when a household is connected to grid electricity compared to no electricity access. Accessing grid electricity increases the substitution effect of agriculture activities to various income generating activities such as hair saloon, groceries, stationery, and barbershops. The presence of grid electricity enables households to seek non-farm employment over time as they slowly adopt electricity as a source of income generating through establishing business ventures (Bensch *et al*., 2011; Ikhsan and Amri, 2022). Further Khandiker *et al. (*2012) observed an increase in non-farm employment of 17% for women and 1.5% for men among connected compared to non-connected households. Similarly, Dinkelman (2011) observed that employment in South Africa among women increased by 13.5% while men employment was statistically insignificant. For monthly income, results are positive and statistically significant across the three categories under consideration with the largest differential impact observed in the GE vs NC category. From Table 2.3, we observe that the ATE between GE vs NC is US$ 160.59 or K1,605.90 equivalent, while between SHS vs NC is US$104.3 or K1,043 equivalent. Accessing grid electricity, households' income improves more than those accessing SHS. This is confirmed

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[13] The exchange rate is K10/US$1 in 2018.

by the differential pairwise impact GE vs SHS of US$56.23 or K562.30 equivalent. The differential impact across electrification technology shows that individuals accessing grid electricity experience larger positive effect in income compared to solar electricity technology. Similar results are obtained by Khandker *et al.* (2012) who observes that grid electrification contributed to rise in the per capita income by nearly 40% in rural India and attributed the increase to growth in non-farm income overtime as households increased consumption of electricity services. However, for solar technology, capacity constraint for solar products did limit user's ability to adopt electricity for income generation activities beyond lighting and charging phones compared to grid electricity.

Furthermore, improvement in household income and earnings is reflected by variations in household expenditure and consumption across electrification technologies (Bonan *et al.* 2017). In short, household expenditure explains better economic status of a household than absolute income. Therefore, results in Table 2.3 reveal statistically significant differential reduction in expenditure on alternative energy in two groups (GE vs NE and SHS vs NE). For instance, the estimated reduction in monthly expenditure on alternative energy of US$1.72 (K17.2) is observed between households connected to grid and control group on average. While a reduction in monthly expenditure of US$1.69 (K16.9) on average is observed between households accessing off-grid electricity (SHS) and control group. The observed reduction in households' expenditure on alternative energy sources applies to traditional energy that include candle, kerosine, charcoal, and firewood. The results obtained here are similar to Karumba and Muchapondwa (2018); Dinkelman (2011) who observe reduction in household expenditure in kerosine and other traditional energy in rural Kenya and South Africa respectively among connected individuals compared to non-connected households. Karumba and Muchapondwa (2018) estimated a reduction in kerosine consumption of 1.3 liters per month in rural Kenya while Komatsu et al (2011) observed a 95% reduction in the household expenditure on kerosine in Bangladeshi after households getting connected to electricity. The failure to completely stop use of kerosine by households is attributed to unreliability of electricity supplied from the min-hydroelectricity.

However, the differential impact between the two technologies is statistically insignificant. The overreliance on traditional energy (charcoal, firewood, and pellets) for cooking despite being connected to either grid or SHS means electricity is only used for lighting which results in maintaining monthly expenditure on charcoal and firewood. For grid electricity the possibility of poor availability and unreliability, while low capacity of off-grid leads to continuous expenditure on traditional energy for cooking (Bhatia and Angelou, 2015).

Despite the estimated reduction in expenditure on alternative energy, studies (Bensch *et al.*, 2013; van de Walle *et al*., 2015) observe an increase in total household expenditure especially among those connected to grid electricity. Therefore, the results in Table 2.3 show that ATE for annual per capita expenditure is statistically significant in GE vs NE and GE vs SHS categories. In both cases, there is a positive effect among those households connected to grid electricity compared to SHS and NC. There is 5.63% and 4.11% increase in the household annual per capita expenditure when a household is connected to GE compared to NC and when a household is connected to GE compared to SHS, respectively. The results are consistent with Khandker *et al.*, (2009) who found 15.4% increase in per capita expenditure at household level after implementing a PSM estimation approach when evaluating rural electrification programme in Bangladesh.

Generally, the results show heterogeneity across the electrification technology. The impact is relatively greater among households connected to grid electricity compared to SHS. This raises the issue of viability of SHS as a mode of electrification technology and its impact on household welfare outcomes. For instance, the differential impact between households accessing grid and SHS electricity is large for monthly income and per capita annual expenditure outcome variables. This shows that if grid electricity is affordable, reliable, and available, it contributes to improvement in welfare indicators through improved household income and expenditure. Despite SHS electricity service having limited capacity, it offers better effects among users compared to non-connected households. The reduction in expenditure on alternative energy sources is an indication that households have shifted to improved energy sources for lighting. Further, improvement in monthly income attributed to SHS electricity compared to non-connected households shows that SHS electricity is key in improving household socio-economic indicators. However, policy makers and implementers should acknowledge the heterogeneity in the impact by the electrification technology when formulating policies, planning for long-term electrification programmes and SDG7 targets such as 51% rural electrification by 2030.

2.5.2. Rural – Urban Sub-sample IPTW Estimation Results

The study disaggregated the sample into rural-urban subsample estimation of the effect of electrification technology on household economic outcomes. The estimation focuses on the rural and urban differences for each pairwise ATE to observe the magnitude in the effects. Table A1.4 in appendix A presents the estimated results. The conclusion observed at country level is similar to the results presented in Table A1.4 in appendix A; access to grid electricity offers better effects across various statistically significant economic outcomes compared to SHS electricity and NE across the two regions. For instance, income improves by an average of $173 among urban households while among rural households it improves by $136 if connected to grid compared to non-connected households. However, for SHS vs NC, income is statistically significant in urban areas with the pairwise ATE of $106.9 while for GE vs SHS the pairwise ATE is statistically significant in rural areas ($113.54). The pairwise ATE observed is not substantially different from the country level estimates observed in Table 2.3 above.

Similarly, across statistically significant pairwise ATE, households accessing grid electricity across the regions have higher probability of being employed in non-farm sector compared non-connected and those accessing SHS electricity. However, the probability of being employed in non-agriculture sector is high in rural areas across the electricity technology; 48.8% for GE vs NC and 47.8% for GE vs SHS while for urban areas the ATE for GE vs NC is 11.8% and SHS vs NC is 12.7%. The probability observed is three times higher in rural areas than the country level estimates of 15% observed in Table 2.3 above. This shows that the effect of transition from agriculture sector employment is high in rural areas due to limited opportunities and access to electricity creates economic opportunities to work away from farm activities. However, the probability of getting employed is low compared to country level estimates of 15% for urban areas;

Furthermore, the results in Table A1.4 show that annual per capita expenditure is statistically significant across all regions except for urban areas under GE vs SHS. The effect is relatively high among household connected to grid electricity compared to non-connected and those connected to SHS electricity across rural areas and urban areas. However, the effect is substantially high in subsample compared to aggregated sample at country level as observed in Table 2.3 above.

Finally, results in Table A1.4 reveal a reduction in household expenditure on alternative energy for grid electricity compared to non-connected in urban areas and rural areas. The reduction is higher among rural households of $2.02 compared to $0.79 monthly for urban areas. The overdependence on traditional energy in rural areas compared to urban areas entails that once a household is connected the expenditure reduces considerably. Similarly, the expenditure on alternative energy sources reduces when a household connect to SHS compared to non-connected households by $1.98 monthly. The reduction is attributed to expenditure on lighting fuels such as candle and kerosine which immediately reduces. However, Komatsu *et al* (2011) and Karumba and Muchapondwa (2018) argue that complete reduction in the household's expenditure on alternative energy sources is observed if the electricity supplied is reliable and available all the time.

2.6.Conclusion and Policy Implications

The study's objective is to understand how electrification technology affects household socioeconomic outcomes. To achieve this objective, the study defines electrification technology as grid and SHS electricity. The electrification technologies together with non-connected individuals as control group formed the treatment group of the experiment. Three socioeconomic outcomes (non-farm employment, monthly income and household expenditure defined by annual per capita and monthly expenditure on alternative energy) were selected and pairwise ATE were estimated using inverse probability treatment weighting approach.

The study results reveal that the differential impact is statistically significant and higher for monthly income between households accessing grid electricity compared to SHS electricity while expenditure per capita is statistically significant for GE vs SHS pairwise. In both pairwise ATE, the impact is higher when a household is accessing electricity from the grid compared to SHS electricity.

However, the results reveal that SHS electricity is still important in the electrification programme in Zambia when compared to non-connected individuals where statistically significant pairwise ATE are observed. The pairwise ATE results reveal a reduction in monthly expenditure on alternative energy sources (kerosine, candle and charcoal) between households connected to SHS electricity and non-connected while the impact on monthly income improved significantly as households connected to SHS electricity compared to non-connected.

Generally, the results from the IPTW estimation strategy reveal heterogeneity in the effects across the two electrification technologies on household welfare indicators. This provides important policy implications to the electrification programmes as it reveals limitations of electrification technology adopted. For instance, grid electricity offers better effect than SHS across the three selected outcomes, but SHS electricity is better when compared to non-connected households. The study observes that if grid electricity is enhanced, it could improve the welfare of the users through engaging in income activities away from farm activities at household level. The improvement in income further enables households to improve their total expenditure on goods and services and reduce overreliance on traditional energy overtime as households acquire electrical appliances such as electric stoves and lighting bulbs. However, for low-income households, adopting SHS is important for income generation activities and contributes to reducing monthly expenditure on alternative energy compared to non-connected. Being affordable, available, and suitable among those living off the grid or fail to maintain grid electricity tariffs, SHS electricity can be rolled out to accelerate towards universal access to electricity despite limited capacity.

Nevertheless, inclusion of quality, availability and reliability of the electrification technology may improve the estimation of the benefits which could be considered for future studies. Disaggregating various types of SHS that include solar lanterns, standalone solar systems and solar lights, help understand within the SHS family which may offer better effect on household welfare indicators. The insufficient sample size of the individuals accessing SHS electricity has contributed to limited analysis that this study could undertake. The study has been limited to undertaking subsample analysis that include within SHS electricity, and urban-rural subsample within the electricity technology. Furthermore, the sample size did not capture individuals who reported using both SHS and grid electricity and those using min-grid (hydro and solar PV) as primary source of electricity thereby, limiting the analysis of this study to the three categories (GE, SHS and NE). Thus, future studies should consider the two categories in their analysis.

Chapter Three
Evaluating the Impact of Electricity Availability on Household Socio-Economic Indicators

Abstract

The concept of electricity access defined by the presence of an electric pole, electricity connection, and a bulb in a house is restrictive as the definition fails to recognise electricity access as a spectrum of services offered to a household. Thus, this study diverts from restrictive traditional binary to use of MTF attributes when evaluating the impact of electricity access on household welfare indicators. The MTF assigns households to overall access Tiers (0 to 5) based on seven electricity attributes; capacity, quality, availability, affordability, reliability, safety and health, and legality. Therefore, the study adopts electricity availability attribute defined as the duration of exposure to electricity service in a typical day as a measure of electricity access when estimating the impact of electricity availability on selected household welfare indicators in Zambia. The study uses generalised propensity score approach with the dose response function (ATE) as estimation strategy. The results reveal that availability of electricity is key to improving household livelihood among users. The study finds that the longer the duration of exposure to electricity service in a typical day, the higher the reduction on household expenditure on alternative energy source; the more time households allocate to working away from home for pay increases the probability of being employed in non-farm sector and school going children tend to spend more time studying. However, the study also observes that certain welfare indicators such as expenditure on alternative energy sources require a certain level of exposure to electricity service to experience meaningful impact. Therefore, electricity services supplied from any technology should consider usability that focuses on the users' perspective to impact positively on their welfare.

3.1. Introduction

3.1.1. Background of the Study

Electrification[14] programmes in developing countries are undertaken with clear development objectives achieved using electricity services at household and community levels. In short, the programme should increase economic opportunities and contribute to poverty reduction in the long term (Blimpo *et al.,* 2020) while effectively contributing to economic development of the country (Torero, 2015). Despite this clear objective of the programme, issues of affordability, adequacy, reliability and availability of the electricity services limit the benefits that households could derive once connected (Bhatia and Angelou, 2015). The emphasis under SDG7 (energy for all) is the need to go beyond mere connectivity and tackle issues that limit electricity users' opportunities once connected. For instance, affordability is a significant issue in connecting households covered by grid as many cannot afford connection fees and maintain usage due to high tariffs for an average household in developing countries (Blimpo *et al.,* 2020). Further, adequate electricity supply requires consistence with attributes of the users' requirements. Solar home system for example, does not provide adequate electricity to power high-capacity appliances such as air conditioners and electric stoves but offers reliable lighting for a few hours. While grid electricity gives capacity that offers unlimited consumption but with limited availability in a typical day (Bhatia and Angelou, 2015).

To compressively understand how electrification programme can contribute to socioeconomic development, the World Bank/ESMAP (2016) and Bhatia and Angelou (2015) broaden the definition of electricity access by households to include seven attributes under the multi-Tier framework[15] (MTF). The traditional binary definition is deemed a narrow way of understanding the dynamics of electrification (Bhatia and Angelou, 2015). However, access to electricity under the multi-Tier framework is taken as a continuum of improvement because attributes comprehensively define households into Tiers starting with no access (Tier 0) to full access (Tier 5). Hence, adopting a broader framework such as multi-Tier framework (MTF) attributes is essential as it provides room to consider critical issues affecting households, communities and productive enterprises accessing electricity in developing countries.

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[14] Electrification in the study is used interchangeably with access to electricity at household level. We assume that a household who has access to electricity is one that is electrified from a given technological source.

[15] See table A3.1 in the appendix for comprehensive understanding of MTF.

The key objective of the study is to divert from the traditional treatment of electricity access as a binary measure to adopting attributes of MTF in the evaluation approach of the benefits of electrification in Zambia. More specifically, the study adopts availability attribute of the multitier approach to evaluate the impact on household socio-economic outcome. Electricity availability is defined as the duration (hours) of electricity service a household receives per day or in the evening (Luzi *et al.*, 2019). Although attributes such as capacity and reliability are critical to electricity access, how long a household is exposed to electricity service helps plan its usage. Furthermore, household's exposure to a given number of hours of electricity services in a particular day is critical for the improvement of the users' welfare and could help stimulate the broader economy (Khandker *et al.*, 2009).

3.1.2. Study Objective

The objective of the study is to evaluate the impact of electricity service availability on socioeconomic outcomes that include time allocation to children studying and income generation activities; employment in non-agriculture sector and expenditure (per-capita and expenditure in alternative energy).

3.1.3. Statement of the Study Contribution

The study provides new insights to literature debate on evaluating the impact of electrification in developing countries. Existing literature on impact evaluation is based on binary approach where a household is either connected or not which is restrictive to understanding the dynamics of access to electricity. The use of MTF provides new measurements to impact evaluation by assigning households to Tiers based on electricity availability as an experiment treatment. According to the knowledge of the researcher, this study, being the first of its kind to be conducted it conceptualizes electricity access beyond binary thereby offering a new policy perspective to electrification programme in developing countries. Furthermore, the study's application of dose-response function estimation strategy with multivalued continuous treatment to estimating the impact of electricity service access on socioeconomic outcomes is a new phenomenon in the energy literature where binary approach (propensity score matching) is a common evaluation approach.

3.1.4. Organization of the Study

The study is composed of five sections. The first section presents the introduction of the study and is followed by the literature review where theoretical and empirical reviews are undertaken to understand the existing gap in literature. The methodology forms the third section of the study. It presents the model adopted in the estimation process, data focus and descriptive statistics of the study. The fourth section presents empirical results beginning with naïve binary estimation and later presents the estimation results from the dose response function. The section also presents estimation on treatment derivative effect and IPTW estimations. Finally, the study presents the conclusion and policy implications.

3.2. Literature Review

3.2.1. Electricity Service Exposure and Theory of Change

Change is only observed after the adoption of electricity services as the primary source of energy for lighting, heating, and cooking at household level (Karumba and Muchapondwa, 2018) Nevertheless, the magnitude of the change is only effective if households are exposed to a certain level of electricity capacity, duration and from a reliable source. Studies such as Niu *et al*., (2016) and Bonan *et al.,* (2017) argue that the effective channel through which access to electricity impact on the user's welfare is through acquisition of electrical appliances. The ability to acquire electrical appliances such as lighting bulbs, computers, refrigeration, stoves, mobile phone, and appliances for small businesses such as saloons, barbershops and irrigation become indispensable among electricity consumers. The acquisition and subsequent use of electrical appliances because of the presence of electricity services at home level, enables household members to increase income from non-farm activities (Modi, 2005); improved access to food security and health (Bhide and Monroy, 2011); increase in years of education attainment among school going children (Bonan *et al* 2017); and improve labour supply among adult women (Gurgul and Lach, 2012; Dilaver and Hunt, 2011) leading to pursuing self-employment at home. Further, the acquisition of improved cookstove reduces household reliance on biomass and/or traditional fuel for cooking as they tend to end stacking given that electricity is available for a reasonable period of the day (Niu *et al*., 2011).

If the channel of electrical appliances acquisition is to be effective, access to electricity should go beyond getting an electrical pole, connection wire and installing a bulb in the house. The attributes of electricity such as capacity, duration and reliability become key in achieving positive change. Overwhelming evidence shows that household access to electricity does not only mean getting a connection, but the quality of the electricity service supplied determines improvement in the livelihood of the user (Khandker *et al*., 2009). ESCA-UN (2021) defines quality access of electricity services either as duration, or capacity or absence of outages of electricity supply while

Bhatia and Angelou (2015) define access of electricity services by the attributes it provides that include capacity, availability, reliability, affordability, quality, legal, health and safety.

3.2.2. Electricity Availability, Consumption and Welfare Indicators: Empirical Review

Empirical studies evaluating electrification programmes neglect availability or duration of electricity supplied to users. Instead, they focus on binary treatment approach. Several household welfare indicators have been estimated based on binary approach (household accessing electricity or not). For instance, Kumar and Rauniyar (2018); Karumba and Muchapondwa (2018); Khandker *et al,* (2009, 2013); Samad *et al.,* (2013); and Litzow *et al.*, (2019) all have focused on binary approach to understanding the impact of binary access to electricity on education outcomes. These studies divide education outcomes into three categories that include years of schooling (Kumar and Rauniyar, 2018; Litzow *et al.*, 2019; Khandker *et al.*, 2009); times spend studying in a day (Bensch *et al.* 2012; Samad *et al*. 2013; Khandker *et al*., 2009; 2013; Aguirre, 2017); children enrolment into schools (Saing, 2017). The studies reveal that overall, being electrified offers better and positive education outcomes apart from Karumba and Muchapondwa (2018) who attributed reduction in time (43minutes) spent studying to substitution effect where children tended to watch TV more often than studying. Despite positive outcome, binary approach may understate the impact given that these studies do not control how long a household is exposed to the electricity service.

However, studies such as Niu *et al.*, (2016); Huang (2015); Jorge *et al.*, (2010) and Lhendup *et al.*, (2010) all observe that a given level of electricity consumption among users improves their welfare indicators. For instance, Huang (2015) used quantile regression approach with the objective of understanding how continuous consumption of electricity over a 30-year period affects households' livelihood. The study reveals that consumption of electricity services differs across the quantiles for each additional year and variation in the consumption of electricity pattern reflects the quality of life of the users (Niu *et al.,* 2011). For example, low-income households use electricity for basic needs that include lighting, cooking, and entertainment activities. As income improves, households increase consumption through diversity of electric appliances beyond basic needs thereby improving their livelihood. Similarly, Niu *et al*., (2016) argue that improvement in the quality of life among users of electricity is only observed after improvement in electricity services availability as it contributes to increased consumption among users. This follows a study conducted across 50 developing countries that concluded that consistence in electricity availability among users led to increased consumption and/or demand with the possibility of improved livelihood.

Another study by Lee *et al.*, (2017) contends that the improvement in the quality of household livelihood is not only gradual but sometimes not enough due to low demand among electrified households. Focusing on rural electrification in Kenya, the objective of the study by Lee *et al.*, (2017) was to observe the impact of being electrified for 18 months or more among rural households on various socioeconomic outcomes. The study undertook a randomised experimental study involving 150 communities that had been connected to grid electricity. The study observed a minimal positive impact of grid electrification among rural households after 18 months of electrification. The study cited low consumption of electricity among connected households such that the average expenditure was about $2 per month. The study also observed that low take up of electrical appliances among connected households contributes to low demand for electricity as majority use electricity for lighting and phone charging. Therefore, the study concluded that low demand of electricity services leads to low consumption of electricity and is attributed to poverty and low income.

Further, Khandker *et al* (2009) estimated the impact of access to electricity on households' income by focusing on the effect of duration of exposure to electricity service in rural Bangladesh. The study grouped households according to period of exposure ranging from 3 months to 5 years such that the longer the time a household is exposed to electricity the better the income effect. The IV estimation approach was adopted with distance to the electricity line/pole from the household dwelling to instrument access to electricity. The study establishe that demand for electricity grows over time due to household acquiring of appliances such that every month consumption increases by 5.0kwh. The empirical estimation revealed that every additional year of exposure to electricity results in 6.9% increase in household income though in the long run, a reduction of 0.4% is observed. The reduction after squaring the duration of exposure shows that there is saturation of growth in income due to electrification in the long run such that its effect keeps on reducing as other factors affect income growth.

However, Rao (2013) observes a 72% rise in non-farm income across the level of electricity supplied. This follows a study conducted in India with the objective of evaluating the impact of electrification focused on levels of electricity services supplied to the household on non-farm income differentials. The levels of electricity supplied were defined by duration and applied multiple methods that included linear regression with an instrument and PSM (propensity score matching). The study conclude that non-farm income improves with the level of electricity supplied among connected households while farm income is statistically insignificant overtime. Related results obtained by Kumar and Rauniyar (2018) in Bhutan show an increase in non-farm income of 61% despite the treatment (electricity access) being binary as opposed to duration.

Similar observations made by Aragaw (2013) and Zhang *et al.* (2019) who argue that electrification impact on household welfare depends on the time horizon of exposure to electricity. However, Aragaw (2013) observed that the immediate benefits of electrification involve improved lighting that could reduce indoor pollution and expenditure on traditional fuels for lighting in Ethiopia. Thereafter, there is a gradual impact including diversified income and improved public services such as education, health, and clean water access as well as off-farm and non-farm employment. This is further amplified by Samad and Zhang (2016) who found that though electrification affects a wider range of socioeconomic factors, the size of the effect depends mostly on the availability and reliability of electricity supplied to users. Their study observed that access to electricity alone increased income by 9.8% for the period of 7 years (2005-2012) while combining electricity access with reliability and duration resulted in 17% increase to household income in India. Similar results were observed by Chakravorty (2014) as non-farm income increased by 9% compared to 28% when improved access defined by duration of access to grid electricity was controlled in India. Further, on the business front, Ganguly *et al.,* (2020) measured the impact of longer duration of accessing electricity on microenterprise revenue in India. Although the results did not show improvement in enterprise revenue the study revealed increase in operating hours and number of people visiting the shop.

3.2.3. Gap in the Literature

Studies reviewed show consensus that electricity access goes beyond getting a connection and the evaluation approach requires a broader definition of the treatment. The treatment definition should consider changes in the level of exposure to electricity services which the binary treatment approach omits. Further, the degree of the impact after a period of exposure to electricity and duration of exposure to experience significant improvement in livelihood is still not clear across numerous studies. Therefore, this study diverts from binary approach to focus on multi-Tier framework where availability of electricity is adopted as a treatment on various socioeconomic outcomes.

3.3. Methodology

This section presents the definition of treatment of the experiment, describes estimation methods, data and finally discusses selected household socio-economic outcome variables used in the study.

3.3.1. Defining the Treatment of the Experiment: *Continuous Treatments to Electrification*

The MTF show that electricity service is a continuum of improvement that should be captured by various attributes that affect the user's experience while being technologically neutral (Bhatia and Angelou, 2015). Each attribute of the MTF that include capacity, availability, reliability, affordability, quality, legal and health and safety classify a household access to electricity service in Tiers that range between no access (Tier 0) and full access (Tier 5). However, the study focuses on availability (duration) attribute as a treatment of the experiment. Duration of electricity services is defined as the number of hours a household is exposed to electricity service in a typical day from a given technology (grid or standalone solar electricity). This entails that the treatment includes only households whose hours of exposure to electricity service is equal or greater than one ($t \geq 1$) in day. Equation 3.1 below defines the treatment (hhcont) as a ratio of duration of electricity service supplied to the maximum duration a household expects (24hours) in a day.

$$\boldsymbol{hhcont\ (T_i) = \frac{hhelectava}{\max\ (24)}} \qquad \textbf{3.1}$$

where $T_i = hhcont$ = a proportional treatment to electricity access; $hhelectava$= actual hours of electricity service supplied to a household in a typical day; $max\ (24)$ = maximum hours of electricity service expected in a day. The ***hhcont*** variable shows that treatment is continuous variable and falls within $0 < t \leq 1$ range. Table 3.1 shows statistical distribution of the households in different Tiers based on the duration of electricity services received from a given source in a typical day.

Table 3.1: Household Tier and Treatment to Electricity Service Availability (continuous)

Tiers	Available Hours *(Ratio=hhcont)*	Frequency
1	***1 – 4*** (0.014 - 0.125)	29
2	***4 – 8*** (0.125 - 0.375)	116
3	***8 – 16*** (0.375 - 0.667)	77
4	***16 – 23*** (0.667 - 958)	174
5	***23 – 24*** (0.958 - 1)	960
Total		**1,356**

Source: Author's own computation.

From Table 3.1, majority of the households are in Tier 5 with 23-24 hours of electricity. This accounts for 68% of the respondents and on average 20.89 hours of electricity is supplied in a day to a household from a given source. The tiers are defined with modification based on access levels of households. For instance, households in tier 1 who only receive less than 4 hours of electricity are defined as households with no electricity, those in tier 2 with 4-8hours are households with low access while in tier households in 3 with 8-16 hours are taken as medium. The households in the highest tiers 4 (16-22) and 5(above 22) regarded as having adequate availability of electricity service in a particular day. Therefore, the allocation of households to tiers are based on Bhatia and Angelou (2015) MTF definition of household access to energy, where attributes of energy are considered as opposed to the binary approach (connected or not).

Although availability (duration) attribute may not reflect the capacity of electricity supplied, it is able to show reliability and quality of service. For instance, a household in Tier 5 which has longer hours of electricity service in a typical day is presumably enjoying good quality of electricity service with no possibility of frequent blackouts. Therefore, the availability attribute is key to defining access to electricity services such as lighting, air conditioning, entertainment and refrigeration as these services depend on long duration of supply. Furthermore, Blimpo *et al.*, (2020) argue that longer duration of supply shows improved electricity service among users allowing a household to choose the time to use electricity in a typical day. The study's assumption, therefore, is that an increase in the household exposure to electricity services given the observable characteristics will lead to improvement in socio-economic outcomes.

3.3.2. Continuous Treatment and Application of the Propensity Score Approach

Evaluation of electrification programmes in developing countries have adopted different methodologies based on the data available. The approaches are based on whether the study adopts experimental or non-experimental designs. Experimental designs are based on randomised experiments where counterfactual is constructed through random assignment of individuals to either control or treatment group while non-experimental designs rely on non-direct manipulation of the assignment to treatment groups (Bonan *et al*., 2016). However, adopting a randomised experiment has been difficult because experimental data is not available due to difficult in evaluating impacts of large infrastructure projects (Kumar and Rauniyar, 2018). A few studies have adopted randomised experiments such as Bernard and Torero (2015); Banerjee and Duflo (2011); Grimm *et al.*, (2015). The use of non-experimental design relies on observational data with the assumption that the observation is in a natural setting (Bonan *et al*., 2016). However, the absence of randomization usually creates selection bias as individuals can self-select into the programme. The identification of the counterfactual requires strong assumption so as reduce self-selection bias. Different methodologies have been adopted to evaluate the electrification programme with observational data. Methods include instrumental variables approach (Dinkelm 2011; Khandker *et al.*, 2009; Rao, 2013; Aguirre, 2014); difference in difference (DID) (Lenz *et al.*,2017; Ganguly *et al*., 2020; Dinkelman, 2011); propensity score (Khandker *et al*, 2009; Samad *et al.*, 2013; Karumba and Muchapondwa, 2018; Kumar and Rauniyar, 2018) where matching, weighting and regression adjustment are adopted as estimation procedures. These methodologies rely on including covariates that can influence decision to connect (treatment) and outcome variables to reduce self-selection bias (Caliendo and Kopeinig, 2005; Bensch *et al.*, 2011).

As earlier stated, majority of the studies rely on binary approach as the treatment, however, in this study treatment to electricity access is continuous and based on the availability of the electricity services to a household in a typical day. Thus, the study adopts propensity score technique with continuous treatment to estimate the average treatment effect of the household exposure to electricity service. This entails estimating the average Dose-Response Function (DRF) and its derivatives among households receiving electricity services. The average DRF and its derivative help in understanding how effective exposure to electricity service is through uncovering heterogeneity given the different duration of exposure (Flores *et al.*, 2012). Furthermore, the average DRF estimation is based on Imbens (2000); Hirano and Imbens (2004) extension of

Rosenbaum and Rubin (1983) propensity score matching methodology to continuous treatments through the concept of Generalised Propensity Score (GPS) approach.

3.3.2.1.Application of ADRF with GPS Methodology under Continuous Treatment

Let individual households in the sample be indexed by $i = 1, \ldots N$ and $Y_i(k)$ be households' potential outcome under a given treatment level k, were $k \epsilon \tau$ for each household and τ is defined as a household Tier; $\tau = \{k_0, k_1\}$. Therefore, equation 4.2 defines ADRF:

$$\mu(k) = E[Y_i(k)|k > 0] \text{ for all } k > 0 \qquad 3.2$$

To estimate average DRF in equation 3.2, Hirano and Imbens (2004) argued that three elements are key; the treatment T_i that should be continuously distributed, a vector of pre-treatment variables X_i that allows us to adjust for pre-treatment differences and help solve the problem of drawing causal inferences and finally potential random outcomes $Y_i(k)$ (Bia and Mattei, 2008). The key identifying assumption in the estimation of average DRF is the weaker version of unconfoundedness assumption proposed by Hirano and Imbens (2004) for continuous treatment effect. The weakly unconfoundedness assumes conditional independence for each value of treatment as opposed to a joint independence of all potential outcome. The assumption further shows that selection into the treatment level is random and conditioned on observable household and community pre-treatment variables (Imbens, 2000; Flores *et al.*,2012) as given in equation 3.3.

$$Y_i(k) \perp T_i|X_{\ i} \quad for\ all\ k \in \tau \qquad 3.3$$

Equation 3.3 shows that the level of the treatment received T_i is independent of the potential outcome $Y_i(k)$ given observable pre-treatment variables of the households. Like the case of categorical treatment, if the weak unconfounded assumption holds, given households pre-treatment variables, it means that the weakly unconfoundedness assumption will hold given GPS, $R(T, X)$. Kluve *et al.*, (2012) and Hirano and Imbens (2004) defined GPS as a conditional density of the treatment given the covariates. The conditional density $r(k, X) = f_{T/X}\ (k/x)$ such that $R = r(T, x)$ is the GPS. Therefore, given the GPS definition- the weakly unconfoundedness assumption given the GPS is defined in equation 3.4.

$$Y_i(k) \perp T_i|R\ (T, x) \quad for\ all\ T \in \tau \qquad 3.4$$

Application of GPS to estimating the average DRF offer attractive properties such as balancing property $X \perp 1\{T = k\}|r(k, X)$ and the weakly unconfoundedness assumption help remove selection bias (Flores *et al.*, 2012). The removal of any systematic selection into each tier $\boldsymbol{\tau}$ of treatment indicate that assignment to treatment is unconfounded given the GPS (Hirano and Imbens, 2004).

3.3.2.2.Implementation of the GPS Approach with Average DRF

The practical process to implement GPS in order to estimate ADRF involves three steps (Bia and Mattei, 2008; Flores *et al.*, 2012). The first step involves estimation of the GPS $r(k, X)$**.** Hirano and Imbens (2004) assume that the treatment variable is normally distributed given the covariates when estimating the GPS. However, with fractional treatment the non-normal distribution is possible as opposed to Hirano and Imbens (2004) scenario. To overcome the possibility of non-normal distribution in the treatment, the study implemented generalized linear model (GLM) when estimating the GPS by following Guardabascio and Ventura (2014) and McCullagh and Nelder (1989) work closely. The implementation of the GLM is based on two assumptions; firstly, treatment distribution should explicitly be specified from exponential family and secondly, non-identity transformation of the treatment mean should be linearly related to explanatory variables. Guardabascio and Ventura (2014) formalized the two assumptions into two functions: family function (equation 3.5) and link function (equation 3.6).

$$f(T_i) = c(T, \emptyset)exp^{\left\{\frac{T\emptyset - \alpha(\theta)}{\emptyset}\right\}} \tag{3.5}$$

$$g\{E(T_i)\} = \beta' X \tag{3.6}$$

Equation 3.5 is a family equation showing that treatment distribution belongs to exponential family with $\alpha(\theta)$ being determined by the nature of the treatment variable. This in turn determines the actual probability function. Equation 3.6 is a link function showing the transformation of the expected value of treatment which is linearly related to covariates variables contained in X. The introduction of link and family into the estimation of the GPS allows the study to accommodate different distribution of the treatment as opposed to normal distribution. For example, the study can further accommodate heteroscedastic treatment, exponential family, or a mixture of normal distribution.[16] Therefore, equation 3.5 and 3.6 allow estimation of GPS using GLM through maximizing the quasi-maximum likelihood function (QML) for the treatment.

Although this approach allows fractional treatment that is bounded $T_i = [0,1]$, this study excludes households with zero hours of electricity service supplied from the treatment; $T_i = (0,1]$. Therefore, taking a fractional treatment means that the maximum likelihood function takes a Bernoulli QML with binomial and logit as a family and link functions, respectively. Equation 3.7 gives the estimated GPS after the identification of the link and family functions given the treatment level k, and covariates X.

$$\hat{R} = r(T, X) = c(T, \hat{\emptyset}) \exp\left\{\frac{T\hat{\theta} - \alpha(\hat{\theta})}{\hat{\emptyset}}\right\} \qquad 3.7$$

where $\hat{\emptyset}$ and $\hat{\theta}$ are estimated parameters.

Following the estimation of the GPS in equation 3.7, the covariate balancing score property is tested and reported (Hirano and Imbens, 2004). The test is important in understanding how well adjustment for GPS works in balancing the covariates (Kluve *et al.*, 2012). For instance, to know whether the specification for the estimation of the GLM is adequate or not. The test follows Hirano and Imbens (2004) model of blocking for the treatment and GPS.

After estimating the GPS, the second stage in the estimation of ADRF involves modelling conditional expectation of the outcome variable $Y(k)$ on the treatment T and the GPS R. Equation 3.8 shows the conditional expectation:

$$\beta(r, k) = E[Y | T = k, R = r] \qquad 3.8$$

The two variables (treatment and GPS) are modelled as flexible function of two arguments and empirically the study employs polynomials of the third order to both the GPS and treatment. Equation 3.9 estimates the conditional expectations of the outcome using ordinary linear regression for continuous outcome variables and discrete model (logit) for discrete outcomes.

$$E[Y_i | T_i, R_i] = \alpha_0 + \alpha_1 T_i + \alpha_2 T_i^2 + \alpha_3 T_i^3 + \alpha_4 R_i + \alpha_5 R_i^2 + \alpha_6 R_i^3 + \alpha_7 T_i . R_i \qquad 3.9$$

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[16] For further reference and understanding of GLM see Guardabascio and Ventura (2014) and McCullagh and Nelder (1989) work

Finally, step 3 involves estimating the average dose response function as given in equation 3.10.

$$\mu(k) = E[\beta\{k, r(k, x)\}], \qquad k \in \tau \qquad 3.10$$

The ADRF is estimated by averaging regression function given by equation 3.9 over the estimated GPS at each level of the treatment k. To estimate the entire dose response function, the study estimates expected potential outcome at each desired treatment level as given in equation 3.11:

$$E\left[\widehat{Y_k}\right] = \frac{1}{N}\sum_{i=0}^{n}(\,\hat{\alpha}_0 + \hat{\alpha}_1 k + \hat{\alpha}_2 k^2 + \hat{\alpha}_3 k^3 + \hat{\alpha}_4 \hat{r}(k,x) + \hat{\alpha}_5 \hat{r}(k,x)^2 + \hat{\alpha}_6 \hat{r}(k,x)^3 + \hat{\alpha}_7 t.\hat{r}(r.k)) \qquad 3.11$$

The study adopts the multi-Tiers given in Table 3.1 as desired treatment levels where the dose response function is estimated. The bootstrap method is applied to obtain standard errors because of its ability to consider both the estimated GPS and α parameters.

3.3.2.3.Data and Socio-economic Outcome Variables

The study exclusively focuses on connected households extracted from the World Bank/ESMAP (2018) dataset. This represents about 1,356 households (37% of the total sample size). In the dataset electricity service availability was defined in two ways; first as the number of hours of electricity supplied to a household in a typical day (as defined in Table 3.1 above) or at night (18 hours to 22 hours). Second, as the number of electricity hours used by a household in a particular day or night (18 hours to 22 hours) from the possible supplied. However, the former was adopted as experiment treatment in the estimation of the impact of electricity availability due to reasons advanced in section 3.3.1 above.

The study identifies three socioeconomic outcome variables from the dataset; time allocation to various activities (studying and working), household expenditure (per capita and expenditure on alternative energy sources), and household head non-farm employment. Table 3.2 below shows average and the standard errors for selected household socio-economic outcomes adopted by the study. The means for the socioeconomic outcomes are estimated based on multitier (1-5) and overall values.

Table 3.2: Descriptive Statistics for Selected Household Socioeconomic Outcomes

			Multitier					**F-test**
	Outcome Variables	**Obs.**	**1**	**2**	**3**	**4**	**5**	**Ho: Means are equal across tiers(P-value))**
Time allocation	Boys Studying	587	26.55 (14.3)	27.13 (5.7)	19 (6.4)	28.15 (5.9)	34.86 (2.7)	1.28(0.277)
	Girls Studying	600	13.81 (8.3)	38.75 (8.4)	12.19 (3.5)	27.46 (6.1)	38.42 (2.8)	3.43 (0.00)
	Women working	1153	46.29 (19.0)	48.38 (12.2)	62.33 (17.2)	62.61 (11.2)	163.34 (9.4)	12.69(0.00)
	Men Working	1129	70.74 (27.2)	93.73 (18.4)	146.51 (27.7)	114.84 (14.2)	263.93 (10.9)	18.27(0.00)
Employment	Employment in non-agriculture	1034	0.57 (0.10)	0.65 (0.05)	0.66 (0.06)	0.85 (0.03)	0.88 (0.01)	15.08(0.00)
Household expenditure	Expenditure in alternative energy	1009	97.18 (14.6)	82.19 (5.5)	94.75 (8.4)	80.76 (4.3)	86.88 (2.2)	15.93(0.00)
	Expenditure per capita	1355	4231.92 (1120)	3407.19 (514.06)	5195.08 (2148)	9250.7 (839)	9120.9 (463.3)	6.48(0.00)

Source: Author's computations from World Bank/ESMAP (2018) dataset: *****Parentheses represent Standard Errors***

The three set of outcomes variables are defined by various indicators as indicated in Table 3.2 above. For instance, time allocation by households to various activities is defined by time children aged 6-15 allocate to studying at home and time adults at household level allocate to working away from home for income or self-pay in a typical day. Further, household expenditure in local currency (Kwacha) is defined by annual per capita expenditure and monthly household expenditure on alternative energy which include charcoal, pellets, kerosine and firewood. The expenditure on charcoal and firewood includes those collected and purchased by the households. Household head employment is defined as whether the household head is employed in non-agriculture sector or not and considers households receiving electricity or resides in an area that is electrified. The objective was to observe whether the rise in duration of electricity service or residing under the grid results in opportunities for household head employment away from agriculture sector which account for over 60% of the employment opportunities (Zamstats, 2015).

From Table 3.2, the mean value for time allocated to studying by both boys and girls is higher among households in Tier 5 compared to Tier 1. Boys aged 6-15 in Tier 5 allocate an average of 34.8 minutes to studying compared to 26.6 minutes for those in Tier 1. For the girls aged 6-15 in

Tier 1 allocate an average of 13.8 minutes while in Tier 5 they allocate 38.4 minutes when duration of exposure to electricity services improves. Similar behaviour pattern is observed with time allocation to working away from home for income or self-pay by adult male and female household members. Adult females in Tier 5 allocate an average of 130.9 minutes compared to 46.3 minutes in Tier 1 while the male adults allocate an average of 218.6 minutes if they fall in Tier 5 compared to 70.7 minutes in Tier 1.

The mean value for household head employment indicates that in Tier 1, 57% are employed in the non-agriculture sector compared to 84% in Tier 5. The mean value for household expenditure on alternative energy sources reduces from K97.8 (US$9.78) in Tier 1 to K86.57 (US$ 8.66) in Tier 5. Furthermore, as duration of exposure to electricity services improves, the mean value of the household annual expenditure per capita doubles from K4,231.92 (US$ 423.19) in Tier 1 to K8,320.7 (US$832.07) in Tier 5.

Furthermore, the study conducted an F- test (anova) to test mean equality across the tiers for outcome variables. The results are presented in Table 3.2 in the last column. The null hypothesis is that the means are equal across the tiers and equal to zero for each outcome variable. Table 3.2 show that only the mean for time boys spend studying is not statistically significant. This shows that the means across the tiers for time boys spend studying is not statistically different. However, other outcomes variables (girls time spend studying; women and men time spend working away from home for income; employment in non-farm activities; household expenditure) are all statistically significant. This means that the means are statistically different across the tiers for these variables.

However, the improvement in the mean values of the socioeconomic indicators across the Tiers cannot solely be attributed to improvement in availability of electricity services. This requires controlling for other household characteristics in order to understand the impact of improved duration of exposure to electricity service. This is the focus of this study.

3.4. Empirical Results and Discussion

3.4.1. Traditional Naïve Binary Average Treatment Effect Results

Before presenting the results for continuous treatment effects, the study estimates traditional naïve binary treatment effect model. The goal of estimating the traditional naïve binary treatment effect is to demonstrate that the binary approach is restrictive measure of electricity access, and its results tend to overstate or understate the impact of being treated. This is because of its inability to consider attributes of the electricity received or used by the connected households. Therefore, study defines the treatment as;

$$\mathrm{T} = \begin{cases} 1 \text{ if a household is treated (GE or SHS)} \\ \qquad 0 \qquad \text{otherwise} \end{cases} \tag{3.12}$$

The propensity score near neighbour (PSM-NN) is adopted in the estimation of the binary average treatment effect (ATE). The neighbourhood approach is adopted based on the definition of the treatment, the common support or overlap assumption and weights assignment. The PSM NN-R approach involves matching with replacement, thereby creating a trade-off between bias and variance (Caliendo and Kopeing, 2008). However, the study also estimated the PSM-NN without replacement as shown in Table 3.3 as PSM NN. Thus, Table 3.3 presents the ATE results for binary treatment on socio-economic outcomes of the households for both PSM NN and PSM NN-R. [17]

Table 3.3: ATE Results for Binary Treatment

Outcome Variables		**Method**	
		PSM NN	PSM-NN-R
Household Time Allocation (Minutes/ Day	Boys studying (6-15yrs)	2.1	6.8
		(4.6)	(5.4)
	Girls studying (6-15yrs)	11.3***	7.7**
		(4.2)	(3.8)
	Men working away from home for pay/self	-0.9	-10.7
		(26.2)	(20.5)
	Women working away from home for pay/self	-31.6**	-36.9**
		(13.3)	(12.1)
Employment	Household head employment in non-agriculture sector	0.049**	0.065*
		(0.017)	(0.037)
Household Expenditure	Annual household expenditure per capita (log)	0.33***	0.35***
		(0.08)	(0.07)
	Monthly Expenditure on alternative sources of energy (Kwacha)	-2.96	-7.09**
		(5.22)	(3.42)

Notes: *, **, *** indicate significance level at, respectively, 10%, 5%, and 1%; standard errors are in parenthesis. Source: Author's computations from World Bank/ESMAP (2018) dataset

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[17] The study used same covariates in appendix B as control variables in the estimation of the PSM. However, the estimated regression has not been reported in study.

The results in Table 3.3 show that PSM-NN-R produces better ATE estimates for the household welfare outcomes compared to PSM NN without replacement. The time girls aged 6-15 allocate to studying under the two estimation procedures (PSM NN and PSM NN-R) is statistically significant with PSM NN having the highest impact of 11.3 minutes. The results show that the differential impact between treated and untreated households is positive for time girls allocate to studying at home.

The results from Table 3.3 show no statistically significant results for time men allocate to working outside home. While for women, results show a reduction in time allocated to working outside their homes for pay/self between those treated and untreated. The results show that women allocate 36.9 minutes less to working away from home for pay or self on average when a household is treated compared to untreated household. Household head employment in non-agriculture sector is statistically significant at different levels. The probability of a household head being employed in non-agriculture sector increases if a household is treated to electricity compared to untreated household. The PSM NN-R shows 6.5% increase in the probability being employed in non-agriculture sector once connected.

Finally, the results reveal that access to electricity impact positively on household annual per capita expenditure. The PSM NN-R results show that ATE is statistically significant for annual per capita expenditure if a household is treated to electricity compared to untreated households. The impact shows that on average the annual per capita expenditure increases by 0.35 if the household has access to electricity compared to those without electricity. Furthermore, the impact on household monthly expenditure on alternative sources of energy is also statistically significant under the PSM NN-R. The results show a reduction of K7.09 (US$0.7) on average in monthly expenditure on alternative sources of energy among households connected to electricity.

Despite showing the differential impact across different socioeconomic outcomes between treated and untreated, the naïve approach falls short of identifying to what extent the level of exposure affects the household welfare. The changes in the availability of the electricity services may affect households differently which the naïve approach fail to identify and capture in the estimation process. Therefore, this study focuses on electricity service availability as a key issue of the electrification programme.

3.4.2. Empirical Estimation of ATE (Dose Response Function) for Continuous Treatment

In the previous section (3.4.1) the study estimated the ATE using naïve (traditional binary treatment) approach with mixed results for various socio-economic outcomes. However, defining the treatment as household having a mere connection or not leaves out key aspects of electricity access such as availability and reliability of electricity service among those connected. For instance, in most rural areas of Zambia, grid electricity unavailability can last for two days while some households tend to switch-off electricity when they fail to afford monthly tariffs (Mudenda *et al.,* 2013). Thus, the focus of this section is to estimate the ATE of a household exposure to electricity services in a typical day. The treatment becomes a continuous variable defined by the availability of electricity service to a household in a day.

3.4.2.1.GPS Estimation and Covariate Balancing

The estimation of the ATE starts with GPS estimation by following Hirano and Imbens (2004) procedure as described in the methodology. To estimate the GPS, covariates are identified just like in the naïve estimation process. Covariates are identified based on Caliendo and Kopeinig (2008) guidance so as to reduce the possibility of omitting key variables. Table B2.1 in the appendix shows the descriptive statistics based on multi-Tiers framework of the households. Furthermore, Table B2.2 in the appendix presents results of the estimated GLM showing conditional distribution of the treatment (duration of the household exposure to electricity services) given the identified covariates. The GPS are predicted post GLM estimation which shows the conditional probability of a household being treated to a given duration of electricity services in a day.

Thereafter, covariate balancing test is conducted to check how adequate the GPS specification is. The objective is to test whether conditional mean of the pre-treatment variables given the generalized propensity score is not different between individuals who belong to a particular treatment interval and individuals who belong to all other treatment intervals (Kluve *et al*., 2012; Hirano and Imbens, 2004). To carry out the test, the study divides the distribution of the duration of the treatment (duration of electricity availability) into five (5) treatment groups represented by the five MTF Tiers. The treatment interval for the five groups includes [0.042, 0.125], [0.167, 0.292], [0.333, 0.625], [0.667, 0.916] and [0.958,1]. For each covariate, the study tested whether the difference in the means for that variable in one group was statistically different from other (Hirano and Imbens, 2004). Bayes factor (BF) was reported for each mean value of the variable.

Higher values for BF show that balancing property was satisfied for the mean value of the variable in each group. Table B2.3 in the appendix shows improved BF for each covariate across five groups after adjusting for GPS. A value of BF equal or greater than one indicates the covariate balancing property of the mean equality is satisfied across the groups. However, there are five values of BF [0.535, 0.810, 0.871, 0.893 and 0.953] below 1. The values close to one show improvement in the covariate balancing property after adjusting the GPS. Generally, the results of BF show that through adjustment of the GPS, the covariate balancing has clearly improved.

Table 3.4: Overall Bayes Factor for Testing the Balancing Property

Treatment variable	**Bayes Factor Test for BP**
hhcont (T)	$0.316(\sqrt{0.1}) < 0.535 < 1.0$ Balancing property satisfied with very slight evidence against BP

Source: Author's computations

Although each covariate is tested for balancing property in each group, the overall covariate balancing property is given by the lowest value of BF across all the groups. Table 3.4 shows BF value of 0.535 which is between 0.316 and 1. This indicates that the covariate balancing is satisfied among covariates across the treatment groups with very slight evidence against balancing property. After verifying that the balancing property holds for covariates, estimation of ATE involves two final steps. The first step involves estimating the conditional expectation of the outcomes given the treatment and the GPS. The regression estimation process includes polynomial of order (3) for both the treatment and GPS for each household outcome variables. However, Hirano and Imbens (2004) emphasized that the estimated coefficients from conditional expected regression have no causal interpretation except testing whether all coefficients involving the GPS are equal to zero and can be used as a test of whether the covariates introduce any bias (Bia and Mattei, 2008). The results of the regression estimation are presented in Table B2.4 in the appendix. The final stage involves estimating the causal effect (ADRF and its derivatives referred to as marginal causal effects). The study averages the conditional expectation regression of the outcome at a desired treatment level (Tiers) over the GPS to get ADRF and the marginal effects. The desired level of the treatment in this study is taken at the MTF Tiers levels used in covariate balancing test.

3.4.2.2.Dose-Response Function Results on Households Socioeconomic Outcome

The ADRF and derivatives results are reported in Table 3.5 below and B2.5 in the appendix while graphical representation of the results are in the appendix (figure B2.1 and B2.2). Hirano and Imbens (2004) recommends the use of bootstrap method to compute the standard errors and confidence intervals while considering the estimation of the GPS and the parameters.

Table 3.5. Average Treatment (Availability) Effect on Household Socioeconomic Outcome

	Outcome Variables						
	Time allocation (Minutes/day)				**Employment in non-Agric**	**Household Expenditure**	
Treatment Level (Tier)	**Children studying (6-15 years)**		**Working away from home for pay/self**			**Expenditure on Alternative Energy (Kwacha)**	**Expenditure per capita (logs)**
	Boys	***Girls***	***Men***	***Women***			
4hrs (0.125)	22.46**	31.71***	71.00***	42.83**	0.76***	93.25***	8.43***
	(12.57)	(6.14)	(20.24)	(15.09)	(0.06)	(9.53)	(0.13)
8hrs (0.333)	18.41***	34.87***	134.82***	84.62***	0.82**	95.52***	8.09***
	(3.59)	(5.61)	(19.91)	(13.60)	(0.49)	(6.18)	(0.09)
16hrs (0.625)	19.99***	19.38***	89.27***	45.58***	0.79**	89.03***	8.16***
	(5.37)	(5.62)	(11.88)	(13.46)	(0.45)	(6.14)	(0.08)
23hrs (0.958)	32.14***	31.47***	209.82***	122.10***	0.84***	85.01***	8.45***
	(2.97)	(3.54)	(11.75)	(10.30)	(0.02)	(2.31)	(0.06)
24hrs (1)	34.45***	38.62***	260.19***	156.69***	0.86***	85.80***	8.47***
	(6.22)	(3.29)	(11.11)	(10.77)	(0.01)	(2.54)	(0.06)
No. Obs	**586**	**598**	**1,147**	**1,126**	**1,029**	**1,006**	**1,325**

Note: *, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent bootstrap SE.**

Source: Author's computations

The results conform to the general expectations that the longer the duration of exposure to electricity service in a day, the better the impact on household socio-economic indicators. From Table 3.5, the differential impact on time allocation at household level to various activities generally improves with increased duration of exposure to electricity services at household level. Considering that majority households are exposed to grid electricity in this sample, the impact on study time for school going children is higher among girls on average. At the lowest Tier (4hrs) girls allocate about 31.7 minutes while boys allocate 22.46 minutes to studying on average. However, as availability of electricity increases in the day the impact on time allocated to studying increases from 22.46 to 34.45 minutes for boys and 31.7 to 38.6 minutes for girls. This shows that as electrification levels improve at household level, children allocate more time to studying in a typical day. Figure B2.1 in the appendix shows this trend in the DRF graphs. For boys there is generally an upward increase in the impact while for girls the increase is relatively slow with a sharp fall at the third Tier. Despite this, the confidence bounds at 95% level show same movements as the ADRF for girls for the entire treatment while for boys the confidence interval is wide at the beginning and narrows after the second Tiers.

Further, the dose response function (ATE) on time allocated to working outside home for pay or self generally improves as duration of the electricity services improves for both men and women. The results have the same trend as employment in non-agriculture by household heads. As electricity service availability improves at household level, the probability of a household head being employed in non-agriculture sectors increases among households residing within electrified areas. From Table 3.5 the results show that the probability of getting employed in non-agriculture sectors increases from 0.76 to 0.86 for a household head as duration of electricity service rises from 4hours to 24 hours in a day. Similarly, the impact on time women allocate to working away from home increases from 42.8 to 156.7 minutes in a day while for men time allocation increases from 71 to 260.2 minutes. This shows that improvement in electricity availability does not only affect employment in non-farm sector but also the time household members spend working. Improvement in the electricity services means more opportunities are being created away from agriculture sector, thus, more time allocated by both women and men to working away from home.

Figure B2.1 in the appendix shows the trend in the DRF graphs for both time allocation to working away from home and employment in non-agriculture sector. The key observation from the three graphs is that the trend in the differential impact as duration of exposure to electricity services in day increases is similar. As the dose of electricity services increases from 4 to 8 hours, the probability of a household getting employed in a non-agriculture sector rises from 0.76 to 0.82 while the time allocation to working away from home by women increases from 42.8 to 84 minutes and 71 to 134.8 minutes for men, respectively. The rise in the differential effect falls sharply as the duration of electricity exposure increases to 16 hours but improves there after until 24 hours. These results show that improved supply of grid electricity improves labour supply especially among women (Dinkelman, 2011) and has a strong effect on household income generation in non-farm sector (Chakravorty *et al.*, 2014).

Even though, results from Table 3.5 show that there is a reduction in the differential impact between Tier 1 (4 hours) to Tier 2 (8 hours), overall annual expenditure per capita increases monotonically from 8.09 to 8.47 as household duration of exposure to electricity services rises from 8 to 24 hours. Similar results are observed on household expenditure on alternative energy sources that include kerosene, charcoal, and wood fire though in an opposite direction. Households reduce their expenditure on alternative energy sources from K93.25 (US$9.3)[18] to K85.80 (US$8.58) on average as duration of exposure rises from 4 to 24 hours in a typical day. Although studies have been inconclusive on the direction of household expenditure on alternative energy sources once connected, Khandker *et al.* (2012) contended that a huge reduction in household expenditure on alternative energy sources is only possible if issues of unreliability and unavailability of electricity services is reduced significantly, otherwise households maintain the same expenditure on these fuels. The DRF graphs in Figure B2.1 show the differential impact for both household annual per capita expenditure and expenditure on alternative energy sources.

3.4.2.3.Derivative Treatment Effect Function Within Tiers and IPTW Across Tiers

The study estimates the derivative function of the treatment with delta = 0.1 equivalent to 2.4hours increment. Hirano and Imbens (2004) referred the derivative treatment function to as marginal effect of the duration of electricity service on household outcomes. Although here a household is within a given Tier, the objective is to see if a household at Tier 1 (4 hours), a change of 0.1 (2.4 hours) within a Tier will lead to a statistically significant impact on household outcomes. Table B2.6 in the appendix gives the results of average marginal effect. Most of the results from derivative treatment effect are not statistically significant showing no differential impact within the Tiers. The study expects non-negative impact among statistically significant derivatives except for household expenditure on alternative energy sources, nevertheless, negative impact is observed at the second Tier (8-10.4 hours) for girls' time allocation for studying -4.57 minutes, men working for pay/self -10.28 minutes and women working for pay/self 9.40 minutes. Another negative differential impact is observed at first Tier showing a 0.21 reduction in a household annual expenditure per capita as duration for electricity services increase from 4-6.4 hours. The statistically significant marginal reduction shows that an increase in duration of household

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[18] The exchange rate: US$1 is equivalent to 10 Zambian Kwacha (K) as of 2018

exposure to electricity within Tiers does not always lead to improvement in quality of life among users unless a substantial duration of exposure to electricity.

To understand the differential effect across Tiers the study further estimated the pairwise impact by applying the inverse probability treatment weighting (IPTW) estimation approach. The objective here is to check whether there is statistically significant differential impact in outcomes, for instance, between a household treated to Tier 1 (duration of 4 hours) compared to Tier 2 (8 hours). However, the number of hours between tiers are not uniform as defined by the World Bank. Some tiers such as tier five has only two hours while tier three and four has eight hours. The lower tiers, one and two has 4 hours each. The results complement the marginal effect results as the pairwise IPTW results were estimated across the Tiers. Same household characteristics are used in the estimation process and the Tiers are taken as categorical treatment. Table 3.6 below presents results estimated using the IPTW approach.

Table 3.6: Pairwise ATE Across Household Tiers for Availability of Electricity Services

	ATE: Outcome Variables						
	Time allocation (Minutes/day)				**Employment in non-Agric**	**Household Expenditure**	
Treatment Level (Tier)	**Children studying (6-15 years)**		**Working away from home for pay/self**			**Expenditure on Alternative Energy (Kwacha)**	**Expenditure per capita (logs)**
	Boys	***Girls***	***Men***	***Women***			
2 vs 1	-28.3	10.3	-16.1	-31.7	0.032	-11.05	-0.17
	(31.8)	(16.3)	(39.7)	(37.8)	(0.113)	(12.06)	(0.16)
3 vs 2	**11.1***	**24.6*****	37.6	-12.03	0.036	**-24.29****	0.09
	(6.8)	(7.9)	(34.3)	(21.9)	(0.064)	(11.89)	(0.17)
4 vs 3	**26.0*****	**22.9****	-12.4	19.9	0.054	**-27.06****	**0.40****
	(7.4)	(8.7)	(32.6)	(17.4)	(0.046)	(11.68)	(0.15)
5 vs 4	-2.4	0.95	**170.2*****	**94.5*****	**0.047***	1.46	-0.02
	(7.1)	(7.9)	(15.6)	(14.2)	(0.026)	(5.58)	(0.09)
No. Obs.	**586**	**598**	**1,147**	**1,126**	**1,029**	**1,006**	**1,325**

Note: *, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent robust SE.**

Source: Author's own estimations

Statistically significant results from Table 3.6 show expected behaviour as households move to a higher Tier of electricity services. The results in lower Tier, for instance, Tier 2 vs Tier 1, show no statistically significant differential impact for a household to move from Tier 1 to 2. However, as households move from Tier 2 (8hrs) to 3 (16hrs), we observe that time allocation to studying by children and household expenditure on alternative energy sources are statistically significant with expected signs. Moving from Tier 3 (16hrs) to 4 (23 hrs), time allocation to studying, household expenditure on alternative energy sources and annual per capita expenditure are all statistically significant. Allocation of time to working away from home for pay/self and employment in non-agriculture sector are only statistically significant when a household moves from Tier 4 to 5. The observed results are statistically significance in middle tiers as opposed to higher tiers which shows that households may not need 24 hours electricity services for certain outcome variables such as children studying time. Generally, the trends from the results show that as the duration of electricity service improves (moving from lower to middle Tiers), the differential impact on socio-economic indicators improves among statistically significant results from Table 3.6. The observation complements ADRF results, and marginal treatment effect (MTEF) which are similar to studies by World Bank (2020); Litzow *et al.*, (2019); Toman *et al.*, (2018); Chakravorty *et al.*, (2014) and Khandker *et al.* (2012). These studies argue that statistically significant and meaningful impact from household electrification programs is only observed if issues of availability, affordability, quality, and reliability of the electricity service is achieved.

3.5. Conclusion and Policy Implications

The study’s objective is to evaluate the impact of electricity availability in Zambia on selected socio-economic indicators of the households. Three socio-economic indictors were selected which included household allocation of time to different activities (studying by children aged 6-15; working away from home for pay/self); household head employment in non-agriculture sector and household expenditure (annual per capita expenditure; monthly expenditure on alternative energy sources including kerosene, charcoal, and firewood). The study adopts the generalized propensity score technique with ADRF estimation approaches to obtain the impact of being treated. Specifically, electricity service availability defined by the duration is adopted as a continuous treatment.

The results from ADRF intuitively revealed that longer duration of household exposure to electricity service, impact better on socio-economic indicators. Children spend more time studying as household exposure to electricity improves. Despite girls spending more time studying, the upward increase in the time allocated to studying is faster among boys relative to girls with a sharp fall at the third Tier. The results further reveal that as duration of exposure to electricity improves, opportunities of being employed in a non-agriculture sector improves such that both women and men start allocating more time working for self/pay away from home. This is observed by similar trends in non-agriculture sector employment and time allocated to working away from home by women and men across Tiers. As the probability of the household head working in a non-agriculture sector increases due to the improvement in duration of electricity service exposure, time allocation to working away from for pay/ self also increases for both male and female to working way from home.

The study also reveals that the differential impact on household annual expenditure per capita in the lower Tiers (between 1 and 2) of electricity services reduces. As treatment to electricity goes beyond Tier 2, the annual expenditure per capita increases monotonically. Similarly, household expenditure on alternative energy sources that include kerosene, charcoal, and wood fire increases in the lower Tiers instead of reducing. However, as exposure to electricity goes beyond 16 hours there is generally a reduction in expenditure on alternative energy sources. Therefore, a meaningful reduction in expenditure on alternative energy can only be recorded if only availability of electricity is relatively high.

Therefore, energy policies and electrification programmes implemented by the Zambian government with the aim of improving user’s livelihood should ensure that the electrification technology provide sufficient duration of electricity service to users. This is because the study reveals the crucial role that improvement in the availability of electricity service play in achieving incremental benefits overtime. In addition, the study shows that the electrification programme should consider the effect of duration of electricity exposure among users as certain welfare indicators such as household expenditure on alternative energy significantly reduces only after a given level of exposure in a day (16 hours) while annual per capita expenditure can only improve significantly if a household is exposed to at least 8 hours of electricity every day.

All in all, the study shows that availability of electricity service is an important attribute in household electricity access in developing countries. The longer the duration of electricity availability, the higher the improvement in welfare indicators through acquiring of domestic appliances and engaging in productive activities. Thus, the study demonstrates that electricity access is beyond connection but is a spectrum of service levels that has incremental benefits on the household livelihood in developing countries like Zambia.

Despite the study observing the importance of electricity availability among connected households, availability alone is not sufficient. Inclusion of other attributes such as capacity, reliability, affordability is essential for a comprehensive evaluation of the impact of electrification programmes based on MTF. Therefore, future studies should consider other attributes or combine them when evaluating electrification programmes in developing countries. Furthermore, future studies should consider undertaking disaggregated analysis that considers rural -urban subsamples; grid and SHS electricity subsamples. Data insufficiency has limited this study to undertake the subsample analysis which would have broadened the analysis and understanding of electricity availability at household level. Thus, future studies with sufficient sample size can conduct subsample analysis.

Chapter Four

Credit Constraints and Willingness to Pay for Electricity among Non-connected Households

Abstract

In Zambia access to electricity remains low among households. The majority depend entirely on traditional energy sources for both lighting and cooking purposes. This entails low demand characterizes electricity access among non-connected households despite the derived socio-economic benefits observed in the previous studies among households who have adopted different electrification. Thus, this study focusses on estimating willingness to pay and its determinants for electricity connection among non-connected household. The study further estimates the willingness to pay given that households are allowed to pay on credit with extended period of one and two years for grid and solar PV, respectively. Contingent valuation approach is applied with single bounded dichotomous responses. Two electrification technologies are identified (grid, and SHS divided into low-capacity SHS and high capacity SHS). The results reveal that the willingness to pay is positive across the payment periods and technology (grid and solar PV). Further, average willingness to pay increases as payment period of the credit facility rises. However, the average willingness to pay for low-capacity standalone PV solar technology falls below market price in shorter payment periods (below 12 months) while for grid electrification and high-capacity standalone PV solar technology, is above the market price across the payment periods. This revelation is key for policy perspectives, as the study underscores household's willingness to pay for electricity technology that offer services beyond lighting. In this scenario, the study observe that grid electricity and high-capacity solar PV could improve household livelihood beyond lighting by engaging in economic activities. Further, households require access to credit financing or subsidies to enable them afford market prices for PV solar offered by private enterprises and smoothen their consumption during the payment period.

4.1.Introduction

4.1.1. Background to the Study

Access to electricity is not only regarded as a basic human need (IEA, 2013) but a pre-requisite for achieving development as it enhances economic productivity in developing countries (Bernard and Torero, 2015). This is evident by empirical results obtained in Chapters Two and Three which attribute improvement in household livelihood to electricity access among connected households and further, duration of exposure to electricity service. For instance, results in Chapter Two revealed that access to grid and standalone solar system PV (SHS) electricity offers better effects compared to being non-connected[19]. In short, being connected to any electrification technology has direct and indirect benefits on household productivity resulting in improvement of the users' livelihood (Bhatia and Angelou, 2015). Extended hours of work due to the presence of electricity improves net income (World Bank, 2008) through proliferation of non-farm activities and enterprises (Kurmar and Rauniyar, 2011). These potential benefits should motivate non-connected individuals to adopt any electrification technology as evidenced by better socio-economic outcomes among connected ones.

However, most of the countries in Sub-Saharan Africa are below 50% in terms of electricity access regardless of the technological source (Sievert and Steinbuk, 2020) with a large portion of the population without electricity access living in remote rural areas where extreme poverty and low-income levels prevail (Knapp *et al.*, 2020). Similarly, World Bank/ESMAP (2018) estimates that over 60% of the population in Zambia have no access to any source of electricity services and rely entirely on traditional energy for lighting, heating and cooking. The situation is worse in rural areas where almost 90% of the households lack access to electricity (Zamstats, 2015); with rural provinces (Luapula, Northern, Muchinga, Eastern, North-western, and Western) having below 10% of its population connected to any source of electricity. Furthermore, only 32.34% are connected to grid electricity while 5.23% are connected to off-grid electricity (Luzi *et al.*, 2019; Zamstats, 2015). Given the observed benefits (as observed in Chapter Two), the perilous dearth to electricity access has subjected households to limited opportunities thereby affecting their socio-economic livelihood negatively.

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[19] Nonconnected households referred in this study are households without access to electricity either grid or solar electricity.

Studies in SSA cite economic status (Blimpo and Cosgrove-Davies, 2019); access to financial services and credit facility (Greenstone and Jack, 2015; Banerjee *et al.*, 2017); subsidies (Abdullah and Jeanty, 2011) as hindrance to increasing demand among non-connected and subsequently increasing electricity access rate. Further, costs associated with getting a connection to either grid or off-grid electricity are cited as constraints to increasing electricity access rate among the non-connected (Sievert and Steinbuks, 2020). For instance, several studies (Knap *et al*., 2020; Sievert and Steinbuk, 2020; Xie and Zhao, 2017; Lee *et al*., 2016; Grim *et al.*, 2016) cite high connection fees for grid electricity as failure for getting connection among non-connected households. Households are required to pay three separate fees for grid electricity; connection fee, wiring fee, and user fees (tariff) to access electricity services (Abdullah and Jeanty, 2011).

Similarly, in Zambia a household is required to pay grid connection fees ranging from \$69.7 to \$74 for rural areas (REA, 2019) while in urban areas fees range between \$240 and \$400 plus standard wiring costs depending on the type of a house as of 2017 (Luzi, 2019). Those away from grid line incur extra costs of acquiring electricity poles (charged per span[20]) and given the sparse densely nature of the settlement in rural areas like Zambia (an average 24.43 persons occupy a square kilometer) (World Bank, 2018). In addition to cost constraints, poor access to financial services due to the economic status of non-connected households in SSA constrains them from accessing electricity services. This is because whatever financial resources households obtain, the first expenditure is to meet basic needs such as food, clothing, and housing thereby making access to electricity unaffordable.

Despite the challenges, Zambia has huge potential to increase electricity access among non-connected households. This is because 57% of the population is covered[21] by grid electricity with a national uptake rate[22] of 64.6%. The grid coverage could translate into a further 20% increase in grid electricity access among non-connected at the national level (Luzi *et al.,* 2019). Further, the potential for solar energy amounting to 5.5Kwh/m^2/day or 2019.97kwh/m^2/year (Mwanza *et al.*, 2017) has also failed to translate into tangible access to solar PV electricity among non-connected

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[20] The span is defined as the distance the between the poles (50metres) which include an additional pole, electric cables and other accessories amounting to atleast \$1000 per span.

[21] Grid coverage in this study is defined as having at least a household in the enumeration area (EA)/ village is connected to the grid electricity.

[22] The percentage of electrified household against households in an electrified village/EA

households. Therefore, disaggregating electrification technology into grid and off-grid technology, this study sought to understand the demand for electricity services among non-connected households in Zambia. Estimating demand for electricity services among non-connected households was done through estimating their willingness to pay (WTP) which is the starting point in understanding household access to electricity.

The policy debate on how to increase electricity access among non-connected by 2030 to meet the SDG (Sustainable Development Goals) goal on universal access requires understanding to what extent households are willing to adopt any form of electrification technology to better their livelihoods. The study identifies two forms of electrification technology; grid and SHS electricity services based on the way electricity is provided to households. For instance, grid electricity is provided through interconnected network owned by a public company, Zambia Electricity Supply Corporation (ZESCO) with set conditions while SHS is self-installation provided by the private sector in Zambia. Further, variation in capacity categorized by low and high across SHS technology entails that the benefits derived from SHS technology are limited by capacity.

Given the financial constraint faced by households especially in rural areas, the study introduces access to credit facility to reduce consumption shock among low-income households if the pay for electricity connection is a lumpsum payment. The objective is to observe changes in household behaviour given that they are allowed to pay on credit with payment period for connection extended up to two years for different electrification technology. Therefore, changes in the payment period help analyse household WTP dynamics for electricity connection given the low rate of access to electricity in Zambia. In short, the study analyses the effect on demand (WTP) for electricity services if credit constraints are relaxed across various electrification technology identified in the electrification programme in Zambia.

4.1.2. Study Questions/Objectives

The study focuses on comprehensively assessing the willingness to pay for electricity connection among non-connected households in Zambia. This is because the energy policy is anchored on ensuring that every household has access to reliable and affordable modern energy to facilitate poverty reduction and promote household business expansion (NEP, 2019). The study endeavors to answer the following questions:

i. What is the household willingness to pay (WTP) for grid vs solar electricity among non-connected households?
ii. How do changes in the credit period affect household WTP for electricity services?
iii. What determines the WTP among non-connected households for grid vs solar electricity?

4.1.3. Organization of the Study

The study is organized in five sections beginning with the introduction to the study. This is followed by literature review divided into three subsections that include theoretical aspects of stated preference, empirical review, and gap in literature. The third section presents the methodology of the study with four main subsections: contingent valuation approach, empirical estimation strategy and data description. The fourth section presents the empirical findings starting with descriptive statistics for household characteristics and then followed by estimated mean WTP with credit facility for grid and SHS estimations. The section further presents the determinants of the WTP for both grid electricity and SHS. Finally, the conclusion and policy implication are drawn from the discussion which are presented in the final section of the study.

4.2. Literature Review

4.2.1. Stated Preference among Non-users of Electricity Services

Consumers hold different beliefs and preferences towards electricity services and the challenge is how to estimate them (Knap *et al.*, 2019). Literature identifies stated preference as the suitable approach in which the preference and beliefs about electricity services are indirectly observed. The approach uses survey technique to elicit willingness to pay and is adopted where there is lack of existing market by soliciting for consumers preference for the good/ services. In such a scenario, stated preference approach estimates WTP for services such as electricity using hypothetical market behaviour situations (Mashayekhi *et al*., 2018). For instance, the non-existence of electricity market among non-connected individuals\households results in failure to establish the demand for the services. Therefore, the stated preference approach provides the analytical framework for analysing individual/joint preferences through adopting direct survey such that the objective is to either examine the quality or quantity of changes due to policy change (Carlsson and Martinsson, 2008; Abdullah and Jeanty, 2011). Focusing on non-connection of electricity, stated preference approach offers an opportunity to construct an electricity services market through asking people what economic value they attach to electricity services (Pearce and Ozedemiroglu, 2002). Therefore, stated preference suits understanding the preference and beliefs consumers attach to adoption of electricity services at household level.

Several studies have adopted stated preference approach to estimating the WTP of household/ individuals to adopt or improve electricity services based on two estimation approaches. The first estimation approach; choice experiment focuses on users WTP for attributes of improved electricity services. Studies such as Carlson and Martinson (2008); Abdullah and Marie (2010); and Gunatilake *et al.,* (2012) have conducted choice experiments to observe the household WTP for attributes of improved electricity services. A choice set of options with attributes of the electricity services are presented to the users of electricity services. Factors such as prices, reliability and quality of electricity services are included as attributes of electricity of the services and are included in the estimation of the WTP. Supporters of the approach argue that the true value of electricity services can be obtained if the users understand the attributes otherwise users will be less informed leading to bias responses (Beenstock *et al.,*1998; Goett *et al.,* 2000). Choice experiments might be inadequate when estimating the WTP for non-connected households as attributes of electricity are best understood by users of electricity services as non-connected of electricity services are excluded from experiencing them.

The Contingent Valuation (CV) approach better suits the scenario under investigation. Studies adopt CV approach due to its ability to capture non-market environment, health, energy related goods and services (Blackman *et al.,* 2018). The approach asks individuals to state their WTP for electricity services as opposed to choosing alternative bundles of electricity services (Tietenberg and Lewis, 2018). The approach can describe a policy intervention that can generate a marginal increase in the good (Blackman *et al.,* 2020). Several studies such as Guo *et al.* (2014) have used the CV approach to estimate the household willingness to pay for renewable electricity in Beijing; Abdullah and Jeanty (2011) attempted to estimate the WTP (willingness to pay) for household electricity in rural Kenya using CV approach. Entele (2020) also adopted CV approach and estimated household willingness to pay for renewable energy in Ethiopia. All these studies generated the direct WTP among non-users. Heterogeneity in consumers preference influences individuals' decision to connect to electricity among non-users (Pattnayak and Pfaff, 2009; Suri, 2011).

4.2.2. Empirical Review

Studies have attempted to empirically estimate household WTP (willingness to pay) for grid electricity connection (Abdullah and Jeanty, 2011; Lee *et al*., 2016; Banerjee *et al*., 2017) and off-grid electricity across developing countries (Bandari and Jana, 2010; Entele, 2020). These studies focus on establishing the demand for electricity connection among non-connected in developing countries. However, Blimpo and Cosgrove-Davies (2019) argue that non-connected individuals may have higher desire for electricity connection but possess a low WTP for a connection that fails to cover the full cost of providing electricity especially in Sub-Saharan Africa. Sievert and Steinbuks (2019) focusing on extreme poor households across three countries in Africa (Rwanda, Senegal, and Burkina Faso) estimated households WTP for various technologies that include solar home system, grid electricity and solar lump and its determinants such as income level and other control variables. The study found that households put high priority on electricity access and are willing to dedicate more than 10% of their monthly income to paying for electricity, showing that WTP rises with a rise in income. However, the study found that the observed WTP is low such that it is not adequate to cover operational cost and capital cost of extending grid supply to poor people in rural areas in the short and medium term.

Similarly, Grim *et al.*, (2016) conducted an experiment on households which revealed WTP for the three types of off-grid solutions in rural Rwanda. The study randomly sampled 325 households from 16 communities across Rwanda and applied Becker-Degroot-Maschak real purchase offer bidding game to elicit for the WTP. The investment cost offer ranged between $13 and $180 for the 0.5W, 3.3W and 20W devices. The results showed that the mean WTP for the off-grid solutions was between 38% to 55% of the market prices with the upper tail of the distribution of the WTP having very few households who were able and willing to pay the amount that was close to the market prices. This study compliments results obtained by Lee et al. (2016), who conducted a randomised study in Kenya across 150 communities focusing on rapid grid coverage rural areas. The study found that access rate only rises with a decrease in fees for connection due to lower low WTP despite heavy subsidies. Furthermore, a study by Entele (2020) explored the household WTP for renewable energy in Ethiopia focusing on solar PV and grid electricity services. The study used the CV (Contingent Valuation) double bounded dichotomous choice model to estimate the WTP from the 220 rural households sampled using the systematic sampling approach. The results revealed that the median WTP was not enough to recover the cost of providing the electricity services despite being positive.

However, differences in economic development, culture, social customs, and energy policies lead to estimated WTP differences across countries and regions (Xie and Zhao, 2017; Sundt and Rehdanz, 2015). In developed countries, studies such as Kim *et al.*, (2012); Nomura and Akai (2004); Yoo and Kwak (2009) have all estimated WTP for improved electricity services among users. Comparably, the studies in developed countries have focused on users as opposed to non-connected in developing countries. For instance, Yoo and Kwak (2009) estimated WTP for the green electricity following policy change that increased percentage use from 0.2% to 7% in South Korea. The study obtained a statistically significant WTP for green energy in South Korea. The monthly mean WTP estimate from the parametric method was U$ 1.8 while the one from the non-parametric method was U$2.2. Later, Lee and Heo (2016) estimated consumers additional WTP using the contingent valuation method in order to understand acceptance levels of renewable energy in South Korea. The study revealed that individuals were willing to pay U$3.1 per month for renewable energy despite being lower than other developed countries to influence investment in renewables.

Further, Bergmann *et al.,* (2008) estimated WTP on rural vs urban preference for renewable energy in Scotland by adopting choice experiment approach. The results show heterogeneity preference between rural and urban areas for renewable energy solar due to differences in type of the technology adopted across the locations. However, the study failed to control for location differences in socio-economic characteristics that has bearing on user's preferences for renewable energy.

Similarly, Zoric and Hrovatin (2012) in their study confirmed that controlling for socio-economic characteristics is key in estimating WTP for green electricity. Their study showed that household head age, income, education, and environmental awareness play a crucial role in explaining household attitude to green energy electricity. The estimated median WTP exceeded the current mandatory charges for green electricity in Slovenia. Similarly, Nomura and Akai (2004) adopting the Weibull distribution approach found that the median WTP of $17 per month in Japan for green electricity was higher than the market value. Borchers *et al.,* (2007), focusing on 128 individuals and using choice experiment approach with nested logit model in the USA, revealed that the mean WTP for generic green electricity vary with the source and type.

Hence, studies in the developed countries show that the estimated WTP for electricity is over the market value compared to the low mean WTP in developing countries. Further, developed countries focus on users as opposed to non-users of electricity in the developing countries. There is high likelihood that households in developing countries may not understand the benefits of the electricity thereby understating or overstating the WTP.

Several factors have been cited toward low WTP in developing countries. The costs involving access (extending and connecting households) and service (ongoing provision of electricity; tariffs) hinder households demand for grid electricity services (Lee *et al.,* 2016; Abdullah and Jeanty, 2011). For instance, Banerjee *et al.,* (2017) estimated the WTP for household grid connection in Liberia. The study offered six randomly assigned connection fees (U$54, US$38, US$31, U$21, U$16, U$8) calculated from the official connection fee of U$54. Getting the mean WTP offers an insight of how connection fees hinder demand for electricity connection. The results show that only 10% of the respondents were willing to pay the full cost of electrification. Even after making the connection fees equal to zero, about 9% of the respondents refused to adopt electricity due to other hidden costs other than connection fees. The costs associated with use and connection such as wiring, poles and maintain monthly tariff. These costs coupled with low income and extreme poverty especially in rural areas of developing countries (Knapp *et al.,* 2020; Abdullah and Jeanty, 2011) have resulted in low demand for electricity services among non-connected households.

Further, strong, and significant correlation between stated WTP and socio-economic status of households is observed across numerous studies. For instance, Taale and Kyeremeh (2006) applying CV estimation approach found that the quality of the household dwelling represented by number of rooms, walls and floor were key determinants of WTP for adopting electricity services. The quality of wall of the house positively determined electricity uptake as those with high quality walls (cement walls) tended to have higher WTP for an electricity connection compared to low quality (mud walls) (Lee *et al.,* 2016). In addition, the quality of the house indicated the socioeconomic status of the household. For instance, a house with iron sheet, cement walls, and ceramic tile floor represented a wealthy individual in the locality with the ability to afford and maintain electricity connection. Similarly, Abdullah and Jeanty (2009) in Kenya and Gunathilake (2012) in India found that the presence of business at household level increased the probability of adopting renewable energy among household in rural areas. However, the type of business at household level should be one that promotes the use of electricity services.

Furthermore, factors including education level, community infrastructure, wealth status of the households, employment in non-farm sectors are controlled when estimating the WTP. Blimpo and Cosgrove-Davies (2019) points that estimating WTP for grid connection requires controlling for education levels, wealth status, employment, and community infrastructure. In addition, studies argue that lack of information about potential benefits and associated costs to potential users reduces willingness to pay for electricity services (Xie and Zhao, 2017; Blankenship *et al*., 2019). The lack of information creates social mistrust about the quality of electricity services especially standalone solar home system and solar lantern thereby reducing the willingness to pay for a connection or additional services. For instance, grid electricity connection in developing countries requires quality trust beyond connection (Golden and Min, 2012).

Further, political belief and confidence also influence the quality of information that can positively affect household WTP grid electricity as it creates a cultural rejection or acceptance of the product/service (Amoah *et al.,* 2017). The potential users tend to trust the ability of the electricity services to improve their livelihood. Bringens and Kallsson (2016) found a positive awareness of the existence of electricity subsides and support for price reforms positively affecting the WTP for an electricity service connection.

Finally, Greenstone and Jack (2015) in their study noted that liquidity constraints are the major obstacle to household WTP for the amenities such as electricity in Sub-Saharan Africa. Blimpo and Cosgrove-Davies (2019) confirmed that affordability and credit availability constraints are key determinants of the WTP for electricity services following their study on four countries in sub-Saharan Africa (Ethiopia, Gambia, Nigeria, and Senegal). The study concluded that WTP for electricity connection is highly driven by income and credit availability across households. Similarly, in Rwanda using the multi-Tier framework data, Blimpo and Cosgrove-Davies (2019) revealed that credit access constraint is the driving factor of the low demand for uptake of electricity among households. To examine the effect of credit constraints on WTP for electricity connection in Liberia, Banerjee *et al*., (2017) relaxed credit constraints by introducing payment period plans of up to 12 months (upfront, 3 months, 6 months and 12 months payment instalments). The results revealed that payment flexibility matter less with high connection fees. For instance, at 6 months payment plan, uptake of electricity services increased only by 15%. However, when credit is available, household prefer monthly payment as opposed to lumpsum payment as it is convenient given low-income levels in Ethiopia (Entele, 2020). This is why Abdullah and Jeanty (2011) recommended subsiding connection costs for any source of electricity by adjusting the payment period and monitoring rural market players in the provision of electricity.

4.2.3. Gap in Literature

Literature has observed that in developing countries the mean WTP is usually below the market value. However, the extent across the different electrification technology is not extensively discussed under the literature. Literature also acknowledges the low income among non-connected households and the need for access to credit facilities to enable households afford electricity connection. Nevertheless, literature does not emphasize the extent to which credit facilities can improve demand or not for electricity services among non-connected households. Therefore, this study contributes to closing this gap in literature and observe how the differences in preference for various electrification technology (grid and solar- high and low capacity) contributes to low WTP among non-connected households.

4.3. Methodology

4.3.1. Contingent Valuation Approach: Theoretical Perspective

The objective of the study is to estimate the household’s WTP and its determinants for an electricity connection from a given electrification technology among non-connected households. To achieve this objective the study adopted contingent valuation (CV) approach to determine the willingness to pay for electricity connection from a given electrification technology. Carson and Hanemann (2005) argue that the objective of undertaking CV study is to estimate the monetary value of either non-market or market product or services by eliciting information about the individuals’ preferences about the product or service (Seck, 2016). CV being a stated preference technique begins with pre-determined bids $(p_1 < p_2 <, \dots \dots \dots \dots . < p_m)$ based on theory and other market conditions (Bateman *et al.*, 2001). The bids are prices of the product or services that are assigned randomly to an individual. The bids allow a respondent to give a closed ended response (yes /no) if he/she is able to pay/not the stated amount. The closed ended responses lead to studies opting for either a single bounded dichotomous (SBD) choice (Bishop and Herbelien, 1979) or double bounded dichotomous (DBD) choice (Hanemann *et al*., 1991). The double bounded dichotomous choice allows for a follow up question with either high or lower bid given the first response to first question while the single bounded dichotomous choice does not have a follow up question to the initial response.

To elicit for the household willingness to pay for electricity connection, the experiment was conducted among households without electricity connection. Getting a connection from any electrification technology and subsequent utilization of the electricity service was assumed as a move from a status quo q^0 to a new level q^1 resulting into improvement in the quality of life. If $q^1 > q^0$, a household will accept the bid $(\boldsymbol{p_1})$ given that they are able to derive positive utility from being connected to electricity. Using the random utility model (RUM) developed by Haneman (1984) which draws its theoretical framework from McFadden (1974), a potential improvement in the quality of life once connected to electricity will lead to a household responding yes to a random assigned bid. This is because the indirect utility derived from paying for the connection is greater than the status quo. Using the RUM means that the direct utility derived from using electricity services is greater than the utility derived from the status quo as given in equation 4.1:

$$U_1(y_j - P_{1j}, Z_j, q^1, \varepsilon_{1j}) > U_0(y_j, Z_j, q^0, \varepsilon_{0j}) \qquad 4.1$$

where y_j is household income, q^1 is household utilization of electricity service or household connection to electricity, q^0 is household not connected to electricity, Z_j is a vector of household characteristics that may affect household willingness to pay for electricity connectivity while P_{1j} is price of electricity service. ε_{1j} and ε_{0j} represent the error term when individual j is consuming electricity services and when not respectively. The RUM requires that the utility function be additively separable in both deterministic and stochastic component such that the direct utility function equals the indirect utility plus the stochastic term. Equation 4.2 shows this relationship below.

$$U_i(y_j, Z_j, q^1, \varepsilon_{1j}) = V_i(y_j, Z_j, q^i) + \varepsilon_{1j} \tag*{4.2}$$

Therefore, the probability that a household will say ’yes’ to electricity connection given individual household characteristics follows that:

$$\begin{aligned} \Pr(Yes = 1|y_j z_j) &= Pr[V_1(y_j - P_{1j}, Z_j, q^1) + \varepsilon_{1j} > V_0(y_j, Z_j, q^0) + \varepsilon_{0j}] && 4.3 \\ &= Pr[V_1(y_j - P_{1j}, Z_j, q^1) - V_0(y_j, Z_j, q^0) > \varepsilon_{0j} - \varepsilon_{1j}] \\ &= Pr[\Delta V_j > \varepsilon_{0j} - \varepsilon_{1j}] \\ &= Pr[\Delta V_j > \varepsilon_j] && 4.4 \end{aligned}$$

where $\varepsilon_j = \varepsilon_{0j} - \varepsilon_{1j}$.

Equation 4.4 gives the WTP distribution which is linked to response probability distribution of the survey through utility maximization response assumption (Carson and Hanemann, 2005). Given that the study uses closed-ended single bounded dichotomous choice, the cumulative distribution function (CDF) is introduced to the WTP distribution such that the probability of getting a ’yes’ response is given by equation 4.5 below.

$$\Pr(Yes = 1|y_j, z_j) = 1 - F_\varepsilon(-\Delta V_j) \tag*{4.5}$$

where F_ε is the CDF of the stochastic difference ε.

4.3.2. Empirical Estimation of the Average WTP

In order for the study to estimate the WTP distribution given in equation 4.5, a linear function form is assumed for the deterministic component of the RUM (Seck, 2016; Carson and Hanemann, 2005; Hanemann and Kanninen, 1996) through the indirect utility function given by equation 4.6.

$$V_{ij}(y_j, Z_j) = \alpha_0 + \alpha_1 Z_j + \alpha_2 y_j - \beta P_{1j} \tag*{4.6}$$

The change in the deterministic utility is given as $\Delta V_j = V_{ij} - V_{0j} = \alpha_j Z_j - \beta P_{1j}$ and the conditional probability of the ‘yes’ response when using change in the deterministic utility is given by equation 4.7 below:

$$\Pr(Yes = 1|y_i, Z_j) = \Pr\,(\varepsilon_i < \alpha_j Z_j - \beta P_{1j}) \tag*{4.7}$$

Therefore, if we assume that the stochastic difference term ε_j is normally distributed ($\varepsilon_j \sim N(0, \sigma^2)$). To estimate the conditional probability of a yes response given by equation 4.7, we assume standard normal distribution such that $\theta_j = {}^{\varepsilon_j}/_{\sigma}$ which is a standard probit model as given by equation 4.8 below.

$$\Pr(Yes = 1|y_i, Z_j) = \Pr\,(\theta_j < \frac{\alpha}{\sigma} Z_j \ - \frac{\beta}{\sigma} P_{1j}$$

$$= \phi(\frac{\alpha}{\sigma} Z_j - \frac{\beta}{\sigma} P_{1j}) \qquad 4.8$$

where ϕ is the standard normal CDF. In short, the mean WTP is estimated by the probit estimation model with 'yes' or 'no' response as outcome variable. This follows a latent variable formulation that conceptualizes that there is a continuous propensity outcome that changes a household from one state of not willing to pay to a state of willing to pay once the certain level of utility has been reached. Therefore, the estimated probit model is given by equation 4.9 below.

$$Pr(Yes = 1|y_j, Z_j) = \alpha_0 + \alpha_1 Z_j + \alpha_2 y_j - \beta P_j \qquad 4.9$$

Here, the outcome variable is a discrete variable represented by 'Yes' or 'No' response to the specified bid (P_{ij})presented to the household. The maximum likelihood method as a parametric model is used to estimate the marginal effect. Therefore, the mean WTP is obtained post estimation probit model following Lopez – Friedman (2012) procedure given by equation 4.10 below.

$$E(WTP) = -\frac{\alpha_0}{\beta} \qquad 4.10$$

Where α_0 is the intercept and β is the coefficient of the bid (P_j) as shown in equation 4.9 above. The mean WTP is positive if the coefficient of the bid (P_j) is negative. Further, estimation of equation 4.9 by probit estimation procedure gives determinants of the mean WTP for each electrification technology and payment period.

The study estimates the mean WTP for the three sources of electricity: grid electricity, high-capacity SHS and the low capacity SHS electricity and the determinants for each category. Furthermore, study introduces credit facility across the three electricity sources to understand the dynamics of the household mean WTP for electricity connection over time. The study further disaggregates the data into subsamples and estimate the mean WTP for rural areas. However, due to data limitations the study did not estimate the urban mean WTP. The objective of disaggregating the data into subsamples is to observe the extent of the differences in the mean WTP across rural-urban given the differences in economic characteristics.

4.3.3. Experiment Design and CV Scenarios

Experiment Design

The study focuses on non-connected households sampled across the country. The WTP estimates for two electrification technologies: grid and standalone solar PV electricity sources. The standalone solar PV are in two categories involving low capacity and high-capacity solar PV. A total of 2140 households with no access to electricity services were drawn from the entire country. The household selection into the sample is based on two stages of stratified random sampling. The first stage involved stratifying the rural-urban strata and the second stage was based on electrification status of the enumeration area (EA)in the study population. Here, a 50-50% ratio of distribution of the sample was achieved as EAs with atleast 3% of the households that are connected to the national grid were classified as electrified while those with less than 3% of the households connected to the national grid were classified as non-electrified. However, the households sampled in these areas are those who depended entirely on traditional sources of energy for cooking and lighting. The sample consisted of 77% of the households from rural areas while 23% were from urban areas. This is because 95% households in rural areas were without any access to any form of electricity while 67% households in urban areas were connected to grid electricity (Luzi *et al*., 2019; World Bank/ESMAP, 2018). Therefore, a questionnaire as a survey instrument[23] was administered with questions on willingness to pay for grid electricity and solar standalone PV electricity. The following sections explain the contingent valuation survey design or scenarios for grid electricity and standalone solar PV electricity.

4.3.3.1. CV Survey Scenario for Grid Electricity Connection

A household with no access to grid electricity but wishes to start utilizing the grid electricity service is required to pay connection fee in addition to wiring costs and meeting monthly

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[23] Readers interested in the survey instrument (questionnaire) used in data collection on Zambia, see the World Bank link: https://microdata.worldbank.org/index.php/catalog/3527/get-microdata

subscription either through pre-paid or post-paid meters. The wiring costs include wiring material and labour costs paid to a certified electrical engineer. This makes the total cost of wiring dependent on the physical size of the house being electrified. Further, monthly subscription fees depend on the consumption capacity of the household. Households with many electrical appliances will spend more on monthly subscription of the electricity services. However, the connection fee is usually fixed and depends on the demographic location of the household.

According to the World Bank/ESMAP (2018), Zambia is divided into four locations for the purpose of electricity connection. The households residing in rural areas pay the lowest connection fees, while the urban areas are divided into three locations based on the population density. Those in low density pay the highest connection fees followed by medium density and lastly those in high density residential areas. Therefore, the study assumes that once the connection fee is paid in full, a household is immediately connected to the grid electricity without delay as long as standard wiring is complete in the house.

The survey introduced credit payment plans to the respondents alongside lumpsum or upfront payment plan. Three months, six months and twelve months are the credit payment plan for grid electricity connection. The longer payment period allows households to decide the best payment period after controlling for households' characteristics. Six bids (price) of getting a grid electricity connection are randomly assigned to households and pegged at 14%, 29%, 43%, 57%, 71% and 100% of the connection fee (K2,124/ $212.4). The bids considered the different payments based on locations of the households. Given that four payment plans were introduced, a single question of yes/ no response ***'would you be willing to pay K{.} upfront for a grid electricity connection?'*** was asked without a follow-up. This gives a closed ended single bounded dichotomous response and from the response a single amount is identified for every respondent in the sample. Table 4.1 shows the distribution of the responses of households to the single question.

Table 4.1: Distribution of the Response to the Bid for Grid Electricity Connection

Bids	**Upfront**		**3 months Payment**		**6 Months payment**		**12 Months**	
K ($) *	***Yes***	***No***	***Yes***	***No***	***Yes***	***No***	***Yes***	***No***
297 (29.7)	153	200	182	171	203	157	222	131
616 (61.6)	502	752	553	701	625	627	706	544
913 (91.3)	29	48	35	42	38	39	40	37
1,211 (121.1)	68	161	78	151	96	134	110	120
1,508 (150.8)	31	83	40	74	44	70	52	62
2,124 (212.4)	40	73	43	70	50	63	54	59
Total	**823**	**1,317**	**931**	**1,209**	**1,056**	**1,084**	**1,184**	**953**
	2,140		***2,140***		***2,140***		***2,137***	

*In Parenthesis represents US dollar value at the exchange rate of K10/US$1 as of 2017/18; Source: Author's computations

To ensure that no response bias is recorded that may affect the quality of the results, the survey provided full information about the cost, benefits, and requirements for the household to get an electricity connection. The provision of full information about the requirements of grid electricity allowed respondents to make rational decisions as they respond to the question. In Table 4.1, there is an increment in the total number of respondents who answered "yes" to the question as the payment period increased. This is because households who expressed willingness to pay for the upfront category were added to subsequent payment period. The study assumed respondents could pay in subsequent payment periods. Therefore, only the no-responses were taken into the next payment period and were asked the same question. Across the payment plan, more respondents accepted the bid to get a connection. For instance, for the bid K297 ($29.7) more (31) respondents agreed to get a connection as the payment increased from upfront to 3 months.

4.3.3.2. CV Survey Scenario for Solar Home System (SHS) Electricity

The households wishing to connect to solar home system electricity were categorized in two Tiers (one and two) based on the capacity of solar panel. This means that two products (lower and high capacity) were considered under the solar PV electricity. Tier 2 was a high-capacity solar panel ranging between 50 – 199 watts and could provide electricity for up to 23 hours while Tier 1 was a low-capacity (up to 49watts) and could provide electricity for at least 4 hours per day (Luzi *et al.*, 2019). Due to its ability to provide longer hours of electricity, the high-capacity solar panel accounted for 73.57% of the respondents while 26.43% of respondents opted for Tier 1 solar home system. Further, the higher capacity solar panel could power a TV, multiple lighting bulbs, phone charging and small load appliances (water pumps; small capacity fridge) while low capacity was able to power multiple lighting bulbs, phone charging and small radio. The number of appliances powered by high-capacity solar panel enabled users to utilize electricity services beyond lighting to include economic activities such as engaging in small business ventures like running a hair salon, barbershop, bar, and grocery shop.

To reduce errors in responses, respondents were shown pictures of two categories (low and higher capacity) of the solar panel with an explanation about the difference, use and the benefits. Further, the suggested prices for both high and low capacity included all required appliances such as batteries and converters. These enabled users not to incur extra cost once adopted. Table 4.2. show the distribution of the responses for the low-capacity solar home system.

Table 4.2: Distribution of the Response to the Bid for Low-capacity SHS Connection

	Bids	**Upfront**		**6 months**		**12 months**		**24 months**	
	K ($) *	Yes	No	Yes	No	Yes	No	Yes	No
Tier 1 (Low Capacity)	*412 (41.2)*	93	158	106	145	120	130	128	118
	825(82.5)	50	133	70	113	83	101	94	90
	1250(125)	13	99	15	97	30	81	44	69
Sub-Total		***156***	***390***	***191***	***355***	***233***	***312***	***266***	***277***
Total			*546*		*546*		*545*		*543*

*In Parenthesis represents US dollar value at the exchange rate of K10/$1 as of 2017/18: Source: Author's computations from World Bank/ESMAP (2018) dataset

From table 4.2 we observe that four payment plans were proposed which include upfront, 6 month, 12 months, and 24 months. The 24 months payment plan was a long period for a household to manage paying due to unpredictable sources of income. However, the study included 24 months plan to observe the extent to which payment period affected household demand for solar home system electricity. The respondents were further randomly assigned to 3 bids for both Tier 1 and Tier 2. Three bids at 33%, 66% and 100% of the full price for each tier (low-capacity solar panel and high capacity) were used in the study. Similarly, a single question was asked to the respondents without a follow up question giving a single bounded dichotomous choice.

Table 4.3: Distribution of the Response to the Bid for High-capacity SHS Connection

	Bids	**Upfront**		**6 months**		**12 months**		**24 months**	
	K ($) *	Yes	No	Yes	No	Yes	No	Yes	No
Tier 2 (High Capacity)	*1534 (153.4)*	81	371	94	368	161	308	197	273
	3069 (306.9)	33	158	42	150	57	139	69	125
	4650 (465)	120	757	154	712	245	670	322	534
Sub-Total		***234***	***1,286***	***290***	***1,230***	***463***	***1057***	***588***	***932***
Total			1,520		1520		1520		1520

*In Parenthesis represents US dollar value at the exchange rate of K10/$1 as of 2017/18.

Table 4.3 shows the distribution of the responses to the bids for the high capacity SHS. A similar pattern in responses is observed under the SHS as the grid electricity. For instance, in the high capacity SHS, more individuals responded yes to the randomly assigned bid as the payment plan period increased. A total of 15.4% respondents accepted the bids for upfront payment but a total of 38.7% respondents accepted the bid as the payment plan extended to 24 months.

4.3.4. Descriptive Statistics for Non-Connected Household Characteristics

To estimate the WTP, the study controlled for prices (bid) of getting a connection and other household characteristics that affected household ability to pay for electricity services from a given electrification technology. Table C3.1 in the appendix shows the control variables used in the estimation of the WTP for each electrification technology. The discussion below takes selected variables from Table C3.1 in Appendix C and their justification for inclusion as control variables. The bid represents the price of getting a connection. There are three bids representing three categories which were under consideration in this study. The mean price (bid) for grid electricity was K764.88 ($76.49) while low-capacity SHS was K 723.6 ($72.36) and the high-capacity SHS was K3,533.7 ($353.37).

The average income for non-connected households is an important indicator of the economic status of the household as it determined whether a household could adopt electricity. The mean income was estimated at K1569 ($156.9) per month with minimum income being zero for certain households. The other notable variable is the distance to the grid from the household place of dwelling with mean value of 9.28 kilometers. The distance to the grid variable was expected to negatively affect grid connection while positively affecting SHS connection. The longer the distance to the grid, the higher the cost to connect to grid electricity, and the more households are expected to adopt SHS electricity. The variable further presents the distance to the district center as all district centers are connected to the grid. Further, majority households without access to electricity reside in rural areas. The mean value shows that 77% of the respondents in this experiment reside in rural areas and looking at grid connection price category, we observe that majority households fall in rural areas price category (1.23) from the four categories that include: rural, urban low cost, urban medium cost, and urban high-cost categories.

4.4. Empirical Findings and Discussion

After generating the CV scenarios for three sources of electricity services (grid electricity, low capacity and high- capacity SHS electricity), the study estimates the probit model following the estimation strategy outline in section 4.3 above. The mean WTP is then estimated from the probit results by dividing the constant with the coefficient of the bid (price) as shown by equation 4.11 above. The estimated mean WTP was for each upfront payment for each electricity service source. However, the study further estimates mean WTP after extending the payment period which was introduction of credit facility as household were allowed to pay in installments. The payment period extended to 1 year for grid electricity while for SHS it went to 2 years. Section 4.4.1 and 4.4.2 present results and discussion for mean WTP for grid and SHS electricity connection, respectively. Further, the study estimates the mean WTP for households in rural areas given that over 70% of household without electricity are in rural areas compared to urban less than 35%. Finally, the study estimates the household determinants for a grid and SHS electricity connection and results are presented in section 4.4.3 below.

4.4.1. WTP Results for Grid Electricity Connection with Credit Facility

Table 4.4 below shows the mean WTP results for grid electricity connection. The estimated mean WTP is positive and statistically significant across all payment plans. This indicates a positive demand for grid electricity connection among non-connected households. The upfront mean WTP is \$242.69, which is 14.26% higher than the market price of \$224. The households are willing to pay \$30.29 more than the market price upfront or as a lump sum payment to get a grid connection.

Table 4.4: WTP Results for Grid Electricity Connection

Variables	Upfront	3 months	6 months	12 months
Mean WTP	*K2426.94**** *(815.2)* *(\$242.69)*[24]	*K3542.2**** *(1191.8)* *(\$354.22)*	*K3729.82**** *(1251.2)* *(\$372.98)*	*K4263.97**** *(1557)* *(\$426.39)*
$\%(\frac{WTP-MP}{MP})$	14.26%	66.76%	75.61%	100.75%

MP is market price (K2124); ******, **, * indicate significance level of 1%, 5% and 10%:*** Source: Author's computations from World Bank/ESMAP (2018) dataset.

Furthermore, the introduction of the credit facility allows households to pay for grid electricity connection overtime. The results in Table 4.4 reveal an increase in the mean WTP as the payment

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[24] Exchange rate as of 2018 is \$1/K10

period rises. For instance, the mean WTP increases to $354.22 for three months payment plan indicating a 66.76% increase compared to market price. Similar trend in the mean WTP is observed for 6 months and 12 months payment plan where the estimated mean WTP is $372.98 and $426.39 respectively. This affirms studies (Blimpo and Cosgrove-Davies, 2019; Banerjee *et al.,* 2017; Greestone and Jack, 2015) which cite liquidity constraints in Sub-Saharan Africa as the major obstacle to household WTP for electricity access. Given that most non-connected individuals are from rural areas with low income and economic activities, introducing credit facility helps not to disturb consumption pattern as the connection fee payment is spread across time.

Although mean WTP for grid connection in Sub-Saharan Africa is relatively lower than the market value (Lee *et al.,* 2016), obtaining a positive and higher than market value mean WTP across the four payment plans/periods in this study is an indication that households in Zambia value positively the adoption of grid electricity given the associated benefits. The low differentiated value between upfront mean WTP and the market value (14.26%) compared to when credit facility is introduced, indicate that grid electricity is still expensive among non-connected households. Thus, non-connected households require either a subside or credit facility to aid their payment for the grid electricity connection.

4.4.2. WTP Results for SHS Electricity Connection with Credit Facility

There are basically two products for standalone solar PV electricity differentiated by the capacity of the solar panels. Table 4.5 shows results for low-capacity solar PV mean WTP while Table 4.6 shows the mean WTP results for high-capacity SHS electricity.

Table 4.5: WTP Results for Low-capacity SHS Electricity Connection

Variables	Upfront	6 months	12 months	24 months
Mean WTP	*K688.69** *(400)* *($68.87)*[25]	*K831.18** *(437.2)* *($83.12)*	*K1227.78* *(801.5)* *($122.78)*	*K2882.85* *(2739.6)* *($288.29)*
$\%(\frac{WTP-MP}{MP})$	-45.4%	-33.5%	-1.8%	66.6%

MP is market price (K1240); ******, **, * indicate significance level of 1%, 5% and 10%:*** Source: Author's computations from World Bank/ESMAP (2018) dataset.

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[25] Exchange rate as of 2018 is $1/K10.

The results in Table 4.5 show a positive mean WTP across all the payment plans despite two being statistically significant at 10%. Further, the mean WTP is positive for upfront payment ($68.87), it is below the market price by 45.4%. This means that for such capacity, households are not willing to pay more than the market value. Instead, they are willing to pay $56.1 less than the market value on average. The introduction of the credit facility shows that only mean WTP for 6 months is statistically significant and still below the market value by 33.5%. The price only clears after 12 months and extending payment period to 24 months, the mean WTP is higher than the market value by 66.6% despite being insignificant. Therefore, the mean WTP for upfront, and 6 months is inadequate for the supplier to cover both operational and fixed cost if the price is pegged at market price.

However, mean WTP for high-capacity solar PV is statistically significant and higher than the market value across the four payment plans. For instance, the upfront payment plan, the WTP is higher than the market value by 0.9% as shown in Table 4.6 below. The introduction of the credit facility shows that households are willing to pay even higher price than the market value of the product. Like grid electricity service, household access to credit facility improves their ability to pay for high-capacity solar electricity. The mean WTP for 6 months payment plan is 18.82% higher than the market value while for 12 and 24 months is even higher by 25.64% and 39.12%, respectively.

Table 4.6: WTP Results for High-capacity SHS Electricity Connection

Variables	**Upfront**	**6months**	**12 months**	**24 months**
Mean WTP	*K4,692.31**** *(1720.41)* *($469.23)*[26]	*K5,525.25**** *(1275.8)* *($552.53)*	*K5841.67**** *(1471.3)* *($584.17)*	*K6469.23**** *(1441.4)* *($646.92)*
$\%(\frac{WTP-MP}{MP})$	0.9%	18.82%	25.64%	39.12%

MP is market price (K4650); *******, **, * indicate significance level of 1%, 5% and 10%***Source: Author's computations from World Bank/ESMAP (2018) dataset.

Therefore, the upfront mean WTP results for the two solar PV products shows that households prefer high-capacity solar PV to low-capacity solar PV despite low-capacity solar PV being

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[26] Exchange rate as of 2018 is $1/K10

cheaper.[27] This is because connecting to high-capacity solar PV enables households to engage in economic activities beyond lighting that improves their socio-economic welfare compared to limited use offered by low-capacity solar PV. In this regard, households are willing to pay the market value or above making it possible for suppliers to recover costs associated with supplying the product. Furthermore, the heterogeneity in households demand behavior across the two solar PV products is explained by the flexibility in use and the cost system (Bhadari and Jana, 2010; Grim *et al.,* 2016). For instance, the lower than market price mean WTP indicates limited use while higher than market price mean WTP should offer flexibility in use.

The access to credit arguments advanced by various studies is reaffirmed by the results for both grid and solar PV electricity connection. The introduction of credit facility allows households to spread payment across time because of irregular and low income and lack of economic activities within communities to raise enough resources to pay upfront (Greenstone and Jack 2015). In addition, accessing credit facility through conventional financial institutions in developing countries is difficult among households with no traceable income and employment (Banerjee *et al.* 2017). This entails that only upfront payment is allowed as model of payment to get a connection; however, low, and irregular income and lack of economic activities hinder those willing to get electricity services thereby contributing to low demand (Blimpo and Cosgrove-Davies, 2019).

Finally, the positive and above market value for upfront WTP for both grid and high-capacity solar indicate that households need electricity beyond lighting. They want to adopt electricity services that help drive improvement in their livelihood through engagement in economic activities. It further indicates that the two categories are driven by cash terms so that private investment or providers especially for off-grid solutions can recover their investment. However, the introduction of credit facility is important in deriving demand for electricity services among non-connected households. This enables consumers smooth their consumption of the basic needs during the payment period due to low and irregular income. Paying upfront for any of the electrification technology may have destabilization effect on their consumption causing them to fail to manage despite the positive desire to allocate financial resources to getting a connection.

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[27] The t-test is conducted to rule out the possibility of differences in households' characteristics and results are shown in the appendix (table C3.8)

4.4.3 Mean WTP for Electricity Across Non-Connected Household in Rural Areas

The study further estimated the rural areas mean WTP for the three sources of electricity that include grid electricity, low-capacity solar home system and high-capacity solar home system. The objective is to observe the changes in the mean WTP in rural areas across the different payment periods and electricity sources[28]. This is because majority households (78%) in the sample are from rural areas and over 80% without electricity are found in rural areas. Tables C3.2, C3.3, and C3.4 in appendix C presents results for mean WTP for grid electricity, low-capacity SHS electricity and high-capacity SHS electricity respectively. The mean WTP for grid electricity in rural areas is statistically significant across all the payment periods and is higher than country level for all the four-payment period. Furthermore, the mean WTP observed in rural areas is above the market price and as the payment period is extend households' WTP for grid electricity increases further. The lack of access electricity to grid electricity in rural areas among households contribute to majority wanting to connect given the opportunity.

However, for solar electricity, the results observed show that the mean WTP for both low capacity and high-capacity SHS are all below the market value across the payment plans except for 24 months under the low capacity SHS. For instance, Table C3.3 in appendix C, indicate the estimated mean WTP for upfront payment is statistically insignificant for low capacity SHS electricity while the access to credit is only statistically significant at 12 and 24 months. The estimated mean WTP for 12months payment plan is below the market value by 21% while for 24months the estimated mean WTP is above the market value by 77%. This indicate that households in rural areas are only willing to pay above the market price if the payment period is extended to 24 months. This is similar trend observed at country level above. Further, the mean WTP for high-capacity SHS electricity is statistically significant across all the payment plans despite all payment periods being below the market value of K4650 ($465). The households in rural areas are not willing to pay the market value for high- capacity SHS electricity contrary to observed mean WTP at country level. Despite increased payment period and all the payment periods being statistically significant,

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[28] The study failed to estimate the mean WTP for urban areas households due to data challenges.

households in rural areas are only willing to pay 32%, 6%, 10% and 6% less than the market value for upfront payment, 6months, 12months and 24months respectively.

4.4.3. Determinants of Household's Electricity Adoption among Non-Connected[29]

The estimation process of mean WTP requires to control for households' characteristics (Seck, 2016). Several studies (Abdullah and Jeanty, 2011; Lee *et al.*, 2016; Banerjee *et al.*, 2017; Entele, 2021) include control variables in the estimation process of the mean WTP. Table 4.7 below shows the determinants for grid connection, low-capacity solar PV and high-capacity solar PV among non-connected households. The results in Table 4.7 show that distance to the grid, household income, education of the household head and employment status of the household head are important factors positively contributing to getting a grid connection and high-capacity solar PV among households. For instance, household economic status represented by income and employment status is positive and statistically significant for grid electricity connection and high-capacity solar PV.

Blimpo and Cosgrove- Davies (2019) argue that electricity affordability in Sub-Saharan Africa is negatively affected by low and unpredictable income and lack of stable employment to sustain use of electricity services. This entails improvement in the economic status drives households to get electricity connection and sustain consumption of electricity services by acquiring various electrical appliances. Further, distance to the grid electricity from the location of the household dwelling measured in kilometers is key in connecting grid electricity and high-capacity solar PV. The longer the distance from the grid electricity, the higher the probability of a household getting connected to grid electricity and high-capacity solar PV *ceteris paribus*. Households close to the grid electricity tend to indirectly benefit from the presence of electricity in their locality. They utilize electricity services that include street lighting, appliances such as fridges and charging phones from connected households especially in densely populated areas. The indirect benefits tend to reduce the urge to get a connection compared to individuals far away from the grid with no direct or indirect benefits.

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[29] The study estimated the WTP determinants when credit facility is introduced to observe whether there are changes in factors affecting WTP. Table C3.5, C3.6, and C3.7 in appendix C show the results for the three technology under considerations. For readers reference check these tables.

Table 4.7: Determinants of Household's Electricity Adoption

Variables	Grid Electricity	Low-capacity Solar PV	High-capacity Solar PV
Bids (Price)	-0.000294***	-0.00092***	-0.000078***
	(0.00007)	(0.00017)	(0.000016)
Household income	0.000023***	0.000089**	0.00013***
	(2.43e-06)	(0.000045)	(0.000018)
Distance to the grid	0.0063***	-0.006	0.0056***
	(0.0015)	(0.004)	(0.0018)
No. of phones	0.268***	0.241**	0.111***
	(0.041)	(0.077)	(0.036)
Asset ownership (yes)	-0.126	-0.195	-0.013
	(0.079)	(0.155)	(0.087)
Household head gender (male)	-0.174**	0.186	0.235**
	(0.082)	(0.176)	(0.098)
Household head years of schooling	0.042***	-0.009	0.014**
	(0.008)	(0.016)	(0.009)
House roof (iron sheets)	0.478***	0.378**	0.280***
	(0.076)	(0.154)	(0.008)
Access to finance			
2. mobile money	-0.274*	-0.188	-0.077
	(0.143)	(0.297)	(0.152)
3. bank account	-0.550***	0.023	0.334
	(0.129)	(0.243)	(0.105)
Household location			
2. urban low cost	-0.129		
	(0.990)		
3.urban medium cost	0.846***		
	(0.136)		
4. urban high cost	0.719		
	(0.469)		
Household location (rural)		0.457**	0.035
		(0.213)	(0.105)
Household employment status (employed)	0.176***	0.125	0.205***
	(0.077)	(0.173)	(0.084)
Constant	0.712***	0.629**	0.366***
	(0.109)	(0.294)	0.035

Note: ***, **, * indicate significance level of 1%, 5% and 10%.; Source: Author's computations from World Bank/ESMAP (2018) dataset

Furthermore, social factors such as gender and education of the household head are important in improving access to electricity. The results in Table 4.7 show that gender and education attainment of the household head are statistically significant and contribute to the mean WTP for grid and high-capacity solar PV. However, being male household head compared to female reduces the probability of willingness to pay for grid electricity. This reveals women preference for grid electricity because of the capacity which enables them to adopt it for cooking. For high-capacity solar PV, having a male household head increases the probability of willing to pay compared to female headed households. Further, several studies (Blimpo and Cosgrove- Davies, 2019; Gunathilake 2012; Abdullah and Jeanty, 2009) have stressed the importance of education attainment to accessing electricity services. An additional year spent in school increases the probability of paying for grid and high-capacity solar PV connections. In developing countries, being educated brings economic opportunities such as employment and business activities which lead to improved livelihood. Thus, an educated household head would like to derive benefits from using electricity by acquiring electric appliances such as TVs, computers, and phones.

In addition, the quality of the household dwelling represented by the quality of the roof is an important determinant of the willingness to pay for electricity connection in the three categories. Houses with iron sheet roofs are likely to get an electricity connection compared to other roofing *ceteris paribus*. Further, the location of the dwelling of the household is key in determining the WTP for grid and low- capacity solar PV. Households residing in medium cost locations have higher probability to pay for grid electricity connection compared to those in rural areas. For low-capacity solar PV, the probability to pay for a connection increase among those in rural areas compared to urban areas *ceteris paribus*. The results reveal the differences in quality of livelihood and preferences for electricity technology between those in urban and rural areas.

Finally, the number of mobile phones owned by household members determines whether the household is willing to pay for electricity connection in all three categories. In rural areas, households with phones but lack electricity services at home, pay for charging services (Luzi *et al.*, 2019). The cost of charging a phone for the purpose of communication and financial transaction (mobile money services) leads to households willing to pay for electricity connection. Therefore, the increase in the number of mobile phones at home, the higher the likelihood of paying for either, grid or solar PV electricity *ceteris paribus*.

4.5. Conclusion and Policy Implications

The study sought to analyze household WTP and its determinants for electricity connection among non-connected households in Zambia. The study further analyzes the changes in WTP after introducing credit facility for electricity connection. Two electrification technologies (grid and off-grid electricity) are considered in the estimation process. The study opts for contingent valuation approach to estimate the mean WTP with single bounded dichotomous (SBD) choice based on data availability. The study reveals that non-connected households have statistically significant positive and higher than market price mean WTP to connect for grid electricity services. The introduction of the credit facility further shows that the differential value between mean WTP and market price of connecting to grid electricity increases as the payment period increases from 3 months to 12 months. Further, the estimated mean WTP for high-capacity solar PV indicate that households can pay for electricity connection upfront and the willingness to pay improves when they access the credit facility with longer payment period. However, the estimated mean WTP for low-capacity solar PV is below the market value and only improves after 12 months payment period. Furthermore, the estimated mean WTP for rural areas for grid electricity above the market value and country level across all the payment periods while for solar PV electricity, the meant WTP is below the market price. For instance, the mean WTP for high- capacity is below the market price across the payment periods while the low-capacity solar PV is only above the market price at 24 months. This show that rural households are not willing to pay beyond the market price for solar PV electricity.

The study underscores household's willingness to pay for electricity technology that offer beyond lighting. In this scenario, the study observes that grid electricity and high-capacity solar PV could improve household livelihood beyond lighting by engaging in economic activities. The study further observes that despite increasing the payment period, not every household is willing to pay for a connection from any electricity technology especially in rural areas. The failure is attributed to household economic status, such as low income, unemployment, and tariff costs as some of the reasons for opting not to connect despite increasing the period of payment. Furthermore, the results suggest that social factors that include quality of the house and education attainment are key determinants of the mean WTP for electricity connection across technology.

The study therefore contributes to policy discussion on how to increase electricity connectivity among non-connected across electrification technology in Zambia while paying attention towards improving their socioeconomic status. The positive WTP observed across all the technology used in the study is an indicator of the desire to connect among non-connected individuals. However, special attention should be paid to the quality, capacity and affordability of the electricity services provided to households as low-capacity electricity source is deemed less beneficial to households seeking electricity service beyond lighting. In addition, the positive demand observed on off-grid solutions (SHS electricity) despite the capacity is key in promoting and rolling out affordable and reliable electricity source beyond grid extension to connect uncovered households in Zambia. However, households especially rural areas need incentives such as subsidies or be part of social protection services among low-income households. This follows the study observation that solar PV electricity as has potential if well enhanced to increase electricity access rate in Zambia as non-connected individuals are willing to pay upfront for high-capacity and low-capacity PV solar electricity services at national level and across rural areas.

Further, provision of connection subsides and/or credit facility among low-income households can enhance their ability to connect to any source of electrification technology. Majority non-connected households (accounting for 78%) are from rural households whose income is irregular and mostly dependent on rain feed agriculture. In addition, lack of access to financial services due to poor economic status entails that subsides and/or credit cannot only help improve access to electricity but can smoothen their expenditure on other goods and services. Therefore, provision of incentives to low-income households that include price subsides, for instance, reducing or zero rating the connection fees for grid electricity and price cut for high-capacity solar PV would contribute to increase in electricity access among non-connected households. However, the emphasis should be on the need for government to provide incentives towards electricity services that contribute to economic wellbeing of the households through engaging in various economic activities as observed by their mean WTP for electricity services. This will help them sustain their use of electricity from these sources and attract private market participation in the electricity market.

Despite the study observation, several challenges or limitations were encountered. First the study failed to estimate mean WTP and the effect of credit access for urban households. This is attributed to small sample size across the different technology sources. Almost 80% of the households considered for estimation of the mean WTP are from the rural areas which reduces the urban sun-sample significantly. However, the study included rural-urban dummy to control for household location in estimation of the mean WTP across various technology. Further, the study would not clearly assert whether the focus group discussions and pilot study were undertaken before administering the questionnaire for willingness to pay study as per standard of the contingent valuation studies. Conducting the pilot study helps improve the quality questions and responses. Nevertheless, the survey instrument used in the collection highlighted the steps undertaken to ensure validity of the data collected as discussed in section 4.4.3 on Experiment design and CV scenarios. Finally, estimation of the WTP under the contingent valuation approach is based on hypothetical scenario. Thus, adoption of SBD as opposed to DBD approach to contingent evaluation is associated with overstating the WTP resulting in possible bias estimation of the WTP. Despite this observation, the study included enough household characteristics that could affect their response and undertook various measures highlighted in the study to reduce the bias in responses. The results add to the debate about the policy perspectives towards household demand for electricity connection given the benefits observed in first study. However, a future study can adopt DBD approach to observe the changes in the responses and estimate the WTP for household connection to various electricity technologies.

Chapter Five

Gender and Cooking Energy Choice, Expenditure, and its Welfare effects

Abstract

The study investigates gender effect of decision making on household choice and expenditure of cooking energy solution and how that impacts on users' welfare indicators across cooking energy solutions Tiers. In the first part, the study focuses on understanding the gendered effect of decision-making indicators on household choice and expenditure of cooking energy solutions. While the second part of the study estimates the impact of multitier cooking energy solution on gendered outcomes that include health and time allocation to various household activities. Using the same data from World Bank/ESMAP (2018) on household access to energy in Zambia, the study adopts probit method and Heckman-selection model as estimation strategies for the effect of gendered decision making on choice and expenditure, respectively. The Inverse Probability Regression Adjustment (IPWRA) with generalized propensity score is used in the estimation of the pairwise average treatment effect of household access to multitier cooking energy solution on welfare indicators. The results reveal that education, social networks and employment are key indicators of female adults' decision making that promote improved cooking fuel expenditure and choice of improved cookstove while similar indicators lead to reduced cooking fuel expenditure and adoption of *mbaula* cookstove. Further, the study shows heterogeneity on the effect among women and men welfare indictors and general improvement in multitier access to cooking energy solutions. The disaggregated gender results show that improvement in access to multitier cooking energy solutions affect health outcomes, time allocation to various activities and drudgery among women and men. Therefore, the study results underscore the need for government to highlight these substantial variations in the impact on gender and location of the household across CES Tiers in policy formulation and implementation in Zambia.

5.1.Introduction

5.1.1. Background to the Study

In the final study of the thesis, the attention shifts to understanding the effect of gendered access to household cooking energy solutions in Zambia. Although there has been improvement in household access to electricity as primary energy for lighting, access to clean cooking energy remains low in Zambia and Sub-Saharan Africa (SSA) at large. IEA (2022) statistics show that only 17% of individuals in SSA have access to clean cooking energy solutions (CES) while the rest rely entirely on traditional energy for cooking. This translates into 900 million individuals without clean energy in SSA with the possibility of increasing to 1.1 billion individuals by 2030. The marginal increase in clean CES remains slow and low at 0.48% annually of individuals accessing improved CES which is overtaken by population growth (IEA, 2022). In Zambia, over 83% rely entirely on traditional sources of CES with charcoal and firewood being the leading sources of cooking fuel while firestove/3stone and traditional *mbaula* are the main cookstoves (Luzi *et al*., 2019). The rural-urban disparities are high such that only 2% of individuals in rural areas have access to improved cooking solutions compared to over 30% in urban areas while the rest rely on traditional cooking energy solutions.

The low access rate has direct impact on human welfare especially on children and women who are directly exposed to indoor pollution (Foell *et al.,* 2011). Studies such as Morrissey (2017) and WHO (2016) have shown that continuous households' exposure to inefficient cooking solutions have negative implications on health leading to loss of lives due to respiratory illnesses. The exposure to indoor pollution is high among women, girls, and children due to daily participation in cooking. For instance, in Zambia women spend an average of 10.6 hours while men spend an average of 4.4 hours per week in the kitchen cooking food (Luzi *et al*.2019). Similarly, girls between the age 6-15 years spend twice more time (3.3 hours) on average than boys in the kitchen. The long exposure does not only affect their health but deprive them of leisure time (Jeuland *et al.,* 2020), income generation and productivity both at home and away (Alan and Chowdhury, 2010). It also constrains them from seeking better opportunities that include paid jobs and education attainment (Jagoe *et al.,* 2020). Further, the physical burden experienced by women in rural areas from walking long distance to collecting firewood affect their physical health overtime as they frequently collect firewood for cooking compared to men (Jenga *et al.*, 2021).

To mitigate the negative effect of women exposure to traditional CES, women empowerment is required to facilitate transition to improved cooking energy solutions (ICS). Studies such as Chandrasekaran *et al.* (2023); Pachauri and Rao (2013) and Keeber (2001) have stressed the importance of women empowerment in promoting household adoption of ICS and improving their welfare. The heterogeneity in preferences across gender towards choices and expenditure at household level require empowered women as they lack authority in decision making on the type of CES to adopt at household level (Dutta *et al.*, 2017). Hence, the need to investigate how gendered empowerment affects household expenditure and choice of CES.

Collective bargaining approach provided the framework for analysing household decision making where household members jointly determined how resources are distributed and accessed using either cooperative rules of sharing (Bourguignon *et al.*, 1993) or the bargaining process (Manser and Brown, 1980). Thus, understanding women empowerment and how it relates to household adoption of various CES, requires adopting collective bargaining approach as it provides a framework where different measures defined women empowerment. Studies including Pachauri and Rao (2013); Burney *et al.*, (2017) and Chandrasekaran *et al.*, (2023), detail women empowerment as multidimensional in nature as opposed to a singular index or indicator. However, several single indicators are proposed in literature that fall under economic, social, and cultural settings and have either direct or indirect effect on the expenditure and choice of cooking energy solutions. Singular indicators of empowerment provide platform for policy shift towards accessing improved cooking energy at household level (Burney *et al.*, 2017). Further, singular indicators such as education, paid employment help explain how decision making through empowerment affects expenditure and choice of improved cooking energy solutions. Additionally, tackling comprehensively the aspects of household access to improved CES starts by identifying gendered decision-making indicators toward choice and expenditure.

The study further examines the welfare effect of household transitioning to ICS through multitier framework. This follows household decisions to adopt a given CES and how the consequences of choices affect their welfare across gender and location. Studies such as Krishnapriya *et al.*, (2021; Brooks et al., (2016); and Bensch and Peters (2015) have shown that access to improved cooking solutions entail improved welfare among users. Despite this this observation, these studies focus on binary access measures (access to ICS or not). The binary framework is a traditional approach that fails to explain the extent of improvement among households in intermediate level of accessing CES. The studies fail to answer extent of improvement in intermediate levels. However, adopting the MTF measures, this study sought to examine the extent of the welfare improvement across gender and location as households transition from one Tier to the other. Hence, the study poses two important questions in section 5.1.2. to understand the extent of welfare improvement and decision making with regards to CES at household level.

5.1.2. Study Questions

i. What effect does gendered decision making have on choice and expenditure of CES at household level?
ii. How does access to improved cooking energy solutions affect gender outcomes?

5.1.3. Statement of Contribution

The study contributes to literature through comprehensively tackling gender aspects of cooking energy solutions by identifying key factors that affect decision making on choice and expenditure. The study identifies gendered decision-making indicators that contribute to possible differences in choices and expenditure regarding CES at household level. The differences in choice and expenditure have stimulated debate across literature of possible power struggle on who is best suited to make cooking energy decisions at household level. Thus, a gender disaggregated study like this one, identifies where power lies regarding decision making and which indicators can help close existing gender disparity in order to access improved CES at household level. Further, the strong gender bias in accessing CES observed in Zambia, requires formulating energy policies based on gendered decision-making indicators that positively influence women empowerment.

Additionally, transitioning to improved CES should always result in improved welfare among users. The question is to what extent is the improvement? Relying on MTF, this study contributes to literature debate about the extent of the welfare improvement across gender and location as household access multitier cooking energy solutions. Studies (Krishnapriya *et al.*, 2021; Brooks *et al.*, 2016; Bensch, and Peters, 2015) focus on binary access (access to ICS or not) to understanding the effect on the welfare indicators of the households. However, the traditional approach fails to explain the extent among households in intermediate level of accessing CES such as improved *mbaula* cookstove with charcoal which is more efficient and cleaner than open fire stoves.

Accordingly, this study provides an opportunity to estimate the differential impact across Tiers that assign a household to different levels of CES access beyond the binary framework.

5.1.4. Organization of the Study

The study is divided into five sections beginning with the introduction to the study. This is followed by the literature review which is presented into four subsections. The first subsection of the literature review involves theoretical perspectives of collective bargaining for household decision making. Thereafter, the study reviews empirical studies for both decision making and welfare indicators on household adoption of ICS and the final subsection presents the gap in literature. The third section presents the methodology of the study where estimation strategies and data description are discussed. The fourth section of the study presents the empirical findings and finally the conclusion and policy implication section are also presented.

5.2. Literature Review

The section is divided into theoretical perspective and empirical review. The theoretical perspective presents the collective bargaining framework for household decision making while the empirical review is divided into two subsections (indicators of decision making and welfare effects of adopting ICS).

5.2.1. Collective Bargaining Framework for Household Decision Making

The Becker theory of modelling household behaviour represented by the single utility is challenged by various scholars for not being a correct approach of representing household preference or utility (Bourguignon and Chiappori, 1992; Chiappori and Lewbel, 2015; Choudhuri and Desai, 2020). According to Agarwal (1997), the single utility approach treats a household under a unitary framework with the objective of seeking to maximise utility based on uniform preferences and the representative decision maker is rational with the interest of every member of the household. The weakness of this approach is the failure to acknowledge the diversity in preferences among household members that exist at household level. Despite this weakness, Becker's framework gives the foundation to understanding non-unitary approach[30] when analysing household utility behaviour and bargaining power (Becker, 1965; Becker, 1981; Chiappori and Lewbel, 2015). Under collective bargaining approach, every household member has his/her own utility function and consumption of commodities is taken as either being private or public. In such a scenario, a

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[30] Non- unitary framework is used as collective bargaining approach in this study.

household make Pareto efficiency decisions (Chiappori and Lewbel, 2015). The approach takes a household as unit that maximises weighted sum of individual utilities where Pareto weights may depend on various factors such as prices, wages, income, and other economic environmental conditions (Browning *et al*., 2014).

Therefore, adopting collective bargaining approach when analysing household decision making entails household members jointly determine how resources are distributed and accessed using either cooperative rules of sharing (Bourguignon *et al.,* 1993) or the bargaining process (Manser and Brown, 1980). For instance, Bourguignon and Chiappori (1992) argue that before marriage, individuals have individual consumption preferences, and their union does not entail adopting a single utility instead their household utility becomes an average of their collective bargaining preferences. This shows heterogeneity in preferences which is observed across gender, age and status of individuals occupying the house. The heterogeneity in preferences across household members entails having some level of power to decide what one needs. Duflo and Udry (2004) argue that if women for example have differentiated preferences and higher bargaining power compared to their partners in the household, they will possess greater influence on decisions and resources allocation. However, collective bargaining framework provides for inclusion of every individual's preference based on their status, age and needs in the household and sometimes targets individuals when implementing decisions for possible efficient outcomes (Alderman *et al*., 1995).

Therefore, trying to understand the effect of gendered intra-household decision making requires drawing theoretical background from studies that cite gender differences in preferences at household level as a source of collective bargaining power (Choudhuri and Desai, 2020; Chiappori and Lewbel, 2015; Becker, 1993*;* Becker, 1981). These studies assume that a member of the household's strength in the bargaining process is determined by the individuals' fall-back position[31] in the household. A possible improvement in the fall-back position leads to improved bargaining power for that individual that will influence the outcome of the bargaining process despite their gender (Agarwal, 1997). In addition, Sen (1981) argues that the persons' endowment representing what a person owns such as labour, assets, income - determine the household members' ability to successfully bargain for goods and services they need. However, critical

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[31] The fall-back position of an individual in the household is defined by McElroy (1990) as extra-household environmental parameters that include wealth, non-wage income, etc.

aspects of gender dynamics; role of social norms and social perception affect the quality of bargaining process despite the individuals' endowments (Agarwal, 1997). Kabeer (1999) on women empowerment noted that empowerment is being able to gain more options to determine your own life at household level despite gender dynamics such as social norms and perceptions.

Gender empowerment is critical in understanding collective approach to adoption of modern energy for cooking. Kabeer (1999) defines empowerment in three aspects that include having the rights, capacity, and assets to be able to make the right choices. However, Friedman (1992) argues that to empower individuals at household level so that they make right decisions and own development; empowerment should be observed into three categories that include social, political, and psychological empowerment. Social empowerment is contingent to access to resources; finance, means of production, information, and education while political empowerment involves being able to understand decision making process; whereas psychological empowerment concerns the development of an individual (Standal and Winther, 2016; Petrova and Simcock, 2019). When implementing policies, policy makers should direct resources differently considering the gender of the recipient despite their fall-back position or endowments in the household.

5.2.2. Empirical Review

5.2.2.1. Indicators of Household Decision Making to Access of Cooking Energy Solution

Literature shows that most home activities in developing countries are carried out by women such as cooking, collecting, and preparing firewood and charcoal compared to men (Luzi *et al.,* 2019; Chourmet *et al.,* 2017; Budlender, 2016). Women empowerment entails giving freedom or power to choose their preferred source of energy. Various indicators of empowerment (social, economic, and cultural) have been adopted to understand women's preference or decision making toward cooking energy solutions at household level.

Therefore, empirical studies have adopted a collective approach to women preferences as a basis of understanding household decision making regarding choices of cooking energy solutions (Pachauri and Rao, 2013; Standal and Winther, 2016; Chourmet *et al.,* 2017; Clancy *et al.*, 2007; Choudhuri and Desai, 2020; Kohlin *et al.*, 2011). A variety of indicators of empowerment affect who makes decisions regarding the cooking energy solutions. For instance, Gould and Urperlainen (2019) argued that if women are sole decision makers in the household there is high possibility of choosing LPG in India, although such indicators do not show heterogeneity in decision making and gender matters at household level (Choudhuri and Desai, 2020). That is why Choudhuri and Desai (2020) in their study used the multidimensional approach to gender empowerment by focusing on family authority; cultural; wife mobility and economic status; wife paid employment. Further, tribally social affiliation especially in rural areas (Ishan, 2000); wife asset accumulation before and within marriage (Beltrano *et al.*, 2014; Pachauri and Rao, 2013; Beegle et al., 2001); society social norms (Kebeer, 2001); social network among women (Bendiera and Rasul, 2016) have been used to understand the effect of women participation in decision making on resource allocation and choice of cooking energy solutions.

In Tanzania, Chourmet *et al*., (2017) estimated differentiated gender effect by focusing on women bargaining power in household energy decision making process and choices. The study relied on three wave data (2008-2013) and used pooled multinomial logit estimation approach to estimate measures of women bargaining power towards energy choices at household level. Indicators such as age differential, couple education, and women education were adopted despite results revealing that only education indicators are statistically significant variables indicating women bargaining power.

The study further argued that other welfare indicators such as economic (income, assets) indicators correlate with the type of cooking energy solutions and to some extents do not represent bargaining power in a household. However, Beeghe *et al* (2001) argue that the role of bargaining power is only successful if the women in the household own some economic assets or resources over their male counterparts. The economic assets that are acquired before marriage and during the marriage are important to improvement in the bargaining power among women as long as the assets can translate into improved income. Similarly, Bloom *et al*., (2001) in their study on women health observed that improvement in economic indicators contribute to women autonomy in decision making. The study focuses on women control over finances, decision making power and freedom of movement as indicators of bargaining power over their health.

Nevertheless, Pachauri and Rao (2013) in their literature review argued that social indicators such as sex of the children, societal relation such as caste, class, and family background can influence women bargaining power in the household thereby affecting choice of cooking energy solutions. The study observed that women’s status should not only be restricted to education and socio-economic levels but should be extended to include societal factors. This is because the low participation of women in economic activities especially in rural areas may affect household decision making process (Nikiema *et al.,* 2008). Studies such as Kebede *et al.,* (2014), Doss (2013) and Malapit and Quisumbing (2014) have observed that strong patriarchal and cultural tendencies in developing countries affect women independency and bargaining power negatively (Deaton, 1990). This is because strong cultural practices have possibility of converging women preferences to their husbands' overtime thereby affecting their independent authority to make choices regarding cooking energy solutions (Miller and Mobarack, 2013). Similarly, Nikiema *at al.,* (2008) argued that restrictive social-cultural setting such as social norms are likely to shape resources negotiations for women seeking better services.

Further, Wangsonne (2016) revealed that women intrahousehold bargaining power measured using a latent trait model simultaneously interact with clean fuel uptake in Senegal. The study observed that while an increase in women intrahousehold bargaining power leads to an increase in clean fuel adoption, households using clean fuel are the ones with women having high levels of bargaining power. Similar observation was made by Mohapatra and Simon (2017) in India after using cross national survey and probit-ordered model approach to estimate the effect of women intrahousehold bargaining power of household uptake of clean energy. The study emphasised that women intrahousehold bargaining would improve uptake of cookstove such that a woman with low intrahousehold bargaining status ends up over relying on traditional energy sources and low uptake of clean fuel (Kishore *et al.,* 2012; Wangsonne, 2016). However, Miller and Mobarak (2013) argued that intrahousehold bargaining power among women is strong compared to men only when the product offered, for instance, health improving stoves are priced low or free. Otherwise, higher price negatively affects women's ability to decide on their own, thus, they always have to seek their husbands' consent.

Furthermore, studies show that social network affects gendered decision making towards adoption of improved cooking technology at household level. For instance, Miller and Mobarak (2013) emphasised that social network across women affects their decision making to adopt new and improved cookstoves in Bangladesh. The study undertook a randomised control trial (RCT) to observe the effect of social network on the decision to adopt improved cookstoves across community members. The study observed a negative effect of social networks on the purchase of improved cookstoves. The negative effect is attributed to information gathered through social networks about the benefits of the stove from users. However, Bonan *et al.,* (2021) observed that women are likely to buy improved cookstove given the information obtained from their peers. Similarly, the study adopted RCT approach in rural Mali where the objective was to observe the effect of social network on the women's decision to purchase cookstoves. The study, therefore, established that social network or peer effect contributed positively to the adoption improved cookstove in Mali.

Therefore, gendered decision-making to adopt and spend on ICS at household level may occur in a given setting within households. For instance, female headed households are likely to adopt ICS than male headed households (Rao and Reddy, 2007) while the number of male children influences women decision making or bargaining position in the household (Pachauri and Rao, 2013). Further, Wickremasinghe (2011) found that women employment activities outside their homes in Sri Lanka contribute positively to households transitioning to cleaner energy. Paid employment outside their homes, increases women's bargaining power or decision making toward acquiring ICS.

5.2.2.2.Effect of Improved Cooking Energy on Household Welfare: Empirical Review

The decision taken either to adopt ICS or not affects the quality of life of the users. Several studies have undertaken impact evaluations to ascertain the extent of either adopting ICS or not on various welfare indicators. For instance, negative consequences on quality of life of users is observed for relying on traditional stoves and fuels that include firewood and biomass (Bonnan *et al.,* 2017). Users of traditional energy mainly women, face smoke inhalation due to indoor air pollution resulting into over 4 million deaths annually (Martin *et al.,* 2011), indicating that health related outcome is key regarding the impact of adopting ICS (Yu, 2011; Beltramo and Levine, 2013). Further, studies such as Lewis *et al.,* (2017); Bensch and Peter (2015); Mastisungu and Pattanayk (2017) emphasise that not only health related outcomes are important when a household adopts ICS but time saving that include cooking and firewood collection especially in rural areas.

However, the effect of adopting ICS on household welfare indicators have mixed empirical results. For instance, studies such as Bensch and Peter (2015); and Masatsugu and Pattanayk (2017) found statistically significant reduction in the quantity of firewood used thereby reducing expenditure on traditional fuels for cooking among households transitioning to ICS. However, other studies found non-statistical reduction in both expenditure and amount of firewood used among household transition (Andadari *et al*., 2014; Bruwen and Levin, 2012). For non-statistically significant results, Bruwen and Levin (2012) observed that despite reduced use of firewood among households using ICS in Ghana compared to traditional cookstove after conducting a randomised control trail, the differential impact was not statistically significant. Nevertheless, studies that observe statistically significant reduction in expenditure and quantity on traditional energy differ in their perspectives. Lewis *et al.,* (2017) focused on establishing the differential effect between use of biogas, LPG, and electric stoves with traditional firestove in India found that there was a 91% reduction in household use of firewood whereas Adrianzen (2013) observed a 46% reduction in the daily use of firewood in the northern Peruvian Andes. Further, Hnyine *et al*., (2015) observed a significant reduction in the costs associated with household cooking energy after adoption of ICS in rural Indonesia while Jain (2014) found that adoption of ICS (biogas) was associated with significant reduction in the use of firewood leading to fuel saving in India.

As earlier alluded, the use of traditional fuel for cooking is linked to poor health among users. Several studies have empirically attempted to estimate the impact of household transition to ICS on their health as a welfare indicator. This follows increased annual deaths estimated at 4 million attributed to indoor pollution (Martin *et al.,* 2011). Therefore, transitioning to ICS from traditional energy use is associated with possible reduction in the use of firewood, kerosine, and charcoal leading to reduction in the possibility of respiratory illness among users (Smith *et al*., 2011; Bensch and Peters, 2015; Lewis *et al.,* 2017). Smith *et al*., (2013) argue that women and children are adversely affected by indoor pollution leading to respiratory illness, pneumonia, and eye related health problems.

Nevertheless, empirical results regarding the impact of ICS adoption on users' health remain unclear. Studies such as Smith *et al.,* (2011); Bensch and Peters (2015); Lewis *et al.,* (2017) have found statistically significant reduction in household illness due to exposure to indoor pollution. Lewis *et al.,* (2017) observed that ICS that include LPG, electric and biogas contribute to reducing indoor air pollution and incidence of acute respiratory system in India. The study found a 72% reduction in particle matter while PAH levels reduced by 78% and significant reduction in soluble organic carbon and nitrogen in water at household level. The improvement in the air quality due to observed reduction in indoor pollution at household level resulted in significant reduction in members visit to the hospital for acute respiratory infections and blood pressure. Further significant reduction in respiratory illness and eye problems based on self-reporting have been observed after households adopt ICS (Bensch and Peters, 2015; Yu, 2011) while other studies highlight the relationship that exists between ICS and illnesses due to indoor pollution exposure (Silwal and McKay, 2015; Mueller *et al.,* 2013).

Similarly, Smith *et al.,* (2011) observed a reduction in carbon monoxide exposure by 50-60% among households after adopting improved cookstoves in Guatemala. The study used RCT with 534 households where a household with a pregnant and/or baby was assigned to treatment while those without pregnant and/or baby were assigned to a control group. They concluded that there is a possibility of a statistically significant reduction in the risk of a household member developing a disease such as pneumonia after adopting an improved cookstove though no significant reduction in respiratory problems was observed by the physician (Bonan *et al.,* 2017). Bensch and Peters (2015) pointed out that behavioural change by household after adopting ICS contributes to reduced firewood consumption leading to reduced smoke exposure and disease symptoms.

However, studies such as Beltrano and Levine (2013); Hannah *et al.,* (2016) observed no statistically significant effects on respiratory illness and other diseases due to exposure to indoor pollution. For instance, Hannah *et al* (2016) found no evidence of changes in health outcomes due to exposure to ICS at household level in India. Similar to Bensch and Peter's (2015) assertion, the study argues that the lack of evidence is attributed to the behaviour of humans who tend to undermine the potential outcomes of being exposed to ICS as they use less due to cost and inappropriate use of the ICS. Duflo *et al.* (2008) further added that the lack of information on health prevention tends to impact on the behaviour of users leading to no effect on health outcome when households adopt ICS. In short, studies do not consider the behavioural responses of households to ICS that may contribute to it being ineffective in reducing smoke inhalation among users (Bonan *et al.,* 2016).

Time saving due to household adoption of ICS is one of the key welfare indicators among users of traditional energy. The impact of ICS on time allocation varies across studies as their focus differ. Studies (Krishnapriya *et al.,* 2021; Jeuland *et al*., 2020; Banes and Samad, 2018; Brooks *et al.,* 2016; Bensch and Peters, 2015) have focused on understanding the impact of ICS on time spent on collecting fuel, fuel consumption and cooking. These studies have mixed results on the extent of the impact of ICS on time allocation or saving by household members as some studies consider the gender perspective. For instance, Krishnapriya *et al.*, (2021) found that time saved accrues to both women and men once a household adopts ICS in the six countries (Zambia, Myanmar, Ethiopia, Rwanda, Cambodia, and Nepal). The study used multivariate regression analysis with MTF data. The study further revealed that ICS adoption at household level can help save time, but this varies across location, technologies, and study methodology. This is because the pooled econometric estimate suggests that ICS use leads to 34 minutes saved per day by households. Similarly, Bensch and Peters (2015); Brooks *et al* (2016) found significant reduction in time spent by households on fuel collection, consumption, and cooking. However, not all studies have found significant reduction in time spent on fuel collection, consumption, and cooking by household members due to adoption of ICS. Studies found statistically insignificant effect on time saving due to household adopting ICS (Hannah *et al.,* 2016; Burwen and Levine, 2012).

5.2.3. Gap in Literature

Literature has empirically pointed out how various gender indicators of decision making and/or women empowerment affect household adoption of ICS. These indicators mainly focus on promoting women's ability to independently decide and spend on cooking energy solutions. However, several studies neglect the role played by men within the households. Therefore, the study extends beyond identifying women decision making indicators to understanding how these indicators affect household expenditure and choice of ICS across gender spectrum, men inclusive.

Furthermore, literature clearly shows that household adoption of ICS is important to users' improvement of their welfare indicators. However, studies overlook the level of transitioning among households such that intermediate users of ICS are regarded as non-users of ICS or users. Relying on MTF data and assigning every household to a Tier based on their attributes of access to ICS, this study contributes to literature by comprehensively estimating the differentiated impact based on disaggregated gender and location.

5.3.Methodology

After reviewing the literature, the study methodology sections explain the empirical procedure of achieving the stated objectives. In the first objective the study examines how gendered decision-making affects choice and expenditure of CES at household level. Thus, the probit estimation procedure and Heckman-selection model are used to examine how gendered decision-making indicators affect choice and expenditure of CES. The former adopts choice of cookstove as dependant variable while the latter uses household expenditure on cooking fuel. The second objective involves assessing the heterogeneity effect when a household has access to improved cooking energy solution on gendered outcomes. Every household in the sample is assigned to a Tier based on access to CES attributes. The overall Tier assigned to a household is based on the lowest Tier across the attributes of their primary CES. Therefore, as one household transitions from lower to higher Tiers the question is to what extent does that affect socio-economic indicators across gender and location. In short, several estimation approaches are outlined in this section to achieve the stated objectives.

5.3.1. Gender Decision Making Indicators and ICS Choice

The study here takes a cookstove and cooking fuel as complementary goods such that the decision to adopt a given cooking fuel depend on how accessible the compatible cookstove is. For instance, majority of the households in rural areas opt for 3 stone stoves because firewood is easily available and affordable. Hence, the decision to adopt a given cooking fuel is jointly determined with the choice of a suitable cookstove such that the household only decides on the cookstove while the daily decision on which fuel to adopt becomes inconsequential. Thus, a probit estimation procedure[32]provides a suitable framework for modelling the effect of decision-making given the discrete outcome variable. The household decides whether to adopt a given cookstove or not given household and community characteristics.

And conceptualising a probit model involves application of the latent variable model. The latent variable model assumes that the underlying discrete outcome which is binary choice of the cookstove (y_i) has a continuous propensity y_i^* that flips the state of the households from non-adoption to adoption of the cookstove when a given critical level is attained. In this regard, we assume that:

$$y_i^* = X_i'\beta_i + \varepsilon_i \qquad 5.1$$

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[32] In this regard, adopting a bivariate probit model will not be appropriate as the two goods are perfect complements that will give same coefficients with a correlation of almost one.

$$y_i = \mathbf{1}\ (\boldsymbol{y_i^*} > \mathbf{0}) \qquad 5.2$$

where X_i is the vector of covariates that include gendered decision-making indicators and ε_i is a random variable with the cumulative density function and $\mathbf{1}\ (\boldsymbol{y_i^*} > \mathbf{0})$ is an indicator function such that the outcome variable given the latent variable is specified as:

$$y_i = \begin{cases} 1 & if\ y_i^* > 0 \\ 0 & if\ y_i^* \leq 0 \end{cases} \qquad 5.3$$

Given the definition of the outcome variable, it follows that

$$\Pr(y_i = 1|x_i) = \Pr(X_i\beta + \varepsilon_i > 0|x_i) = \Pr\ (-\varepsilon_i < X_i\beta) \qquad 5.4$$

If we assume that error term is normally distributed given the X-vector of covariates, then we have a probit model such that we estimate equation 5.5.

$$\Pr(y_i = 1|x_i) = \Pr(\varepsilon_i < X_i\beta) = F(X_i\beta) \qquad 5.5$$

where F is cumulative standard normal and $\varepsilon_i \sim N(0{,}1)$

Therefore, the study identifies three types of primary cookstoves[33] and their respective cooking fuel from the dataset as observed in Table D4.1 and D4.2 in Appendix D, respectively. From Table D4.1, we observe that majority households use *mbaula* (46.73%) followed by firestove/3stone (39.35%) while electric stove (13.96%) is the least used primarily stove. Similarly, tables D4.2 show that charcoal (46.43%) is the major source of fuel for cooking followed by firewood (39.61%) while electricity (13.96%) is the least used (World Bank/ESMAP, 2018). A *mbaula* stove relies on charcoal as cooking fuel and accounts for the largest source of CES among households. However, there are few households who adopt 3stone stove but use charcoal as cooking fuel especially those that produce charcoal for sale. Focusing on how choice of a cookstove is affected by gendered decision-making indicators, the study estimates three independent probit models involving electric cookstove referred to as clean cook stoves defined in equation 5.6 below, *mbaula* stove taken as transitional or intermediate cookstove and the 3stone/firestove.

$$y_i = \begin{cases} 1 & improved\ cookstoves \\ 0 & otherwise \end{cases} \qquad 5.6$$

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[33] Figure D4.1, D4.2, D4.3 and D4.4 in Appendix D show the pictures of the primary cookstove considered in this study.

Mbaula stove is taken as transitional stove due to its low pollution emissions with improved efficiency compared to 3stones/firestove despite both relying on wood as source of fuel. It is commonly adopted by middle income households and those dwelling in urban areas. Although there is improved *mbaula* stove that emits low pollution with higher efficiency level compared to traditional *mbaula,* both rely on charcoal and that is why in this study they are in the same category. In this dataset we observed the non-use of LPG cookstove among households. The challenge of supply constraints has resulted in majority households in urban areas adopting charcoal as intermediate source of energy in the transition process.

5.3.2. Gender Decision Making Indicators and Household Expenditure on ICS

Apart from availability of CES, households are concerned about affordability issues when deciding to adopt a particular CES especially cooking fuel on either daily or monthly basis. How much they spend monthly or daily on cooking fuel has implication on what type of CES they adopt given their economic status. The decision made collectively has implications on how much the household will spend on cooking energy fuel daily or monthly.

Considering expenditure on fuel entails excluding those households who do not participate in the market but use energy fuel for cooking during the reported period. The World Bank/ESMAP (2018) data shows that 58.13% did not reveal their monthly expenditure on cooking fuel. While majority did not report their expenditure, the average expenditure on fuel was K173.12 ($17.3[34]) with maximum expenditure being K5,000($500). However, majority households who did not report their monthly fuel expenditure reside in rural areas as energy market is nonexistence making it impossible to participate but rely on collected firewood and own produced charcoal. In urban areas, some households report use of electricity for cooking but do not pay directly for the electricity used. This includes households who rent accommodation such that their rentals include fees for electricity, or their employers (companies or institutions) pay on their behalf.

The non-reported expenditure results in missing (zero) expenditure on cooking energy. The possibility of the sample selection bias due to unobserved expenditure among non-reported households, despite using various sources of cooking energy. The objective is to understand the effect of decision-making regarding household expenditure on cooking energy. Thus, to avert the

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[34] The currency exchange rate in 2018 was $1=K10

possibility of sample selection bias the study estimates the two-part estimation model (Heckman selection model) as it helps correct for sample selection bias when estimating the effect of decision making on the household's expenditure on cooking energy (Heckman, 1979).

5.3.2.1.Heckman-Selection Estimation: ICS Expenditure and Decision Making

The study estimates Heckman Selection Model on households' expenditure on cooking energy solutions (fuel and cookstove). The approach is adopted to reduce selection bias problem among households not participating in the market. The study observes that households who do not participate in the energy market especially those in rural areas do not report their expenditure on cooking energy but make daily or monthly decisions on fuel and cookstove for cooking. The Heckman selection model captures the decision to participate (participation model) in the market and select those who decide to participate through the expenditure regression (quantity model) thereby minimising self-selection problem. Thus, equation 5.7 is the expenditure regression model with the objective of estimating the effect of gendered decision making on household expenditure on ICS.

$$y_j = x_j\beta + \varepsilon_{1j} \qquad 5.7$$

However, equation 5.7 is only observed for j if a household decides to participate in the market as given in equation 5.8.

$$w_j = z_j\alpha + \varepsilon_{2j} \qquad 5.8$$

where $w = \begin{cases} 1 & if\ y > 0 \\ 0 & otherwise \end{cases}$ such that participation w =1 if $x_j\beta + \varepsilon_{1j}$>0. The error terms are given by equation 5.9:

$$\varepsilon_{1j} \sim N(0,\delta)\ ,\ \ \varepsilon_{2j} \sim N(0,1)\ \text{ and } corr(\varepsilon_1, \varepsilon_2) = \rho \qquad 5.9$$

The correlation between the error terms is not equal to zero ($\rho \neq 0$) while both equations (expenditure and decision) are conditioned on X and Z vector of covariates, respectively. The correlation between ε_{1j} and ε_{2j} produces the sample selection bias and if we project ε_{1j} on ε_{2j}, then we have;

$$\varepsilon_1 = \rho\sigma\varepsilon_2 + \eta_i \qquad 5.10$$

The η_i variable is $N(0,\sigma^2(1-\rho^2)$ and ε_1 is independent of ε_2. Given this information, it means that:

$$E(y_i|X_i, w_j = 1) = X_i\beta + \rho\sigma\frac{\phi(z_j\alpha)}{\Phi(z_j\alpha)} \tag{5.11}$$

Heckman model argues that equation 5.11can be estimated in two stages. The first stage involves estimating the selection equation given by equation 5.11 using the probit estimation strategy. The estimated coefficients $\hat{\alpha}$ are used to form the inverse Mills ratio given by $\hat{\lambda} = \frac{\phi(z_j\hat{\alpha})}{\Phi(z_j\hat{\alpha})}$ and the estimated $\hat{\lambda}$ is added to the expenditure regression equation in the second stage given by equation 5.11. Equation 5.11 becomes:

$$y_j = x_j\beta + \gamma\hat{\lambda} + \eta_j \tag{5.12}$$

The error term η_j in 5.12 will have a zero mean. The model (equation 5.12) produces consistent and asymptotically efficient estimates for all the parameters given that some covariates used in the selection model are not incorporated in the participation model (Sartori, 2003). The model further considers households who are not spending in the participation equation thereby reducing selection bias in the expenditure equation (Woodridge, 2002). The inclusion of $\hat{\lambda}$ in the regression model justifies the presence of selection bias. Additionally, if the coefficient of $\hat{\lambda}$ given by γ is statistically significant, then there is a presence of selection bias, and the use of Heckman selection estimation model is justified in correcting it.

5.3.3. Household Access to Multi-Tier Cooking Energy Solutions

Some studies such as Krishnapriya *et al*., 2021; Barnes and Samad, (2018) have emphasised the benefits of accessing ICS at household level. Using different methodologies in different countries, these studies have estimated the benefits of accessing ICS and/or clean energy compared to those without. Improvement in gendered welfare indicators have been observed across individuals accessing ICS; time allocation to education outcome (Jeuland *et al.,* 2020), labour participation (Dinkelman, 2011) and time spend on civic participation (IEA, 2022).

However, adopting MTF to measuring access to cooking energy solutions (see Bhatia and Angelou, 2015) introduces different perspectives to understanding the effect of household access to ICS in developing countries. As alluded to earlier, MTF defines every household to a Tier through the six attributes[35] (cooking exposure, efficiency, convenience, safety, affordability, and availability of the fuel) (Luzi *et al.*, 2019). The assignment to the overall Tier is based on the lowest Tier received across the six attributes. There are basically six Tiers with 0 indicating access completely inefficient CES while Tier 5 being access to clean or modern cooking energy solutions that include electricity and LPG. In between 0 and 5 we have transition or improved sources of energy solution such as improved cookstove that use traditional fuels with less emissions (charcoal, kerosine). Moving from a lower to high Tier indicates improvement in the quality of cooking energy solution including exposure, type of cookstove, fuel and its availability at household level. Whether this movement translates into tangible benefits at household level and to what extent does that differ across gender and location among the users are the two matters of interest in this section?

5.3.3.1. Defining and Assigning Households to MTF Cooking Energy (Treatment)

The assignment of households to the overall Tier creates different levels of access and is taken as household treatment to CES. The Tiers are estimated based on the six attributes of CES where both the cookstove and fuel used are considered when assigning households to Tiers as access level. The attributes include exposure, efficiency, convenience, safety, availability, and affordability of the fuel as defined by Figure 1B in the appendices. However, Table 5.1 below present household allocation to individual tiers defined by figure 1B in the appendix. The frequencies are presented in Table 5.1 below across the 6 attributes and tiers of cooking energy solutions in Zambia.

Table 5.1: Household Assignment to Individual CES Attributes (Frequency -%)

Tiers	Exposure	Efficiency	Convenience	Availability	Safety	Affordability
0	17.80	43.62	0			
1	13.60	43.19	10.87			
2	50.31	0.32	20.69			
3	0.78	0	32.01	4.45	2.50	36.73
4	0	0	27.28	31.52		
5	17.51	12.88	9.17	64.02	97.50	63.27
Total (%)	**100**	**100**	**100**	**100**	**100**	**100**

Source: Authors' own estimation from World Bank/ESMAP (2018) dataset

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[35] For definition of attributes of MTF for cooking energy solution see Figure 1B in the appendix or see Bhatia and Angelou (2015)

From Table 5.1, we observe that majority (50.31%) of the households are in tier 2 for exposure with 0% in tier 4. However, majority fall in lower tier (0 and 1) for cooking efficiency with 0% in tier 3 and 4 while for cooking convenience the largest number of household falls in the middle tiers (2, 3 and 4) with 0% in tier 0. For fuel availability, the attribute is defined in three tiers (3,4 and 5). Majority of the households fall in tier 5(64%) meaning that the primary fuel is readily available aways throughout the year. The last two attributes on the table (safety and affordability) are defined by two tiers (3 and 5). Cooking safety is defined as either a household has experienced any serious injuries or not in the last 12 months while using the cooking stove or fuel. Table 5.1 show that 97.5% of the household have not recorded any serious injuries and fall in tier 5. Affordability attribute is defined as whether household spend either 5% of their income on fuel or not. Majority of the household (63.27%) could afford fuel as they spend less than 5% of their income on fuel and fall in tier 5.

After assigning each household to individual attributes, the nest step involves assignment to overall tier based on individual attributes. Table 5.2 below shows descriptive distribution of the household overall treatment across Tiers. The lowest tier across the six attributes is assigned to a household as the overall tier. Thus, we observe that households in the lower Tiers (0-1) show zero transitioning as they entirely depend on firewood with firestove/3stone cookstove. The intermediate Tiers (2-3) indicate transitioning levels where households adopt *mbaula* stove with charcoal which are safer with reduced pollution and higher efficiency compared to firestoves. The upper Tiers (4-5) indicate access to modern energy where LPG and electric cookstoves are adopted as primary cooking energy solutions by households. Further, we observe that about 87% are in Tier 0 to 2 while 13% are in Tiers 3-5. For rural areas 96% are assigned to Tier 0 to 2 while for urban areas, 79% are assigned to the same tiers. This indicates that more individuals in urban areas (21%) are in higher tiers compared to 4% in rural areas who access improved cooking energy solutions.

Table 5.2: Distribution of Household Treatment (Tiers) to Cooking Energy Solutions

Tiers	**Full sample**		Rural areas		Urban areas	
	Frequency	%	Frequency	%	Frequency	%
0	496	14.1	453	25.87	43	2.43
1	1542	43.83	1044	59.62	498	28.18
2	1033	29.36	183	10.57	848	47.99
3	275	7.82	46	2.63	229	12.96
4	76	2.16	7	0.40	69	3.90
5	96	2.73	16	0.91	80	4.53
Total	3518	100	1752	100	1767	100

Source: Author's computations from World Bank/ESMAP (2018) dataset

5.3.3.2.Estimation Strategy: Application of Regression Adjustment with Propensity Score

The objective of the study here is to estimate the effect of moving up the tiers of CES on the differentiated gender welfare indicators. The difference in household characteristics across tiers makes it impossible to impose a simple naïve regression when estimating effects across the tiers on gendered outcomes. The ordinary least square (OLS) regression despite controlling for differences in the household characteristics across the Tiers will still produce biased results due to possibility of self-selection bias within the Tiers. And to help minimise the potential self-selection problem across the tiers and ensure that we have efficient results, the estimation strategy follows two steps.

The first stage involves estimating generalized propensity score as proposed by Imbens (2000). The generalised propensity scores are obtained through weighting strategy. The weighting strategy as proposed by Hirano and Imbens (2003) helps predict scores[36] through constructing a counterfactual for each tier through weighting the probability of being treated to a given Tier conditioned on household characteristics. Hirano *et al.*, (2000) argue that if the generalised propensity scores are sufficiently estimated, a weighted based estimator can achieve a semiparametric efficiency band for the estimation of the average causal effect (Hirano and Imbens, 2001). The use of the weighting as opposed to matching procedure when estimating the propensity score is to accommodate treatment beyond binary treatment ($t > 2$). Just like matching procedure, weighting is also limited to observable differences across households when controlling for

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[36] Imbens (2000) proposed generalised propensity scores in case of multiple treatment or multivalued treatment.

selection bias (Krishnapriya *et al*., 2021). However, the procedure helps minimise the differences across the Tiers. Multinomial logit is applied in the estimation of the GPS as opposed to logit because $T > 2$. Furthermore, to ensure that the estimated GPS for each tier gives us the probability of a household being treated to that Tier conditioned on the characteristics, two key assumptions should be fulfilled that include the treatment being independent of the outcome variable given household characteristics and the overlap[37] assumption across the Tiers for the estimated GPS (Imbens, 2000).

To compute the casual effect, the second stage involves the use generalised propensity scores to construct weights that are used in the adjusted OLS regression of the outcome as proposed by Hirano and Imbens (2003). In this scenario, the first stage of GPS estimation is a pre-process that helps create sub-sample within the Tiers based on observational characteristics of the households (Krishnapriya et al., 2021), to help reduce potential selection bias across the Tiers. Therefore, to get the causal effect, OLS regression is estimated on weighted GPS of the entire sample. Equation 5.13 below shows the estimated OLS regression.

$$y_i = \alpha + \beta_i X_i + \theta_i T_i + \varepsilon_i \qquad 5.13$$

where y_i is the gendered outcome variables, X_i is vector of household characteristics, T_i is the treatment or household Tiers for cooking energy solutions at starting with 0 up to 5 and ε_i is the error term. Equation 5.13 is referred to as reweighted regression or regression adjustment is run on pre-processed sample using GPS as weights in the treatment (Hirano and Imbens, 2001). The coefficient θ_i gives pairwise average treatment effect on treated (ATT) or ATE across Tiers.

5.3.4. Data, Gender Decision Making and Household Welfare Indicators

5.3.4.1.Data Description

The study uses gender disaggregated data for the first objective which estimates the effect of decision-making indicators on choice and expenditure. Individual level data for adult household members (15 years and above) are considered in the estimation of the effect of decision-making indicators on choice and expenditure at household level. In the dataset there are about 17,000 individuals who form the 3,612 households with an average of 5 individuals per household. The study extracted 2,924 female and 2,924 male adults from the individual sample who belong to the

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[37] For overlap assumption, the study used the kernel density to plot the assumption and graphs are in the appendix 1.

same household to be part of the estimation of the effect of gendered decision-making indicators on household expenditure and choice cooking energy solutions. For the Heckman selection estimation, 1,766 households are participating in the energy market while 1,158 households are non-participants. The study extracted variables on type of cookstove, fuels and monthly energy expenditure while individual characteristics clustered at household level are also obtained from the data set.

However, the second part of the study utilises almost the entire dataset (3,518 households). The households are assigned to Tiers based on cooking energy solution attributes. The data is further disaggregated into rural-urban areas with 1,752 households assigned to rural areas while 1,767 households to urban areas. Further, two outcome variables; health and time allocation defined as time allocated to household activities; cooking and fuel collection and preparation and studying by adult members of the households. The outcome variables are disaggregated into gender and location among household members as discussed in section 5.3.4.2 and 5.3.4.3 below. In addition, several household characteristics are also obtained from the dataset.

5.3.4.2.Gender Decision Making Indicators

Literature has proposed various measures of decision making at household level by various individuals. To understand the effect of gendered decision making on household access to cooking energy solutions the study draws its theoretical framework from the non-unitary framework that uses collective approach were household members jointly determine how resources are distributed and accessed using bargaining process (Manser and Brown, 1980). From the dataset the study has identified strands of attributes of gendered decision-making with regards to cooking energy solutions at household level. These are regarded as direct and indirect decision-making indicators. Table 5.3 below shows descriptive statistics for the identified decision-making indicators.

Table 5.3. Indicators of Gendered Decision Making

Variables	Obs	Mean	Standard Deviation	Min	Max
Female Indicators					
Social Network (yes/no)	2924	0.85	0.35	0	1
Female Participation in Cooking (yes/no)	2924	0.88	0.32	0	1
Female Employment (yes/no)	2924	0.32	0.46	0	1
Female Economic Activity	2924	2.94	1.63	1	4
Years of Schooling	2924	6.7	4.25	0	19
Educated Female (Grade 12 and above) (yes/no)	2924	0.27	0.007	0	1
Male Indicators	2924				
Male Participation in Cooking (yes/no)	2924	0.22	0.41	0	1
Male Employment (yes/no)	2924	0.66	0.47	0	1
Male Economic Activity	2924	2.02	0.79	1	3
Years of Schooling	2924	8.06	4.07	0	20
Educated Male (Grade 12 and above) (yes/no)	2924	0.34	0.008	0	1
Male -Female Years of Schooling Ratio	2924	0.89	0.93	0	16

Source: Author’s computations from World Bank/ESMAP (2018) dataset

The study identified three sets of decision-making indicators that can affect household decision to adopt certain type of CES. These include economic indicators (employment status and economic activity); social factors (education and social networking among women); and direct participation in cooking at household level.

From the literature reviewed, studies such as Bloom *et al.,* (2001) and Beeghe *et al.*, (2001) emphasise the importance of economic status of the individual making the decision. The study opted for employment status and the economic activity of an individual. Employment status is binary, either the individual is employed or not. From Table 5.3, we observe that 32% of the adult female are employed while 66% of the adult male are employed. Employment in this scenario is defined as any legal activity performed by an individual that generates income. Further, economic activity is defined as disaggregated economic activities performed by an individual to earn an income. Thus, the variable is a categorical variable defined by employment categories of the individuals (salaried, non-wage/self-employment, not employed and housewife for female).

Furthermore, social status of the individual is key in influencing the decision to adopt ICS at household level (Kebede *et al.*, 2013). The study identified social network and education status of the individual as indicators of social status. Miller and Mobarak (2014) emphasised that social network across women affect their decision making to adopt new and improved cookstoves in Bangladesh due to peer effect or information sharing. Thus, social network is taken as a dummy variable indicating whether a woman belongs to any social group or not and 85% of the women belong to some social grouping. Choumert-Nkolo *et al.*, (2017) link education status of adult females to adoption of clean energy at household level. Education status variable is defined by several indicators; years of schooling, duration of educated individual (grade 12 and above) and male-female ratio of years of schooling. From Table 5.3, the average number of years female spend schooling is 6.7 (primary level) while men spend 8.06 years (junior secondary). Educated female shows whether an individual has attained grade 12 (completing secondary school) or not. Only 27% female adult on average have completed grade 12 or secondary school compared to 34% for male.

Finally, the study includes household member participation in cooking on a daily basis. Participation in cooking activities make the participant to be partly a producer and primary user of the cooking energy solutions adopted at household level. The adopted CES directly affect their welfare. Thus, the daily participation enables an individual to understand the quality of the CES adopted and given his/her household status (household head, husband, wife or employed child) may influence positively the adoption of ICS. Table 5.3 shows an average of 85% female while 22% male household members participate in cooking daily.

5.3.4.3.Household Welfare Indicators

Table 5.4 below presents selected household welfare indicators. As observed from the reviewed literature, access to ICS has mixed effects on various welfare indicators. One of the key welfare indicators cited in literature is health related outcome of the users. Studies such as Smith *et al.*, (2011); Beltramo and Levine (2013) and Bensch and Peters (2015) define health related outcomes by reported respiratory illness of the users of the cooking energy solutions. The study adopts the reported respiratory illness to represent health related outcome. The variable is defined as whether an adult household reported a respiratory illness in the last 14 days. Moving up the Tiers entails improvement in the quality of cooking energy solutions adopted at household level, and the expectation is reduced reported respiratory illness among adult members due to indoor pollution. Table 5.4 shows an average of 10% reported respiratory illness across households; for women, an average of 6.4% reported respiratory illness while an average of 3.6% of men reported respiratory illness during the same period.

Table 5.4: Household Welfare Indicators as Outcome Variables

Outcome Variables		**Full sample**		**Female (≥15years)**		**Male (≥15years)**	
		Mean	SD	Mean	SD	Mean	SD
Time spent on (min/day)	Fuel collection and preparation	21.6	(57.7)	15.9	(37.3)	10.8	(33.9)
	Cooking	81.0	(84.2)	75.0	(76.2)	25.6	(39.9)
	Income generation within home	32.9	(111.3)	21.6	(211.0)	19.4	(72.6)
	Studying	36.9	(81.1)	22.4	(52.0)	24.3	(50.9)
Health	Respiratory illness	0.10	(0.30)	0.064	(0.23)	0.036	(0.17)
	Observation		3518		2,924		2,924

Source: Author's computations from World Bank/ESMAP (2018) dataset

Further, the study identified time allocation to various household activities as a key welfare indicator among users of CES and that any improvement in the quality of CES has implication on time allocation to various household activities. Studies such as Krishnapriya *et al.,* (2021); Jeuland *et al.,* (2020); Banes and Samad (2018); Brooks *et al.,* (2016); Bensch and Peters (2015) have all estimated the impact of access to ICS on time spent on various activities such as collecting fuel, fuel consumption, and cooking.

Four welfare indicators are selected for time allocation that include time allocation to fuel preparation and collection, cooking, income generation and studying by adult household members. From Table 5.4 an adult household member spends an average of 22 minutes collecting and preparing fuel for cooking while for gender disaggregated, women spend an average of 16 minutes while the men spend 11 minutes. For cooking, women spend 75 minutes daily while men only take 26 minutes. This shows how women are exposed longer than men to CES. Similarly, women spend more time engaging in income generation activities at household level of about 22 minutes compared to an average of 20 minutes for men. However, male adults spend more time on average studying (24.3 minutes per day) compared to females (22.4 minutes per day).

5.4. Empirical Results and Discussion

This section presents empirical estimations and discussion of the results. The section begins with descriptive statistics for household characteristics used in the estimation process as control variables. Thereafter, the section presents probit and Heckman-selection estimations for the effect of gendered decision-making indicators on cooking energy solution choice and expenditure respectively. In the latter part, the section presents the empirical results for regression adjustment estimation that shows the impact of accessing MTF cooking energy solution on household welfare indicators.

5.4.1. Household Characteristics for Cooking Energy Solutions

Table 5.5 presents the descriptive statistics for household characteristics and cooking energy practices used as control variables for choice, expenditure, and impact estimations. They include social, economic, and household head characteristics. From Table 5.5 below, the number of rooms represents the quality of the household dwelling. The average number of rooms is 2.7 with a minimum of 1 and maximum of 15 rooms excluding the toilets and kitchen if they are found inside the house. Further, dwelling ownership is defined as a dummy (1- yes and 0- no) and majority (70%) of the households own their dwelling.

Other notable household characteristics are the economic variables that include household income, expenditure, access to financial services and price of candle at district level. The average monthly income is K2,356 (US$ 235.6) while the monthly expenditure is K1,624 (US$162.4) which is below the average monthly income. Furthermore, access to financial services enable households to plan expenditure and utilize financial institutions for savings and borrowing to acquire improved cooking solutions. Access to financial services is taken as a categorical variable (1 – no access, 2- access to mobile money banking and 3- bank account ownership). From Table 5.5, on average a household owns a mobile money account as it is evident that every household on average owns at least a mobile phone.

Table 5.5. Household Characteristics and Cooking Energy Practices

Variables	Mean	Standard deviation	Min	Max
Household characteristics				
Number of rooms	2.7	1.4	1	15
Household head age	41.1	14.6	16	95
Access to finance service	1.6	0.9	1	3
Household size	4.9	2.2	1	20
Monthly household expenditure	1624.99	3219.03	0	73736.
Area price of candle	2.43	0.56	0.25	10
Number of mobile phones	1.2	1.5	0	9
Location (urban)	0.5	0.5	0	1
Dwelling ownership (yes/no)	0.7	0.5	0	1
Agric land ownership (yes/no)	0.4	0.5	0	1
Monthly household income	2356.63	2251.15	850	15000
Household cooking practices				
Fuel availability	1.4	0.6	1	4
Cooking place	0.56	0.4	0	1
Time to prepare cookstove	6.27	4.31	0	15

Source: Author's computations from World Bank/ESMAP (2018) dataset

Furthermore, factors such as household size and location are important in explaining adoption of clean energy for cooking at household level. For instance, household size shows that there are basically 5 individuals at every household on average and those residing in rural areas equals those in urban areas in this dataset.

Finally, cooking practices are included as control variables in the estimation process. Three variables (fuel availability, cooking place and time taken to prepare cookstove) are included as control variables. Fuel availability is a categorical variable defined by levels of availability of the fuel starting with available to rarely available while cooking place is whether a household cooks indoors or not showing that on average majority households (56%) cook from indoors. The average time households spent preparing cookstove was 6.27 minutes every time they were cooking a meal regardless of the CES.

5.4.2. Empirical Results: Gendered Decision-Making on Choice and Expenditure

The first objective of the study focuses on understanding how gender disaggregated decision-making indictors affect choice and expenditure of cooking energy at household level. The assumption that differences in preference toward cooking energy solutions exist across gender require collective bargaining given available choices. Therefore, for the first empirical results, the study estimates the probit model where the marginal effects are reported in Table 5.6 while in the second empirical estimation the Heckman-selection model is reported in Table 5.7. In both estimations the study focused on the gendered decision-making indicators while controlling for individual, household and community characteristics that affect expenditure and choice of cooking energy solutions.

5.4.2.1.Gendered Decision-Making Indicators and Improved Cookstove Choice (Probit Estimation Strategy)

Table 5.6 present the probit estimation[38] results with respect to the household choice of the three key types of cookstove (improved cookstove; traditional cookstove; and 3 stone stove/ fire stove). Interpretation and discussion of the results focus on gender disaggregated decision-making indicators.

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[38] The study also estimated the bivariate probit model for robustness check using the same data and gender indicator variables. The bivariate probit model included both the cookstove and fuel. The results in Table D4.3 in Appendix 4 are similar to the probit model estimation in table 5.6 for gendered decision-making indicators which validates the results obtain under the probit model.

Table 5.6: Marginal Effect of Gendered Decision-Making on the Choice of the Cook Stove

Variables	Electric Stove (=1)		*Mbaula* Stove (=1)		3 stone/fire stove (=1)	
Household characteristics						
Household number of rooms	0.006**	(0.003)	0.019**	(0.007)	-0.001	(0.046)
Household head age	0.0001	(0.002)	0.013**	(0.004)	-0.011***	(0.026)
Household head age squared	8.08e-7	(0.00003)	-0.0001**	(0.00005)	0.0001***	(0.0003)
Access to finance service						
2. Mobile account	-0.019	(0.018)	0.114**	(0.039)	-0.052	(0.211)
3. Bank account	0.055***	(0.015)	0.026	(0.027)	-0.127***	(0.168)
Household size	-0.009***	(0.002)	-0.004	(0.005)	0.009**	(0.030)
Monthly household expenditure	3.70e-6**	(1.89e-6)	-5.98e-06	(6.36e-6)	-2.1e-05**	(0.00088)
Area price of candle	0.018*	(0.011)	-0.058**	(0.025)	0.016	(0.135)
Number of mobile phones	-0.001	(0.003)	0.034***	(0.08)	-0.022**	(0.052)
Location (urban)	0.068***	(0.016)	0.320***	(0.032)	-0.333***	(0.131)
Dwelling ownership (yes)	-0.004	(0.011)	-0.155***	(0.025)	0.146***	(0.143)
Agric land ownership (yes)	0.013	(0.012)	-0.024	(0.025)	0.036*	(0.119)
Cooking fuel available						
2.mostly available	0.032**	(0.011)	-0.023	(0.022)	0.0005	(0.141)
3.sometime available	-0.050***	(0.014)	0.170**	(0.061)	-0.056	(0.433)
4.rarely available	-	-	0.234	(0.169)	-0.071	(0.981)
Cooking place						
1. Outdoors/outside	-0.257***	(0.014)	0.318***	(0.019)	0.043**	(0.112)
Duration preparing cookstove and fuel	-0.009***	(0.001)	0.015***	(0.002)	0.003**	(0.013)
Female decision-making indictors						
Women social network (yes)	0.025*	(0.013)	-0.033*	(0.019)	-0.025	(0.023)
Female cooking daily (yes)	-0.008	(0.014)	0.014	(0.034)	0.034	(0.029)
Female employment (yes)	0.367***	(0.093)	-0.497***	(0.008)	-0.542***	(0.009)
Female economic activity						
2. Housewife	0.023	(0.019)	0.010	(0.021)	0.001	(0.019)
3. Self employed	0.168***	(0.027)	-0.504***	(0.018)	-0.446***	(0.016)
4. Salaried employed	0.185***	(0.023)	-0.523***	(0.019)	-0.438***	(0.017)
Female years of schooling	0.007***	(0.002)	-0.002	(0.0.003)	-0.002	(0.002)
Educated female (yes)	-0.017	(0.013)	-0.070**	(0.035)	0.052	(0.036)
Male decision-making indicators						
Male cooking daily (yes)	-0.019	(0.014)	0.022	(0.044)	0.021	(0.034)

Male employment (yes)	-0.211***	(0.042)	0.467***	(0.038)	-0.394***	(0.031)
Male economic activity						
2. Self-employment	-0.273***	(0.080)	0.397**	(0.035)	-0.417***	(0.056)
3. Salary employee	-0.274***	(0.063)	0.444***	(0.032)	-0.473***	(0.055)
Male years of schooling	-0.001	(0.002)	0.012***	(0.003)	-0.008***	(0.002)
Educated male (yes)	0.016	(0.017)	-0.079**	(0.029)	0.016	(0.027)
No. Observation	2924		2924		2924	

Robust standard errors in parenthesis. ***, **, * *represent 1%, 5% and 10% statistical significance level respectively;* Source: Author's computations from World Bank/ESMAP (2018) dataset

Starting with female adults, the results in Table 5.6 reveal that women social network improves the probability of adopting electric stove (2.5 percentage points) and reduces the probability (3.3 percentage points) of adopting *Mbaula* stove holding other factors constant. Women's social network defined as whether an adult female belongs to a social grouping within the community or not is a positive indicator of women decision making. Similar results are obtained by Bonan *et al.*, (2021) who argue that adult women interaction at community level contribute positively to flow of information that inform them about the benefits of adopting improved cookstove for cooking. The interaction, either formal or informal, increases the confidence built towards certain products adopted or introduced in the community for cooking (Miller and Mubarak, 2014).

The results in Table 5.6 suggest that in households if an adult female is employed, the probability of adopting electric cookstove increases by almost 37 percentage points while it reduces by almost 50 percentage points and 54 percentage point of adopting *Mbaula* and fire stove/3tone stove, respectively. The reduction in the probability increases as we move from *Mbaula* stove to 3stone/firestove. This indicates that women oppose adoption of *Mbaula* and firewood stoves once employed. Employment gives them a strong position to bargain for improved cooking solutions such as electric stove if available.

Further, the study disaggregated employment status/economic activity of the adult female. The results suggest that having a self-employed adult female at household level increases the probability of adopting electric cookstove (16.8 percentage points) but reduces for *Mbaula* stove (50.4 percentage points) compared to unemployed *ceteris paribus*. Similarly, the presence of an adult salaried female employee at household level increases the probability of adopting an electric cooking stove (18.5 percentage point) increases and reduces for *Mbaula* stove (52.3 percentage point) compared to unemployed adult female. However, having an adult female self-employed result in 44.6 percentage point reduction in the probability of a household adopting firestove/3stone cookstove while having a salaried employed female at household level will result in 43.8 percentage point reduction in the probability of adopting firestove/3stone stove as primary cookstove. Therefore, female empowerment improves their economic status through employment and income increases their bargaining power and leads to adoption of improved cook stove which comes with low emissions and efficiency.

Educational decision-making indicators are only statistically significant for electric cookstove and *Mbaula* stove. The results in Table 5.6 suggest that an additional year of schooling by an adult female household member will result in a 0.7 percentage point rise in the probability of adopting improved cooking stove. Choumert-Nkolo *et al* (2017) argue that an additional year of education may not contribute a large effect to adopting improved cookstove but achieving a certain level of education changes the perception of females toward adopting particular cookstoves. For instance, results suggest that having an educated female adult (someone who at least attained secondary school and above) at household level leads to a 7-percentage point reduction in the probability of adopting traditional stoves *ceteris paribus*.

Regarding male adults, the results in Table 5.6 show similarities with the female indicators affecting choice of CES. Basically, employment status of the adult male members of the household is important in deciding the choice of the cookstove. The results are statistically significant in all three categories of the stoves despite the differences in the coefficient signs. For instance, the presence of a male employed adult at household leads to 21.1 percentage point reduction in the probability of adopting electric stove at household level while increasing the influence of choosing *Mbaula* cookstove by 46.7 percentage point and a reduction of 39.4 percentage point for firestove/3stone stove *ceteris paribus.*

For disaggregated economic activities/employment status, the results suggest that the preference for *Mbaula* cookstove among self-employed or salaried employee male adults at household level is positive. However, the probability of adopting electric cookstove reduces for a self-employed adult male (27.3 percentage point) and a salaried employee (27.4 percentage point) at household level. Further, the results reveal that the preference for fire stove/3 stone stove reduces for household male adult members if they are either self-employed or salaried employees. Therefore, the direction of the preference for the three types of cooking energy stoves differs significantly between men and women of similar age. The employed male adult either as a salaried or self will opt for *Mbaula* cookstove as opposed to electric cookstove while the women of the similar employment and age will opt for electric cookstove. This shows the disparities that exist across gender in the preference of the type of cooking energy solutions. Despite the differences in the preferences for improved and traditional cookstoves, both male and female are averse against firestove given their economic status.

Like adult females, the results for education indicators among male adults reveal that only the choice of *Mbaula* cookstove and firestove/3stone stove at household level are statistically significant. The results suggest that an additional year of school attainment by male adults lead to 1.2 percentage point increase in the probability of choosing *Mbaula* cookstove while it leads to reduced probability of adopting firestove by 0.8 percentage point. Further, the educated male individual who has attained grade 12 and above will lower the likelihood of choosing *Mbaula* stove by 7.9 percentage points compared to the uneducated male of the same age holding other factors constant. For the educated adult male just like the adult female, the probability of adopting traditional energy reduces.

5.4.2.2.Gendered Decision Making and Expenditure on Cooking Energy Solution

The study estimates Heckman selection regression with two assumptions; first, an adult female is likely to participate in CES market relative to a male adult. Secondly, once a household decides to participate in CES market, the gender effect on CES expenditure differ significantly.

Table 5.7: Heckman- Selection Results for Expenditure on Cooking Energy Solutions

Variables	Heckman Model (Log Expenditure)		Selection Model (Participation Equation)	
Household characteristics				
Number of rooms	0.085***	0. (0.012)	0.761***	(0.031)
Access to finance service				
2. Mobile account	0.051	(0.060)	0.409**	(0.166)
3. Bank account	0.255***	(0.041)	0.157	(0.157)
Household size	0.044***	(0.007)	0.049***	(0.015)
Log monthly household expenditure	0.277***	(0.017)	0.079***	(0.031)
Area price of candle	-0.100***	(0.034)	-0.009	(0.051)
Dwelling ownership (yes)	-0.049	(0.037)	0.302***	(0.092)
Agric land ownership (yes)	-0.304***	(0.048)	-0.106	(0.080)
Cooking place				
1. Outdoors/outside	-0.226***	(0.053)	-0.203**	(0.079)
Duration preparing cookstove and fuel	-0.013***	(0.006)	-0.008	(0.009)

Female decision-making indictors				
Women social network (yes)	-0.198**	(0.082)	0.212**	(0.105)
Female cooking daily (yes)	-0.308***	(0.074)	0.018	(0.119)
Female employment (yes)	-0.031	(0.064)	0.144*	(0.089)
Female economic activity				
2. Housewife	-0.145**	(0.062)	-0.158*	(0.092)
3. Self- employee	0.263***	(0.085)	0.044	(0.116)
4. Salaried employee	0.286***	(0.089)	0.060	(0.177)
Female years of schooling	0.477***	(0.117)	0.046***	(0.014)
Educated female (yes)	0.447***	(0.077)	0.083	(0.166)
Male decision-making indicators				
Male cooking daily (yes)	0.144	(0.121)	-0.049	(0.171)
Male employment (yes)	-0.132***	(0.060)	0.037	(0.103)
Male economic activity				
2. Self-employment	-0.227***	(0.069)	0.389***	(0.089)
3. Salaried employee	0.092	(0.061)	0.216**	(0.103)
Male years of schooling	0.617***	(0.010)	-0.064***	(0.013)
Male-female education difference	-0.0191***	(0.0008)	0.042***	(0.0117)
Educated male (yes)	0.161***	(0.062)	0.202*	(0.116)
Location (urban)			0.567***	(0.088)
Household cooking energy				
2. Charcoal			1.975***	(0.116)
3. Electricity			2.187***	(0.235)
Constant	4.426***	(0.093)	-2.951***	(0.314)
Anthrho(p)	-0.563		(0.084)	
Lnsigma	-0.226***		(0.022)	
Lambda $(\widehat{\lambda})$	-0.339***		(0.039)	
Lr test (rho=0) chi2(1)	45.35			
Prob>chi2	0.000			
No. Observation	1,766		2,924	

Standard errors in parenthesis. ******, **, **** *represent 1%, 5% and 10% statistical significance level respectively;* Source: Author's computations from World Bank/ESMAP (2018) dataset

Table 5.7 above presents Heckman-selection regression results. The selection model represents household decision to participate in the CES market with a binary dependent variable (participate or not). The estimation is undertaken at household level with 1,766 households participating in the cooking energy market while 1,158 households are non-participants. The estimated *lambda* coefficient ($\hat{\lambda}$) -0.339 is statistically significant at all levels indicating the presence of selection bias and justifies the adoption of Heckman selection estimation approach to correct the selection bias.

Further in the selection model, restriction variables; household cooking energy choice (electricity/ LPG, charcoal, and firewood) and location (rural-urban) are included. Inclusion of additional variables in the selection equation enables us to deal with problems of multicollinearity and large standard errors if the same independent variables appear in both the Heckman and selection equations (Sartori, 2003). The likelihood ratio (LR) test is undertaken with the hypothesis *rho=0*. The LR test achieves two issues; first it tests that all coefficients in the models except constants are equal to zero. Secondly, it is joint likelihood test for the independence of the participation selection equation and the observed expenditure equation. From Table 5.7, the result of the LR test shows chi-square of 45.35 meaning that the null hypothesis is rejected and there is independence of the participation and expenditure equations with the selection equation justified.

The analysis and discussion start with Heckman model (expenditure equation) in the first column of Table 5.7 above involving gendered decision-making variables. Therefore, results in Table 5.7 suggest that social networking, female daily participation in cooking, being employed and being a housewife have a negative effect on household expenditure while being a salaried employee, self-employee, and education contribute to increased expenditure of the CES among women. The results entail that where women have strong bargaining powers, there is both likelihood of increased and reduced expenditure at household level for cooking energy solutions.

For instance, adult women being socially connected in the community leads to 19.8% reduction in household expenditure on CES compared to non-socially connected holding other factors constant. Intuitively, social networking among women results in knowledge sharing that is useful to both adoption of and expenditure on cooking fuel. Further, adult female participation in daily cooking contributes 30.8% reduction in household expenditure on CES (fuel) compared to non-participants. Although women being employed is statistically significant, the contribution to reduced expenditure is relatively small. The results in Table 5.7 show that being employed among adult women leads to 3.1% reduction in household monthly expenditure on cooking fuel compared to unemployed women of the same age *ceteris paribus*. However, women whose economic activity is being a housewife tend to influence household spending on cooking energy fuel negatively compared to those who are not employed. The results reveal that being a full-time housewife, women tend to devote all their time and labour to attending to kitchen activities leading to a reduction in monthly expenditure of 14.5% compared to those women who are unemployed but actively pursuing employment *ceteris paribus*. This reduction in household cooking energy spending is attributed to the ability to control kitchen cooking activities despite not influencing choice of cooking energy as observed in the previous section.

However, for an adult female engaged in economic activities (self or salaried employment) there is a likelihood of increased monthly expenditure on cooking energy. The results suggest that an adult female engaged in self-employment is likely to increase monthly expenditure on fuel by 26.3% while a salaried female employee may result in 28.6% increment relative to those who are not employed *ceteris paribus*. Intuitively, economically empowered women, contribute to increase in general household expenditure and being a daily participant in cooking, they decide to spend more on improved cooking fuels. This entails that economic empowerment among women influences the decision to spend at household level and probably spend on improved cooking energy solution with the ability to improve their welfare. Okonkwo (2021) argues that education is key to explaining household expenditure and choice of CES. The study further observes that improved education attainment among females has strong bargaining power if it translates in improved earning through employment. Lundberg and Pollak (1994) in their study reveal that an educated adult female can undertake independent decisions without the influence of their male counterpart in the household. Therefore, the results suggest that an additional year spent by a female adult in school results in 47.7% increase in household monthly expenditure on cooking fuel while an educated female spends 44.7% higher on cooking energy fuel than those who are not educated *ceteris paribus*.

For adult men, their presence at household level leads to most influential decisions being undertaken by them as they usually command that any household member ought to consult them before any decision is made (Miller and Mubarak, 2011). The results in Table 4.7 suggest that an employed male adult is likely to expend less (13.2% reduction) on monthly cooking energy fuel compared to unemployed individual. A reduced expenditure among employed men reflects their willingness to spend less on monthly cooking energy fuel which may affect the quantity, quality, and type of cooking energy fuel. This behaviour is further compounded when the study categorises economic activities showing that an adult self-employed man is likely to spend 22.7% less on cooking energy fuel compared to unemployed adult man holding other factors constant. This is contrary to their counterpart the female whose monthly expenditure is likely to increase when they are in self-employment.

In terms of education, an additional year spent in school by an adult male result in an increase in expenditure on cooking energy fuel. The results indicate a 61.7% increase in monthly expenditure on cooking fuel when a male adult spends an additional year in school *ceteris paribus*. Further, having an educated male adult household member result in 16.1% increase in monthly expenditure on cooking energy solutions compared to the uneducated male of the same age holding other factors constant. Therefore, a certain level of education attainment by adult members of the household is important in influencing expenditure on cooking energy fuel. However, male-female education attainment difference results in reduced expenditure on cooking energy fuel. The reduction in monthly expenditure on cooking energy fuel is low (1.9%) compared to the observed increase by both male and female adults in Table 5.7. As alluded to earlier, the effect of education on cooking energy solution expenditure tends to ether be direct or indirect. The direct effect hinges more on the knowledge acquisition that leads to educated individuals appreciating the benefit of spending an extra earning on improving the quality of CES. The indirect effect depends on the economic activity that the adult female engages in after attaining a certain level of education. Higher education attainment increases the probability of getting a good job with higher income leading to increased monthly expenditure.

Thus, focusing on the transition process as observed by IEA (2022) to cleaner cooking energy sources in Sub-Saharan Africa (SSA) involves three stages of adopting different cooking energy solutions. The first stage is transitioning within the biomass where households acquire improved cooked stoves that use biomass such as charcoal and firewood. The improved cookstoves are more efficient with low emission and use less of the biomass fuel. In Zambia’s scenario, this stage involves acquiring improved *Mbaula* stove that uses charcoal as fuel. In the second stage households moves to cleaner energy away from biomass by adopting of LPG cookstoves. This stage in Zambia is relatively absent due to supply constraints of LPG infrastructure. Less than one percent of the households use LPG for cooking (Luzi et al., 2019). In this case, the transitioning involves moving from improved cookstove with biomass to grid electricity which is contrary to the rest of SSA. The third and final stage involves transitioning to grid electricity, ethanol, or biogas. However, the third stage is constrained by the supply challenges. For instance, in most SSA countries, grid electricity is unavailable, unreliable, and unaffordable to use for cooking instead households use it for lighting and other activities.

Hence, given the results in the previous Section 5.4.2.1, the study observes that employed female adults are likely to choose clean energy stove (electric stove) leading to increased expenditure on cooking fuel while employed male adult are likely to choose *mbaula* stove leading to reduced expenditure cooking energy solution. This means that transitioning to cleaner cooking energy led to increase in household expenditure on cooking energy solution. Thus, the decision to adopt clean cooking energy solutions is affected by the cost of acquiring clean energy. The economic activities performed by the decision maker matter in deciding whether to adopt clean energy compared to improved cooking solutions. And given that majority women in SSA are housewives, their choice is inclined to their husbands' decisions. Their choice depends on their husband's preference given that husband provides financial resources. However, women who are employed tend to make their own decision making and will opt for clean energy as observed in this study's results.

Turning to selection model, results in Table 5.7 suggest that women social network, employment and years of schooling are all positive and statistically significant for female adults. These factors contribute positively to the probability of participating in cooking energy market *ceteris paribus*. Adult females who socialise in the community are likely to participate in the energy market due to product information exposure. They tend to influence decisions to participate based on information obtained through their social interaction with their peers in the community. Similarly, women who are employed have a positive probability of participating in the market as they seek for improved source of CES compared to unemployed women holding other factors constant. An additional year spent in school by an adult female member of the household contributes to a positive probability of participating in the market.

However, categorising female economic activities shows that only being a housewife is statistically significant with the expected sign. This shows that being a housewife reduces the probability of a household participating in the market holding other factors constant compared to those who are unemployed. Intuitively, a housewife's lack of economic activities to generate an income result in being dependent on the husband's economic activity. This forces the household to entirely depend on traditional energy sources as the housewife takes up the role to collect firewood as opposed to buying from the organised market.

The decision to participate in the market by a male adult is positively influenced by economic activities (self and salaried employment) and being an educated male adult while years spent in school negatively affect participation in the market. These variables are statistically significant at different levels (1%, 5% and 10%) and have expected signs apart from years spent in school by an adult male household member that is expected to be positive. Comparably, results show that decision making indicators that are statistically significant differ across gender. For instance, variables such as years spent in school, employment status and social network are key for a female adult to decide to participate in the market while for a male adult; disaggregated economic activities (self and salaried employment) are key to household participation in energy market.

5.4.3. Empirical Results of MTF Cooking Energy Solutions Access

5.4.3.1. Overall Effect of Access to Improved Cooking Energy Solution Across Tiers

The study controlled for socio-economic differences across tiers and households. Table 5.8 below presents results for overall effect of access to MTF cooking energy solutions on household welfare indicators. The pairwise average treatment effect across tiers shows differential effect between one tier and the other. For instance, as quality of CES adopted at household level improves, we observe the probability of an adult household member suffering a respiratory illness reducing at a diminishing rate. In the lower Tiers 1vs 0 the effect is positive and not statistically significant. However, as the quality of CES substantially improves we observe a statistically significant reduction in the probability of an adult household member suffering from respiratory illness. The probability of suffering a respiratory illness reduces from 9.9% to 4.4% across pairwise treatment effects as households move to higher tiers. The diminishing ATE is attributed to the fact that in higher Tier 4 and 5, the overall difference is very minimal and the quality of CES is basically clean (LPG and electricity).

Similar behaviour is observed with time saved from cooking and fuel collection and preparation. The differential impact in lower tiers is positive but statistically insignificant. However, in higher tiers, the differential impact suggests that moving from Tier 1 to Tier 2, a household saves about 37 minutes from cooking due to improved access to CES with highest impact being between 3 vs 2 where a household saves 44 minutes. Further, for fuel collection and preparation, statistically significant impact is observed in higher tiers; moving from 2 to 3 a household saves 18 minutes; 21.5 minutes for 4 vs 3 and 22.6 minutes for 5 vs 4 among adult household members. Here, the differential impact increases as quality of cooking energy solutions improves.

Table 5.8: Overall Effect of Access to Improved Cooking Energy Solution Across Tiers

Tiers	Health	Time spent on (min/day			
	Respiratory Illness	Cooking	Fuel Collection and Preparation	Studying	Income Generation
1 vs 0	0.106	8.89	-4.51	10.81*	22.47**
	(0.042)	(8.23)	(7.13)	(6.39)	(9.46)
2 vs 1	-0.099**	-36.95***	14.41	13.10**	24.49**
	(0.032)	(8.16)	(8.85)	(6.40)	(10.57)
3 vs 2	-0.068*	-44.00***	-17.78**	30.01***	44.28***
	(0.058)	(7.82)	(8.94)	(9.69)	(12.57)
4 vs 3	-0.066**	-16.39**	-21.54**	26.90**	38.99**
	(0.028)	(8.90)	(10.66)	(11.00)	(15.60)
5 vs 4	-0.044**	-43.16***	-22.55***	25.83**	33.91
	(0.021)	***(10.77)***	***(7.48)***	***(13.16)***	***(24.96)***

Robust Standard errors in parenthesis. ******, **, **** *represent 1%, 5% and 10% statistical significance level respectively;* Source: Author's computations from World Bank/ESMAP (2018) dataset

Furthermore, the impact on studying and income generation is expected to be positive as a household transition from lower to higher tiers. From Table 5.8, we observe a positive increase in the time households spend studying as household transition from using traditional cooking energy solutions to modern cooking energy solutions. The time across tiers increases from 10 to 30 minutes per day with the highest level occurring when a household moves from Tier 2 to 3. A similar trend is observed with time allocated to income generation despite differential impact in higher tiers (Tier 5 vs 4) is statistically insignificant. An adult member of the household is able to improve their time spent on income generation as access to CES improves across tiers with 44 minutes being the highest on average.

5.4.3.2. Gendered Effect of Access to Improved Cooking Energy Solution Across Tiers

The study disaggregated data into subsamples focusing on the gender of the adults aged 15 and above at household level and location (rural-urban areas). Table 5.9 below presents gender disaggregated effect of household access to improved cooking energy on respiratory illness and time allocation. The results suggest that the pairwise ATE of experiencing respiratory illness among women is statistically significant across the tiers expect for 2 vs1 while for men only two pairwise ATE are statistically significant; 2 vs 1 and 4 vs 3 with 3.7% and 3.9% reduction in the probability of being ill among adult men, respectively. However, for female adults the probability of suffering a respiratory illness reduces between 3.2% and 5.5% across the tiers as the quality of

CES improves. The highest pairwise ATE is recorded between Tier 3 vs 2 of 5.5% reduction while the lowest is between Tier 5 and 4 of 3.2% among households.

Table 5.9: Gendered Effect of Access to Cooking Energy Solution Across Tiers

	Health Outcomes		**Time spent on (min/day**							
Tiers	Respiratory Illness		Cooking		Fuel Collection and Preparation		Studying		Income Generation	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1 vs 0	**-0.038****	-0.055	12.56	-1.88	-0.199	**-8.39***	-1.70	-1.14	**10.13****	**11.52***
	(0.014)	(0.036)	(7.86)	(3.63)	(3.02)	(5.02)	(3.82)	(4.99)	(4.17)	(6.63)
2 vs 1	-0.034	**-0.037****	**-23.32*****	**-15.33****	**-10.25****	3.60	-6.23	**9.14****	**9.64***	**16.36****
	(0.024)	(0.018)	(6.11)	(6.05)	(5.03)	(4.17)	(4.02)	(3.37)	(5.62)	(6.70)
3 vs 2	**-0.055****	0.019	**-31.89*****	**-14.04*****	-3.60	-6.80	**13.01****	**16.15****	**17.98****	**26.86****
	(0.022)	(0.015)	(5.89)	(4.67)	(6.27)	(5.66)	(5.71)	(4.74)	(6.57)	(7.53)
4 vs 3	**-0.035****	**-0.039****	**-37.80*****	**-14.65*****	**-22.99****	**-13.59****	**14.67****	**11.87****	**17.62****	**23.76****
	(0.016)	(0.017)	(8.86)	(4.31)	(4.52)	(5.26)	(6.61)	(5.86)	(6.75)	(9.30)
5 vs 4	**-0.032***	-0.019	**-31.60*****	**-10.84****	**-15.40****	**-7.42****	**14.95****	**11.39***	**21.89***	14.54
	(0.018)	(0.014)	(9.88)	(3.74)	(5.36)	(3.64)	(7.56)	(6.80)	(12.63)	(12.54)

Robust Standard errors in parenthesis. ******, **, **** *represent 1%, 5% and 10% statistical significance level respectively:* Source: Author's computations from World Bank/ESMAP (2018) dataset

Regarding time saved from cooking, results in Table 5.9 suggest that the pairwise ATE is significant in Tiers above 0. For instance, female adults save 23.3 minutes by moving from Tier 1 to 2 while men save 15.3 minutes. In higher tiers (moving from 5 vs 4) women save 31.6 minutes and men save 10.8 minutes from cooking. However, for both men and women the results for time allocated to cooking are not statistically significant in the lower Tier of 1 v 0 at all conventional levels. The results on time spent on fuel collection and preparation suggest that the pairwise ATE doubles for women relative to men in statistically significant tiers. Tier 4 vs 3 shows that a female adult household member saves 23 minutes while men save 13.6 minutes and in Tiers 5 vs 4, females save 15.4 minutes while men save 7.4 minutes. The gender disaggregated impact for the time allocated to fuel collection and preparation is higher for females than what was obtained in the overall sample in some pairwise ATE shown in Table 5.8; for example, in Tier 4 vs 3, the disaggregated results for female would save 22 minutes while the household overall effect is 21.5 minutes.

Further, the gender disaggregated pairwise ATE results reveal that improvement in time allocated to studying is statistically significant in higher tiers for females. The highest time allocated to studying is 16.15 minutes per day for males for 3 vs 2 Tiers while for female is 14.95 minutes for 5 vs 4 Tiers. Due to low cooking activities among males relative to females of the same age at household level the probability of them spending more time studying compared to females is high as observed by Luzi *et al.,* (2019).

Finally, the time allocated to income generation is statistically significant across all the differential tiers for women at different significant levels while for men only Tiers 5 vs 4 is not statistically significant. Generally, as access to CES improves across the tiers, for female additional time spent on income generation improves. The pairwise ATE in the lower Tiers (1 vs 0) indicate that time allocated to income generation by females improves by 10 minutes per day as a household moves from Tier 0 to Tier 1 while in higher Tiers (5 vs 4), additional 21.9 minutes are allocated to income generation by females due to the improvement in the quality of cooking energy solutions. Similar results are observed among adult males where differential impact improves as a household moves up the tiers. For instance, additional 11.5 minutes are allocated to income generation activities as a household moves from Tier 0 to Tier 1 while moving from Tier 3 to 4 a male adult adds 23.8 minutes to income generation after controlling for household socio-economic characteristics.

5.4.3.3.Rural-Urban Effect of Access to Cooking Energy Solution Across Tiers

The study further disaggregated the sample into rural-urban subsamples to observe the impact of multi-tier treatment across location after controlling for socio-economic characteristics of the households. Table 5.10 presents the results of the disaggregated rural-urban effect of household access to cooking energy solution across tiers.

Table 5.10: Rural-Urban Effect of Improved Cooking Energy Solution Across Tiers

	Health Outcomes		**Time spent on (min/day**							
Tiers	**Respiratory Illness**		**Cooking**		**Fuel Collection & Preparation**		**Studying**		**Income Generation**	
	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
1 vs 0	0.030	-0.009	**38.90*** **	-7.61	7.60	**-45.26*** **	-3.82	-19.17	**39.13*** **	14.13
	(0.032)	(0.164)	(7.81)	(14.87)	(10.29)	(16.86)	(11.40)	(20.74)	(11.88)	(16.74)
2 vs 1	**-0.143** **	-0.035	**-49.85*** **	-8.61	12.43	**-8.45** **	-16.65	-2.13	**54.43*** **	**22.30** **
	(0.054)	(0.087)	(7.67)	(5.66)	(14.79)	(3.71)	(11.51)	(5.56)	(12.56)	(9.74)
3 vs 2	**-0.122** **	0.144	**-53.86*** **	-6.89	6.83	-3.53	**34.73** **	**27.09** **	**50.41** **	**12.35* **
	(0.053)	(0.126)	(8.49)	(5.17)	(14.15)	(2.91)	(11.16)	(12.38)	(14.98)	(7.04)
4 vs 3	**-0.055*** **	**0.235** **	**-47.61*** **	**-20.19** **	**-31.55** **	**-10.56** **	**21.84* **	18.63	**58.95*** **	4.01
	(0.015)	(0.116)	(11.74)	(8.15)	(11.93)	(2.73)	(12.46)	(13.51)	(14.55)	(11.34)
5 vs 4	**-0.048* **	0.121	**-18.03*** **	**-22.50** **	**-23.37** **	**-11.89*** **	8.44	9.14	26.75	3.15
	(0.025)	(0.217)	(4.98)	(9.02)	(7.32)	(3.85)	(11.22)	(16.53)	(16.43)	(15.45)

Robust Standard errors in parenthesis. ***, **, * *represent 1%, 5% and 10% statistical significance level respectively;* Source: Author's computations from World Bank/ESMAP (2018) dataset

Households in rural areas experience reduction probability of respiration illness as quality access to cooking energy solutions improves. For instance, moving from Tier 1 to 2 a household experiences 14.3% possibility of reduced respiratory illness. However, this effect reduces from 14.3% to 4.8% in higher tiers as shown in Table 5.10. The reduction in the pairwise ATE in higher tiers shows that improved cooking solutions have low emissions that may contribute to reduced respiratory illness at household level.

Studies such as Krishnapriya *et al* (2021); Damte *et al* (2012) found time saved from fuel collection and preparation in rural areas to be relatively higher than urban areas. These studies attribute this to long-time households take collecting firewood due to deforestation. Looking at Table 5.10, we observe that for households 53 minutes is the highest time saved in rural areas from cooking a meal per day while in urban areas the highest is 22.5 minutes. Just like the probability of experiencing respiratory illness, the time saved on cooking reduces as one moves up the tiers due to improved quality of cooking energy solutions adopted.

The time allocated to fuel collection and preparation is statistically significant in higher tiers in rural areas with Tier 4 vs 3 having the largest reduction of 31.5 minutes. However, in urban areas, the largest reduction is recorded in the lower tiers of 45.26 minutes for 1 vs 0 Tiers. Long distance among households relying on firewood in urban areas due to urbanization of the places contribute to spending more time looking for firewood if they are unable to buy. Similarly, the results suggest that the trend of the effect reduces as households transition from traditional to modern energy solutions for cooking across the tiers. For instance, in urban areas the time saved reduces from 45.26 minutes per day to 11.89 minutes in the higher tiers due to improvement in the quality of household CES. Also, in rural areas as households' transition, the pairwise ATE reduces from 31.5 minutes (4 vs 3) to 23.37 minutes (5 vs 4).

Furthermore, the results in Table 5.10 reveal that additional time for income generation activities is significant in lower tiers in rural areas while in urban areas the variable is significant in transition Tiers (2 and 3). The differential impact is large in transitional Tiers (2 and 3) and rises in rural areas while in urban areas the opposite is true on average. In the lower Tiers (1 vs 0), an adult household member in a rural area adds an average of 39.13 minutes per day to income generation activities as transition from Tier 0 to Tier 1 while in higher Tiers (4 vs 3), almost an hour is added to income generation activities on average per day. The saved time from collecting and preparation of cooking fuel and cooking a meal in a day in rural areas lead to improved allocation of time to income generation activities as households transition across tiers. In urban areas, the pairwise ATE reduces from 22.30 minutes (2 vs 1) to 12.35 minutes (3 vs 2). Households in urban areas depend on purchased charcoal while few rely on firewood, therefore, efficiency in use is high relative to firewood and transition upward on the tiers may not add larger time to income generation activities.

Finally, the results from Table 5.10 reveal that the effect of transitioning across tiers provides larger effect to both rural and urban areas though the pairwise ATE are high among rural households. Households largely depend on tradition fuel and technology for cooking activities contributes to higher effects as they transition. For instance, over 85% of the households fall between Tier 0 and 1 where majority depend on firewood and fire stove/ 3 stone stoves. Transitioning from traditional CES greatly contributes to improved health, large time saving from fuel collection, preparation and actual cooking as revealed by the results in Table 5.10 especially in rural areas.

5.4.3.4.Gender and Rural-Urban Effect of Cooking Energy Solution Across Tiers

The study further disaggregated the results into gender effect based on location (rural-urban) using the same outcome variables. The objective was to observe how gendered outcomes were affected by improvement in quality of the CES across location in Zambia and given the heterogeneity across gender and location in terms of access to cooking energy solutions at household level. Tables D4.4 and D4.5 in the appendix present the results of regression adjustment estimations for gender differential impact for rural and urban areas, respectively.

The results in Table D4.4 in the appendix suggest that adult female household members in rural areas experience general improvement in the quality of life as household access to multitier cooking energy solutions improves. For instance, in the lower tiers, adult female households' members experience a reduction of 6.2% on average on the possibility of suffering a respiratory illness due to exposure to cooking energy fuels and technology as they transition from Tier 0 to 1. However, as observed in the previous results the differential effect reduces to 3.1% as households transition to higher Tiers (5 vs 4) with improved cooking energy solutions. With adult males, the effect is only statistically significant in the lower Tier (2 vs 1) with an average of 5.9% reduction in the possibility of suffering a respiratory illness. The results though lower than the overall effect are similar across the pairwise ATE for rural areas.

For time allocated to various activities by adult male and female household members, the results reveal that the sum of gender disaggregated effects are almost the same as the overall effects for rural areas across statistically significant tiers. However, for cooking activities, the largest differentiated time saved for the adult female in a day is 33.55 minutes (in Tier 4 vs 3) while for the male is 24 minutes (in Tier 2 vs 1). The larger time saved among women is attributed to their daily participation in cooking in rural areas. Furthermore, the high use of firewood means that in rural areas time spent on fuel collection and preparation tends to be larger and its effect is only reduced in higher tiers as households transition to clean CES. This is observed by the results in Table D4.5 in the appendix where statistically significant time saved is obtained in higher tiers with 17.7 minutes (Tier 4 vs 3) for males while 14.6minutes (Tier 5 vs 4) for females is the largest. The effect on time females allocate to studying is only statistically significant in the transition tiers while for males it is in lower tiers. Lastly, the results highlight that similar time is added to income generation activities as access to CES improves across tiers and gender in rural areas.

In urban areas, results are presented in Table D4.5 in the appendix. Notably from the results is the probability of an adult female and male suffering a respiratory illness that is only statistically significant in lower Tiers (1 vs 2). The results suggest a possible reduction in reported respiratory illness of 15.8% for female and 14.7 for male adults is observed in lower Tiers (1 vs 0). The overreliance on firewood among households in Tier 0 leads to a higher possible reduction of around 15% among both males and females when a household transitions to Tier 1.

In addition, majority of the households who rely on firewood in urban areas lack proper ventilation in their kitchens resulting in respiratory illness. Further, time saved from cooking by females is statistically significant across all pairwise ATE except 1 vs 0 and a high effect is observed in higher Tiers (5 vs 4) with 23 minutes in a day. For males the pairwise ATE is high in lower Tiers (2 vs 1) of 25 minutes. Similarly, time saved from fuel collection and preparation is large and significant for pairwise ATE in lower tiers for both adult males and females. The study results suggest that male adults save about 33 minutes daily in lower Tiers (1 vs 0) while women save 27minutes in the same tiers. Regarding time allocated to studying in urban areas, the study estimates that the pairwise ATE is statistically significant in higher Tiers (3 vs2; 4vs3; 5 vs 4) while for males we observe statistically significant impact in Tiers 3 vs 2 and 4 vs 3. The highest pairwise ATE is 19 minutes for women while for men it is 19.55 minutes. Finally, the study observes a statistically significant effect pairwise ATE for additional time to income generation activities at home among adult women in Tier 2 vs 1 and 3 vs 2 while for men it is only Tier 4 vs 3. In both scenarios, the results indicate positive time added to income generation activity at home as households transition from the lower to the higher tiers of cooking energy solutions by both male and female.

5.4.3.5.Discussion of the Results on the Effect of Cooking Energy Solutions across Tiers

Studies have stressed the importance of households accessing improved cooking energy solutions on various welfare indicators. Welfare indicators such as time saving from improved cookstove (Krishnapriya *et al.*,2021); reported respiratory illness (Bensch and Peters, 2015) and health burden among females (Kohlin *et al.*, 2011); clean energy and gender outcomes (Barnes and Samad, 2018) have been estimated. However, these studies ignore households in transitional levels by focusing mainly on the quality of cookstove or level of emission from a given cookstove. Therefore, relying on MTF data, the study considered all attributes of cooking energy solution and assigned a household to an overall tier. The differences across the 6 tiers entails that the effect across household welfare indicators differ such that households exposed to cooking energy solutions in lower tiers are expected to experience low outcome effect. Further, the study observes the effect in the transitional levels (Tiers 2 and 3) by obtaining the pairwise ATE. The study highlights substantial variation in the impact based on gender and location of the household.

The findings of the study are consistent with the observation that transitioning from lower tiers to higher tiers entails household experiencing better effects. For instance, the estimated pairwise ATE show reduced probability of experiencing or reporting respiratory illness among users of cooking energy solutions. The overall pairwise ATEs estimated for the possibility of respiratory illness indicates reduction from 9% in lower tiers to 4.4% in high tiers. This is attributed to improved efficiency of the cooking appliances and fuel adopted as household transition through tiers. The reduced emissions exposure may contribute to low differential effect in the higher tiers as opposed to lower tiers.

Regarding disaggregated gender effect, the results observed reduced respiratory illness across gender (male and female) as households transition from a lower to a higher tier. Females being daily participants in cooking with high possibility of suffering from respiratory illness experienced largest reduction of almost 6% in Tiers 3 vs 2. For rural areas where majority households rely on firewood and firestove, the estimated pairwise ATE are statistically significant across all tiers except the lower Tier (1 vs 0). The highest reduction (at 14%) of the possibility of reporting respiratory illness among adult members of the households is higher than the overall effect observed.

Two time saving activities considered in the study; cooking and time spent on collecting and preparing fuel. The time saved from cooking across statistically significant pairwise ATE ranges between 16 to 44 minutes while from fuel collection and preparation is between 18-23 minutes. Studies such Krishnapriya *et al.*, (2021); Jeuland *et al*., (2020); Banes and Samad (2018); Bensch and Peters (2015); Brooks *et al*., (2016) have observed time saved from fuel collection, preparation, and cooking as households transition to improved cookstove. Similarly, disaggregating gender, the study found that adult females save from 23 to 38 minutes from cooking while males save between 11 and 15 minutes across statistically significant pairwise ATE. The largest impact for women is observed in Tier 4 vs 3 of 38 minutes while for men it is in the lower Tiers 2 vs 1 of 15 minutes.

Regarding fuel collection and preparation, women save between 10 and 23 minutes and men save between 7 and 14 minutes across statistically significant pairwise ATE. For the rural-urban differential, the study observe that time saved from cooking ranges from 18 to 54 for rural households while in urban it is between 20-23 minutes. However, the pairwise ATE is statistically significant in all the categories estimated for rural areas while for urban areas it is only statistically significant in higher tiers. The overdependence on inefficient cookstove in rural areas results in more time saved if a household transition to improved cookstove. Krishinapriya *et al.*, (2021) found similar results in six developing countries after estimating the impact of adopting improved cookstove on time saved. The study found that households save 23 minutes per day using a pooled data while across countries, the time saved range between 22 and 55 minutes in rural areas. For fuel collection and preparation, the results indicate that more time is saved among urban households ranging from 11 to 45 minutes per day while in rural areas it ranges from 23 to 31 minutes per day across statistically significant pairwise ATE.

The study further observed that time saved from cooking and fuel collection and preparation is distributed to other activities that include studying and engaging in income generating activities at household level. The estimated pairwise ATE for time allocated to studying among adult household members are statistically significant across all tiers at different levels. The overall additional time allocated to studying range from 11 to 30 minutes among adult individuals at household level while among women, additional time allocated to studying range from 13 to 15 minutes and for men between 9 and 16 minutes per day. The improvement in time allocated to studying among adult individuals is attributed to observed improvement in availability, exposure, and efficiency of cooking energy solutions.

Luzi *et al.*, (2019) observed that majority of the households rely on traditional energy sources (firewood and charcoal) which negatively affect school attendance among young adults aged between 15- 25 years. So, transitioning to improved cooking energy solutions leads to more time allocated to studying as observed in this study. Furthermore, creating time for income generating activities at household level contributes to improvement in their livelihood. The study observe that additional time is allocated to income generating activities in lower tiers. The overall additional time allocated to income generating activities ranges from 24 to 44 minutes per day. For adult female household members, the study found that 9 to 21 minutes are allocated to income generating ventures every day across statistically significant pairwise ATE while men allocate additional 11 to 24 minutes per day. For women who are not in formal employment such as housewives, engaging in a small business activity at household level depends on how much time is spared from kitchen activities.

5.5.Conclusion and Policy Implications

The study has comprehensively tackled household access to cooking energy solution with the objective of understanding gendered effect on choice, expenditure, and its impact on welfare indicators. In the first objective the study sought to understand how gendered decision-making indicators (direct and indirect decision-making indicators) affect choice and expenditure of cooking energy solutions at household level. After estimating the effect of decision-making indicators, the second objective focused on estimating the impact of access to multitier cooking energy solutions on selected household welfare indicators.

In the first objective, the social (social networking and education indicators), economic (employment and economic activities) and participation in cooking on the daily basis were taken as gender indicators of decision making. Thus, the study compared the effect when females were involved in decision making compared to men in their choice and expenditure of cooking energy solutions at household level. Regarding choice of cooking energy solutions, the study used probit estimation approach to estimate the effect of gender decision making indicators on three types of cookstove: electric cookstove, *mbaula* cookstove and firestove/3stone stoves. The results show that women social networks positively influence households' ability to adopt improved cookstoves.

Further, the study observes that female years of schooling and being educated are key in deciding whether a household adopts improved cookstove or not. The economic indicators show that the presence of an employed female adult members at household level contribute positively to adopting improved cookstove while reducing the probability of adopting *Mbaula* cookstove and firestoves. Disaggregating economic activities also shows that females who are self and salaried employed favour adopting improved cookstove. However, for men, indicators such as men education attainment and economic activities (salaried and self-employment) all promote adoption of *mbaula* as opposed to electric cookstove. This contrasts with females whom any improvement in economic and education status increases the probability of adopting improved cooking cookstoves.

Using the same disaggregated gender decision making indicators, the study adopted Heckman selection estimation approach in the second part of the first objective to estimate the effect of these indicators on household monthly expenditure on cooking energy solutions. Similar pattern of behaviour was observed across gender. Female adults at household level promoted increased expenditure given that they chose electric cookstove while adult men promoted reduced expenditure at household level with regard to cooking energy fuels. Decision making indicators such as education and employment promoted female increased expenditure while the same indicators promoted reduced expenditure among men. However, for men, their presence at household level influenced most decisions as they usually command that any household member consults them which may undermine the women's ability to use clean energy.

In short, the study findings regarding choice and expenditure of CES at household level suggest that policies focusing on closing gender inequalities should pay attention to the economic status and education attainment of the adult female as these contribute to improved decision making at household level. The unbalanced power observed through participation in cooking activities across gender at household level in Zambia can be reduced through women empowerment defined by economic status, education, and social network. The results indicate that equal opportunity across gender promoted by SDG5 and access to modern cooking energy as envisaged by SDG7 are possible if the economic situation of the adult individuals (both male and female) at household level is improved.

Further, the study comprehensively estimates the impact of multitier access to CES where attributes were considered when assigning households to treatment. Issues of availability, exposure, efficiency, and affordability of the CES were all included in the estimation of the overall household tier which defined household access level. Further, the study considered households in intermediate levels access. The results reveal that the overall impact on welfare indicators is high when households transition from low level of access (Tier 0 and 1) to intermediate level (Tiers 2 and 3) and clean energy levels (Tiers 4 and 5). The importance of transitioning to higher tiers is observed in the overall impact on health outcome (respiratory illness) and time allocation to various activities.

The inclusion of disaggregated gender outcomes in understanding the effect of access to multitier CES show heterogeneity in the effects among women and men. The results reveal the impact of transitioning across tiers significantly improves among female households such that welfare indicators; users' health and time allocation to cooking, fuel collection and income generating activities significantly improve once a household transition from lower Tiers (0-2) which account for majority households (87%). Similar results are observed after disaggregating outcome variables based on household location (urban and rural). Households in rural areas who transition to higher tiers face improved welfare such as large reduced respiratory illness.

Therefore, the results show the incremental benefits derived in each tier as household transition across tiers. This is welfare improvement and contributes to poverty reduction as households transition from open fire stove and traditional stoves – *mbaula stoves* to cleaner and more efficient stoves. Thus, the study provides reference points in policy formulation as transitioning to higher tiers improves gender outcomes and reduces social inequalities among users of cooking energy solution.

However, the study was conducted with limitations to the quality of data. The data did not include sufficient direct decision-making indicators that may point out who is in charge of decisions. The limitation of the gender decision making indicators limits the extent to which this study would discuss the effect on both choice and expenditure. Further, to estimate the impact of multitier cooking energy solution, the study controlled for observed characteristics through weighting that influences household self-selection into a given tier but not unobserved factors that may have effect on the results.

Chapter Six
Conclusion and Policy Implications

6.1.Concluding the Thesis

Understanding the improvement in the livelihood derived from the use of the modern energy has become critical especially in Sub-Saharan Africa where access to modern energy remains extremely low. The UN-SDG goal number 7 centres on ensuring that individuals globally have access to clean, affordable, and reliable energy sources by 2030. Further, the 2019 National Energy Policy in Zambia argues that households should be encouraged to adopt clean, affordable, and reliable energy to improve their livelihood, protect the environment and contribute to the economic growth of the country. Thus, this thesis sought to understand the impact of household energy access on user's livelihood through various socio-economic outcomes. To achieve its objectives, the thesis identifies four closely related areas of scholarly and policy interest in developing countries towards household energy access.

The first three studies concentrate on examining electricity access and the impact on household welfare in Zambia. This is because electricity access remains low with less than 40% of the households connected in Zambia. Thus, Chapter Two examined the effect of electrification technology on non-farm employment, monthly income, household expenditure defined by annual per capital expenditure and monthly expenditure on alternative energy in Zambia. Studies have identified various benefits among households connected to electricity however, differential effect across electrification technology is ignored. The limitations of technology in improving the livelihood of the user negatively affect the objective of the electrification programmes in developing countries and further contribute to users falling back on traditional energy.

Grid electricity technology though known to be unreliable and sometimes unaffordable is better in terms of capacity while SHS technology though deemed affordable and reliable has limited capacity in many instances. Therefore, given the attributes of the two technologies, to what extent they can affect household welfare is the key objective of the first study as presented in Chapter Two. The electrification technologies together with non-connected individuals as control group were taken as treatments of the experiment. Three socioeconomic outcomes (non-farm employment, monthly income and household expenditure defined by annual per capita and monthly expenditure on alternative energy) were selected. The study estimated pairwise ATE using the inverse probability treatment weighting approach. The estimation approach relies on

Generalised Propensity Score (GPS). The GPS shows the weighted probability of being treated to a particular treatment group given individual, household and community characteristics.

The third chapter diverts from the restrictive binary measure of household electricity access to adopting the MTF measures in the estimation of the impact of electrification on socio economic outcomes. The MTF provided a broader measure that defines electricity access as a spectrum of services offered to the household. However, the focus in this chapter is exclusively on connected households with treatment defined as electricity service availability in a typical day. The study argues that duration of exposure to electricity service in a day matter for the improvement of household welfare outcomes, but the extent is unknown. Thus, the objective of the chapter is to evaluate the impact of electricity availability in Zambia on selected socio-economic indicators of the households.

Three socio-economic indicators were selected that included household allocation of time to different activities (studying by children aged 6-15; working away from home for pay/self); household head non-farm employment and household expenditure (annual per capita expenditure; monthly expenditure on alternative energy sources including kerosene, charcoal, and firewood). The generalized propensity score technique with ADRF estimation strategy was used to estimate the impact of being treated to certain duration of electricity services in a day.

The fourth chapter's focus is on examining household WTP and its determinants for electricity connection among non-connected households in Zambia. Further access to credit was introduced in the study to understand how household demand (WTP) for electricity technology changes over payment period. The challenge of affordability due to low income among household was cited as the major constraint affecting access to electricity. The high poverty level especially in rural areas constrains majority of the households from accessing electricity. Introducing payment plans that span for two years may improve the demand for electricity adoption at household level. Two electrification technologies (grid and off-grid electricity) were considered in the estimation process with off-grid solutions (SHS) categorized into low and high-capacity solar PV. The study opted for contingent valuation approach to estimate the mean WTP with single bounded dichotomous (SBD) choice based on data availability. The chapter further estimated the mean WTP for the rural sub-sample across the payment plans to observe the changes in the mean WTP.

The fifth chapter comprehensively tackled household access to cooking energy solution with the objective of understanding gendered effect on choice, expenditure, and the impact on welfare indicators. Two objectives were set starting with the effect of gendered decision-making indicators on choice and expenditure of cooking energy solutions. The second objective focused on estimating the impact of access to multitier cooking energy solutions on selected household welfare indicators. In the first objective, the social (social networking and education indicators), economic (employment and economic activities) and participation in cooking on the daily basis are taken as gender indicators affecting decision making regarding choice and expenditure on cooking energy solutions. Thus, the study compared the effect when women are involved in decision making relative to men in their choice and expenditure of cooking energy solutions at household level. Three cookstoves namely, improved cookstove (LPG, and electrical stoves), traditional *mbaula* stoves and firestove/3stone were considered regarding choice of CES. The probit estimation approach was adopted to estimate the effect of gender decision making indicators on the choice of three types of cookstove. Further, Heckman-selection estimation approach was adopted to estimate the effect of gendered decision-making indicators on household monthly expenditure on CES. The same disaggregated gender decision making indicators were adopted while expenditure variable was defined as total monthly expenditure on cooking fuel at household level.

In the second objective of the chapter, the study introduced the MTF measure of the CES when estimating the impact on socio-economic outcomes. The multitier measures relied on attributes and assigned households to treatment (Tiers). Issues of availability, exposure, efficiency, safety, convenience, and affordability of the cooking energy solutions were included in the estimation of the overall household Tier which defines household access level. Further, the study considered households in intermediate levels access and argued that the benefits derived from transition from low level of access (Tier 0 and 1) to intermediate level (Tiers 2 and 3) and modern or clean energy levels (Tiers 4 and 5) increases. The inverse probability treatment regression adjustment estimation strategy was used in the estimation of the pairwise ATE.

The entire thesis estimations relied on MTF survey data collected by World Bank/ESMAP on Zambia household energy sector in 2017/18. The data included household social, economic and energy characteristics. Therefore, each chapter extracted the sample required for the estimations.

The findings in Chapter Two from IPTW estimation strategy clearly revealed heterogeneity in the effect across the two electrification technologies on selected household welfare indicators. For instance, the pairwise ATE between GE vs SHS electricity was positive and statistically significant for monthly income and annual per capita expenditure. The results suggested that being treated to grid offers better effects. For instance, monthly income, the study observed that the pairwise ATE was higher by an average of $56.41 among households accessing grid compared to SHS electricity. For the household expenditure outcome variable, only expenditure per capita was statistically significant for GE vs NC and GE vs SHS pairwise. In both pairwise ATE, the impact was higher when a household was accessing electricity from the grid compared to SHS. Clearly, the results suggest that grid electricity offers better effect than SHS across the outcomes and if well enhanced it could improve the welfare of the users through engaging in income activities away from farm activities. However, for low-income households, adopting SHS is important for income generation activities and contributes to reducing monthly expenditure on alternative energy.

Further, results in Chapter Three from the average dose response estimation intuitively revealed that longer duration of household exposure to electricity service, improves socio-economic welfare indicators. For example, as duration of exposure to electricity improves, opportunities of being employed in a non-farm sector also improve such that both women and men start allocating more time to working for self/pay away from home. A similar trend was observed in non-farm employment and time allocated to working away from home by women and men across tiers. As the probability of the household head working in a non-agriculture sector increased due to the improvement in duration of electricity service exposure, time allocation to working away from home for pay/ self also increased for both male and female working away from home.

The findings also revealed that the differential impact on household annual expenditure per capita in the lower Tiers (between 1 and 2) of electricity services reduces. As treatment to electricity went beyond Tier 2, the annual expenditure per capita increased monotonically. Similarly, household expenditure on alternative energy sources that include kerosene, charcoal and wood fire increased in the lower tiers instead of reducing. However, as exposure to electricity went beyond 16 hours there was generally a reduction in expenditure on alternative energy sources. Therefore, a meaningful reduction in expenditure on alternative energy could only be recorded if availability of electricity was relatively high.

Furthermore, Chapter Four findings revealed that non-connected households had positive and higher than market price mean WTP to connect for grid electricity services. The estimated mean WTP for grid connection was $244.69 which was 14.26% higher than the market price. The introduction of the credit facility led to an increase in the differential value between mean WTP and market price by 66.7%, 75.6% and 100.7% for grid electricity connection as the payment period increased from 3 months, 6months and 12 months, respectively. Regarding SHS, the estimated mean WTP for high-capacity solar PV revealed that households can afford to pay upfront and the willingness to pay improved when they accessed the credit facility with longer payment period. However, the estimated mean WTP for low-capacity solar PV was below the market value by 45.4% for upfront and six months payment plan. Similar to the effect of electrification technology observed in Chapter Two, the demand for grid electricity adoption at household level was better compared to high-capacity SHS while households may not have been willing to pay higher than $68.37 for low-capacity SHS despite value being below the market value. This suggest that households were willing to pay for electricity technology that offered services beyond lighting as grid electricity and high-capacity solar PV could improve households' livelihood through engaging in economic activities supported by electricity availability with high capacity.

In the final chapter, results showed that women social networks positively influence household ability to adopt improved cookstove while female years of schooling and being educated are key in deciding whether a household adopts improved cookstove or not. The economic indicators showed that the presence of an employed female adult members at household level contributes positively to adopting improved cookstove while reducing the probability of adopting *mbaula* and 3 stone stoves. Disaggregating economic activities also showed that women who are self and salaried employed favour adopting improved cookstove. However, for men, indicators such as education attainment and economic activities (salaried and self-employment) all promote adoption of traditional *mbaula* as opposed to improved cookstove. This contrasted with women for whom any improvement in economic and education status increased the probability of adopting improved cooking cookstoves.

The findings from Heckman-selection estimation approach with the same disaggregated gender decision making indicators revealed that the effect of these indicators on household monthly expenditure on cooking fuel have similar patterns across gender. Female adults at household level promote increased expenditure given that they choose improved cookstove while adult men promote reduced expenditure at household level with regard to cooking energy fuels. Decision making indicators such as education, and employment promote female increased expenditure while the same indicators promote reduced expenditure among men. However, for men their presence at household level influences most decisions and they usually command that any household member ought to consult them which may undermine the women’s ability to use clean energy.

Finally, the multitier treatment effect findings in the second part of Chapter Five revealed the importance of households transitioning to higher tiers on the overall impact that include health outcome (respiratory illness) and time allocation to various activities. The results further showed heterogeneity in the effect among women and men but that general improvement in multitier access to electricity reduces drudgery, improves health outcomes and time allocation to various activities on both adult women and men.

6.2.Policy Implications

The findings from the studies provide important policy implications on household access to electricity, non-connected households, and access to cooking energy solutions in Zambia. For instance, the findings in Chapter Two possess a challenge to the electrification programme as results reveal limitations of electrification technology adopted. Households’ adoption of SHS and grid electricity services provide relatively different levels of effects on their welfare indicators. The differential effect on the socio-economic outcomes in the long run between the two-electrification technology (grid versus SHS) widens if grid electricity improves in terms of availability and reliability. The capacity of SHS limits users’ opportunities to further improve their livelihood once adopted compared to grid electricity despite affordability issues. Stable grid electricity contributes to improvement in income through engaging in income generating activities that enables households to improve their total expenditure on goods and services and reduce overreliance on traditional energy overtime as households acquire electrical appliances such as electric stoves and lighting bulbs. However, for low-income households, adopting SHS is important for income generation activities and contributes to reducing monthly expenditure on alternative energy compared to non-connected households. Therefore, for rural households where the cost of providing grid electricity is high coupled with low income and economic activities, SHS provides perfect opportunities for household energy transition and offers income generating activities that can improve their welfare overtime.

Similarly, the results obtained from Chapter Three show the importance of duration of electricity exposure among users as certain welfare indicators (household expenditure on alternative energy) improves only after a given level of exposure in a day (16 hours). The longer the duration of electricity availability, the higher the improvement in household welfare indicators. The key takeaway from the results is that improved household exposure to electricity service increases the probability of having improved livelihood (better welfare indicators) once connected to electricity and electricity provided in the electrification programme should always take into account the attributes that include availability, reliability and affordability. Failure to account for such attributes as observed in this study will limit the benefits that households derive from being connected.

Further, the distinction in WTP across the two technologies (grid and SHS) observed in Chapter Four indicate the importance households attach to these technologies which should be taken into consideration during electrification process. The low upfront mean WTP for low-capacity SHS is an indication of the preference for high-capacity source of electricity by households who want to adopt electricity technology offering beyond lighting. This indicates that non-connected households prefer grid electricity to SHS in Zambia despite associated issues of reliability, availability, and tariff affordability. Hence, the need for electrification programme to consider attributes especially for SHS as the electrification technology as this can hinder electricity access. In addition, the positive and above the market mean WTP for grid electricity and high-capacity solar PV show that private firms market participation in the provision of electricity can increase the access rate as households are able to pay beyond the market value.

Further, we observed that not every household was willing to pay for a connection from any electricity technology despite introducing credit facility. The economic status of many non-connected households is a crucial limiting factor in addition to the price of adopting technology. Low income, unemployment, and affordability of electricity services were observed as reasons affecting mean WTP despite introducing credit financing and require urgent government attention. Thus, the study suggests the need to improve access to financial services households especially in rural areas where poverty and low income are major challenges. Further general improvement in people’s livelihood can enhance adoption and sustaining of consumption of electricity once connected.

Finally, the findings in Chapter Five demonstrate the importance of formulating gender inclusive energy policies due to differing in perspective towards cooking energy solutions. Given that over 80% of the women participate in cooking on daily basis compared to less than 20% for men in Zambia, improving their collective bargaining power can help households adopt clean energy for cooking. The study suggests policies that promote women empowerment such as promoting education attainment and improvement in their economic status. Highlighting such issues in policies will have positive implication on households transitioning to clean energy for cooking. Similarly, assigning households into tiers based on CES attributes has revealed the importance of addressing these attributes and given a broader definition of access to CES. Issues of availability, exposure, efficiency, and affordability are important aspects of the cooking energy solutions and should be addressed in order to improve household welfare especially among women. The study has shown that the observed differences across the 6 tiers affect household welfare indicators differently such that households exposed to cooking energy solutions in lower tiers are expected to experience low outcome effect compared to higher tiers. Therefore, government should highlight these substantial variations in the impact based on gender and location of the household across CES tiers in policy formulation.

However, the policy implications drawn here are based on the dataset collected in 2017/18 such that several energy policy pronouncements and changes have taken place. Furthermore, economic situations have changed post COVID era. For instance, a new energy policy (2019) has been enacted replacing the 2008 energy policy. The objective of the policy has shifted to increasing access to reliable and affordable clean energy as a building block to poverty reduction and business expansion so as to achieve economic growth especially in rural areas. The policy promotes adoption of various sources of clean energy including adoption of improved cooking solution at household level. However, in 2022, the government revised both electricity tariffs and connection fees upward thereby affecting connections and consumption of electricity service as observed in study three. This has negatively affected households’ ability to connect to grid electricity especially in rural areas where access rate is below 5%. Furthermore, the policy promotes alternative energy sources and technologies for increased provision of clean and efficient energy services. Nevertheless, this objective is hampered by worsening economic conditions among households' post COVID era.

6.3. Limitations and Area of Further Research

The objective of the study is to comprehensively understand the impact of household access to energy in Zambia. This has been achieved through the four studies presented from Chapter Two to Five. However, achieving this objective faced data quality limitations. For instance, the data would not permit adopting a double bounded dichotomous choice model to estimate the mean WTP. The adoption of SBD as opposed to DBD approach to contingent evaluation is associated with overstating the WTP resulting in possible bias estimation of the WTP. Despite this limitation, the study included enough household characteristics that would affect their response and undertook various measures highlighted in the study to reduce the bias in responses. Therefore, future studies can comprehensively collect data that allows adoption DBD approach to observe the changes in the responses and estimate the WTP for household connection to various electricity technologies.

Further for rigorous understanding of the effect of electrification technology, future studies should consider disaggregating electrification technology into various types. The solar PV can be disaggregated into solar lanterns, standalone solar system, solar torch, and solar lights to understand within the SHS family which technology offers better effects. While grid electricity can be disaggregated main grid and mini-grid technology. In addition, disaggregating electrification technology based on the attributes of access to electricity such as capacity, availability, reliability, affordability is essential for a comprehensive evaluation of the impact of electrification programmes based on MTF in developing countries.

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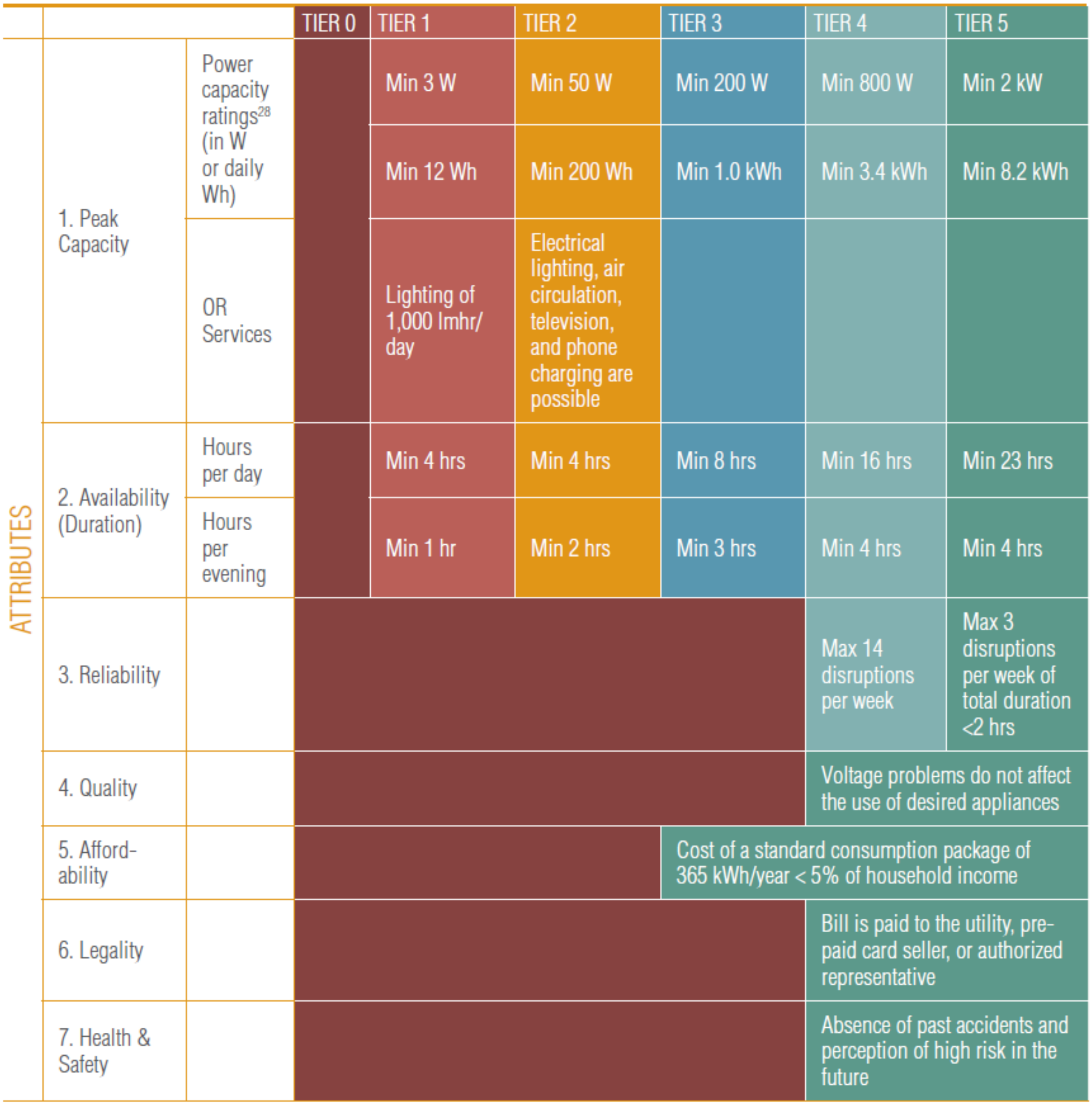
Appendices

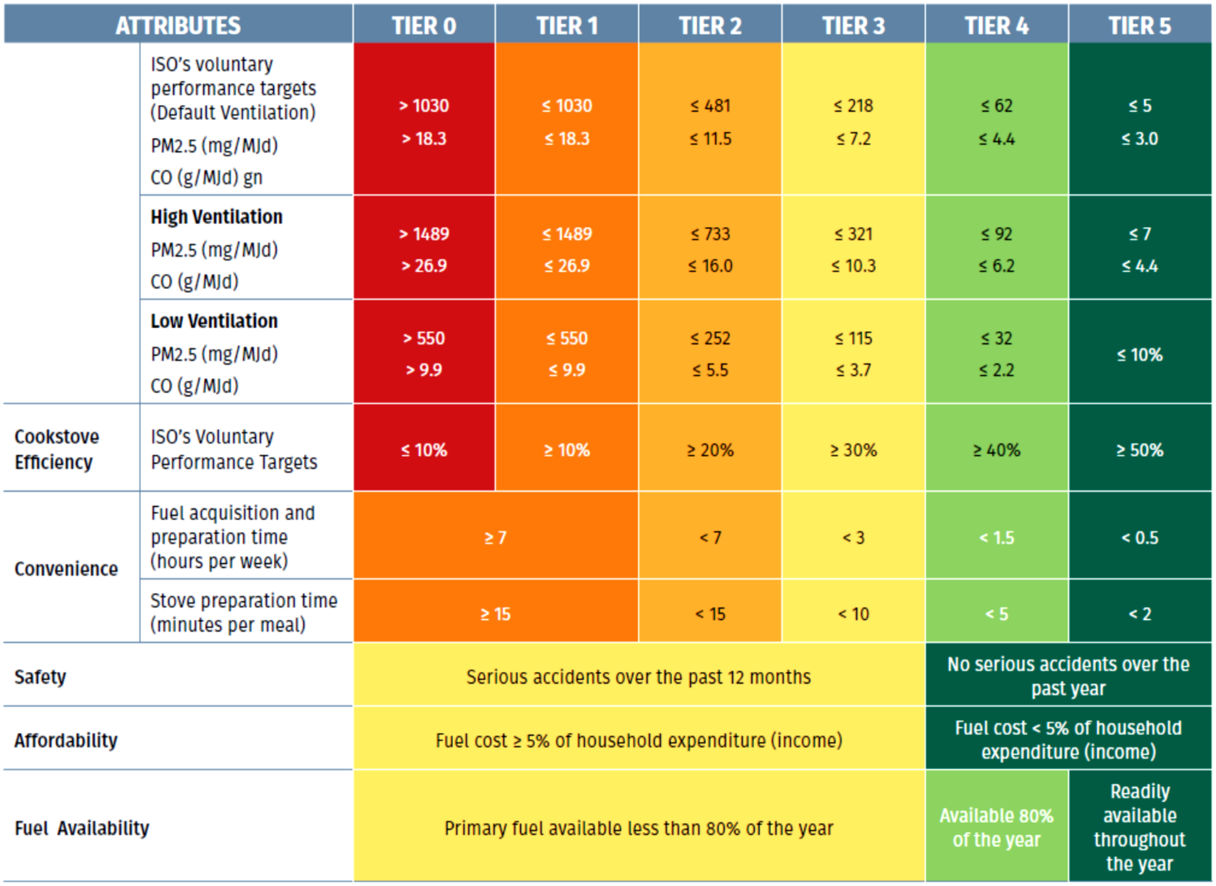
Table 1A: MTF For Household Access to Electricity



			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATTRIBUTES	1. Peak Capacity	Power capacity ratings[28] (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/ day	Electrical lighting, air circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hr	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2 hrs
	4. Quality						Voltage problems do not affect the use of desired appliances	
	5. Afford-ability					Cost of a standard consumption package of 365 kWh/year < 5% of household income		
	6. Legality						Bill is paid to the utility, pre-paid card seller, or authorized representative	
	7. Health & Safety						Absence of past accidents and perception of high risk in the future	

Adapted from Bhatia and Angelou (2015).

Table 1B: MTF for Household Access to Cooking Energy Solutions



ATTRIBUTES		TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
	ISO's voluntary performance targets (Default Ventilation) PM2.5 (mg/MJd) CO (g/MJd) gn	> 1030 > 18.3	≤ 1030 ≤ 18.3	≤ 481 ≤ 11.5	≤ 218 ≤ 7.2	≤ 62 ≤ 4.4	≤ 5 ≤ 3.0
	High Ventilation PM2.5 (mg/MJd) CO (g/MJd)	> 1489 > 26.9	≤ 1489 ≤ 26.9	≤ 733 ≤ 16.0	≤ 321 ≤ 10.3	≤ 92 ≤ 6.2	≤ 7 ≤ 4.4
	Low Ventilation PM2.5 (mg/MJd) CO (g/MJd)	> 550 > 9.9	≤ 550 ≤ 9.9	≤ 252 ≤ 5.5	≤ 115 ≤ 3.7	≤ 32 ≤ 2.2	≤ 10%
Cookstove Efficiency	ISO's Voluntary Performance Targets	≤ 10%	≥ 10%	≥ 20%	≥ 30%	≥ 40%	≥ 50%
Convenience	Fuel acquisition and preparation time (hours per week)	≥ 7		< 7	< 3	< 1.5	< 0.5
	Stove preparation time (minutes per meal)	≥ 15		< 15	< 10	< 5	< 2
Safety		Serious accidents over the past 12 months				No serious accidents over the past year	
Affordability		Fuel cost ≥ 5% of household expenditure (income)				Fuel cost < 5% of household expenditure (income)	
Fuel Availability		Primary fuel available less than 80% of the year				Available 80% of the year	Readily available throughout the year

Adapted from Bhatia and Angelou (2015).

Appendix A: Paper One

Table A1.1: Descriptive Statistics for Covariates

Variables	**Treatment: Access to Electricity Services**		
	Treatment= 0: Not Connected	**Treatment =1: Grid Electricity**	**Treatment= 2: Standalone Solar System**
Household Location (Urban)	0.310(0.009)	0.877(0.009)	0.455(0.036)
Years Of Schooling (Head)	6.198(0.083)	10.249(0.124)	8.444(0.322)
No. Rooms	2.403(0.023)	3.262(0.049)	3.291(0.0124)
House Walls (Blocks\Burnt Bricks)	0.219(0.008)	0.812(0.011)	0.534(0.036)
House Floor *(1=Mud/Dung, 2=Cement Screed; 3=Floor Tiles)*	1.338(0.010)	2.089(0.011)	1.687(0.044)
Area Price Of Candle	2.471(0.0137)	2.374(0.010)	2.288(0.025)
Agriculture Land Ownership (Hectares)	3.39 (0.504)	2.36 (1.071)	17.11(7.72)
Agriculture Land Ownership (Yes)	0.55(0.010)	0.11(0.009)	0.43(0.036)
Dwelling Ownership (Yes)	0.80 (0.009)	0.49(0.015)	0.75(0.031)
No. Of Mobile Phone	0.613(0.021)	2.263(0.048)	2.179(0.111)
Household Size	4.6(0.052)	5.1(0.072)	6.5(0.190)
Household Head Age	41(0.33)	42(0.38)	45(1.05)
Household Head Gender (Male)	0.735(0.009)	0.756(0.012)	0.756(0.031)
Access To Financial Services *(1=No Access, 2=Mobile Money, 3= Bank Account*	1.215(0.012)	2.347(0.025)	1.761(0.066)
No. Observations			**3,509**

Note: standard deviations in parenthesis

Table A1.2: Descriptive Statistics for Household Socioeconomic Outcomes

			Source of Electricity			
Outcome Variables		**Obs**	**NC**	**GE**	**SHS**	**Overall**
Household Income	Household Monthly Income	3537	1538.50	3144.33	2580.21	2123.54
			(32.9)	(90.1)	(230.1)	(40.2)
Employment Outcome	Employment in non-Agric sector	2602	0.34	0.89	0.53	0.54
			(0.12)	(0.01)	(0.04)	(0.01)
Household Expenditure	Annual per capita Expenditure (Kwacha)	3515	2466.05	8670.07	6165.53	4722.97
			(78.33)	(405.82)	(920.28)	(158.97)
	Expenditure on alternative energy sources (Kwacha)	1831	69.43	86.68	85.61	78.87
			(2.01)	(1.86)	(8.60)	(13.8)

Note: Figures in parenthesis are standard errors

Table A1.3: Average Marginal Effect for Multinomial Logit

VARIABLES	**Treatment: Access to Electricity Services**		
	Treatment= 0: Not Connected	**Treatment =1: Grid Electricity**	**Treatment= 2: Standalone Solar System**
Household Location (Urban)	-0.0592***	0.1181***	-0.053***
	(0.0162)	(0.0175)	(0.0121)
Household Head Years of Schooling	-0.00590***	0.0044**	0.0014
	(0.0015)	(0.0015)	(0.0010)
No. Rooms in the dwelling	-0.0137**	0.0086*	0.0030
	(0.0049)	(0.004)	(0.0027)
Walls of the House (Blocks\Burnt Bricks)	-0.097***	0.054***	0.0413***
	(0.0189)	(0.015)	(0.013)
House Floor	-0.099***	0.190***	-0.0753**
2)- Cement Screed	(0.0267)	(0.022)	(0.0203)
3)- Floor Tiles	-0.282***	0.3146***	-0.0299
	(0.056)	(0.0560)	(0.0356)
Area Price Of Candle	-0.00012	0.0180	0.00181**
	(0.0123)	(0.0127)	(0.0084)
No. Of Mobile Phone at Household Level	-0.0548***	0.0385***	0.0156***
	(0.0051)	(0.0046)	(0.0029)
Household Size	0.0044**	-0.0108***	0.0064**
	(0.0028)	(0.0027)	(0.0015)
Household Head Age	0.0002	-0.0006**	-0.0002
	(0.0004)	(0.00048)	(0.0003)
Household Head Gender (Male)	0.0089	0.0233	-0.0628**
	(0.0138)	(0.0163)	(0.009)
Agriculture Land Ownership (Yes)	0.065**	-0.069***	0.005
	(0.017)	(0.018)	(0.009)
Dwelling Ownership (Yes)	0.025**	-0.036***	0.011***
	(0.014)	(0.013)	(0.009)
Farmland Ownership (Hectares)	-0.0003*	0.0002	0.001***
	(0.002)	(0.002)	(0.00006)
Access To Financial Services	-0.0618**	0.0298	0.0237*
2)- Mobile Money	(0.024)	(0.022)	(0.0187)
3)- Bank Account	-0.151***	0.1535***	0.00113
	(0.0198)	(0.0169)	(0.0128)
No. Observations			**3,509**

*, **, *** indicate 10%, 5% and 1% significance level

Table A1.4: Rural- Urban Results of the Pairwise ATE from IPTW Estimation

Outcome Variables		**Pairwise Average Treatment Effect**					
		GE vs NC		**SHS vs NC**		**GE vs SHS**	
		Urban	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
Household[39] Income	Monthly income (US$)	**173.78****	**136.05*****	**106.90*****	22.52	-33.12	**113.54*****
		(10.91)	(21.35)	(36.55)	(27.3)	(37.55)	(34.17)
Employment	Household head employment in non-agriculture sector	**0.118*****	**0.482*****	**0.127*****	0.004	-0.008	**0.478*****
		(0.02)	(0.03)	(0.04)	(0.05)	(0.03)	(0.06)
Household Expenditure	Annual household expenditure per capita (log)	**0.88****	**1.02****	**0.88*****	**0.54****	-0.009	**0.90*****
		(0.05)	(0.11)	(0.14)	(0.17)	(0.13)	(0.14)
	Household Monthly Expenditure on Alternative Energy (US$)	**-0.789****	**-2.02****	**-1.98***	-0.92	-1.19	-0.43
		(0.31)	(0.56)	(1.11)	(0.80)	(1.10)	(1.15)

Note: ***, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent Robust Standard Error

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[39] The exchange rate is K10/US$1 in 2018.

Figure A1.1: Overlap Test for GPS for Categorical Treatment

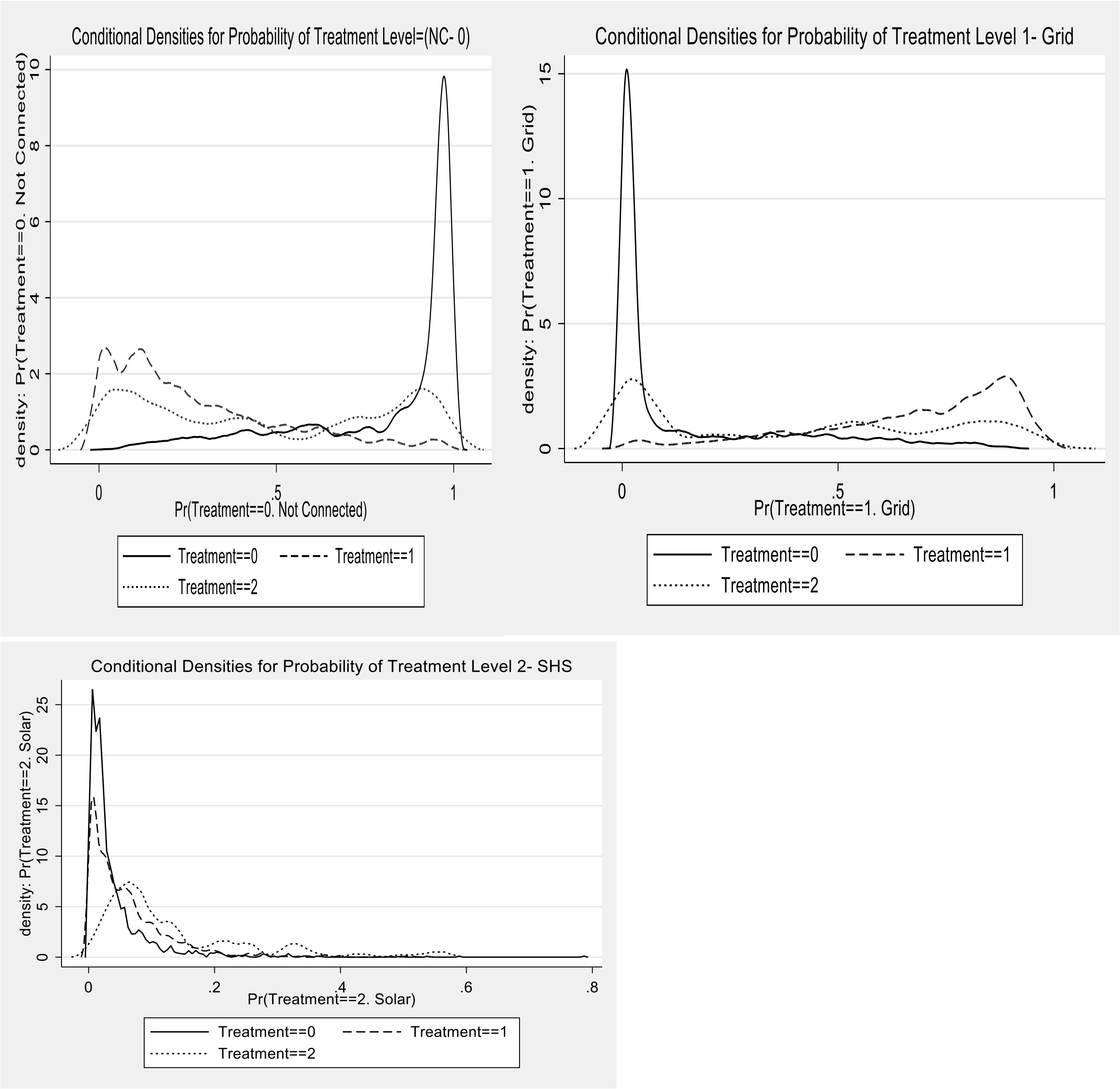


Figure A1.2: Overlap Test for GPS for Categorical Treatment for Rural Areas

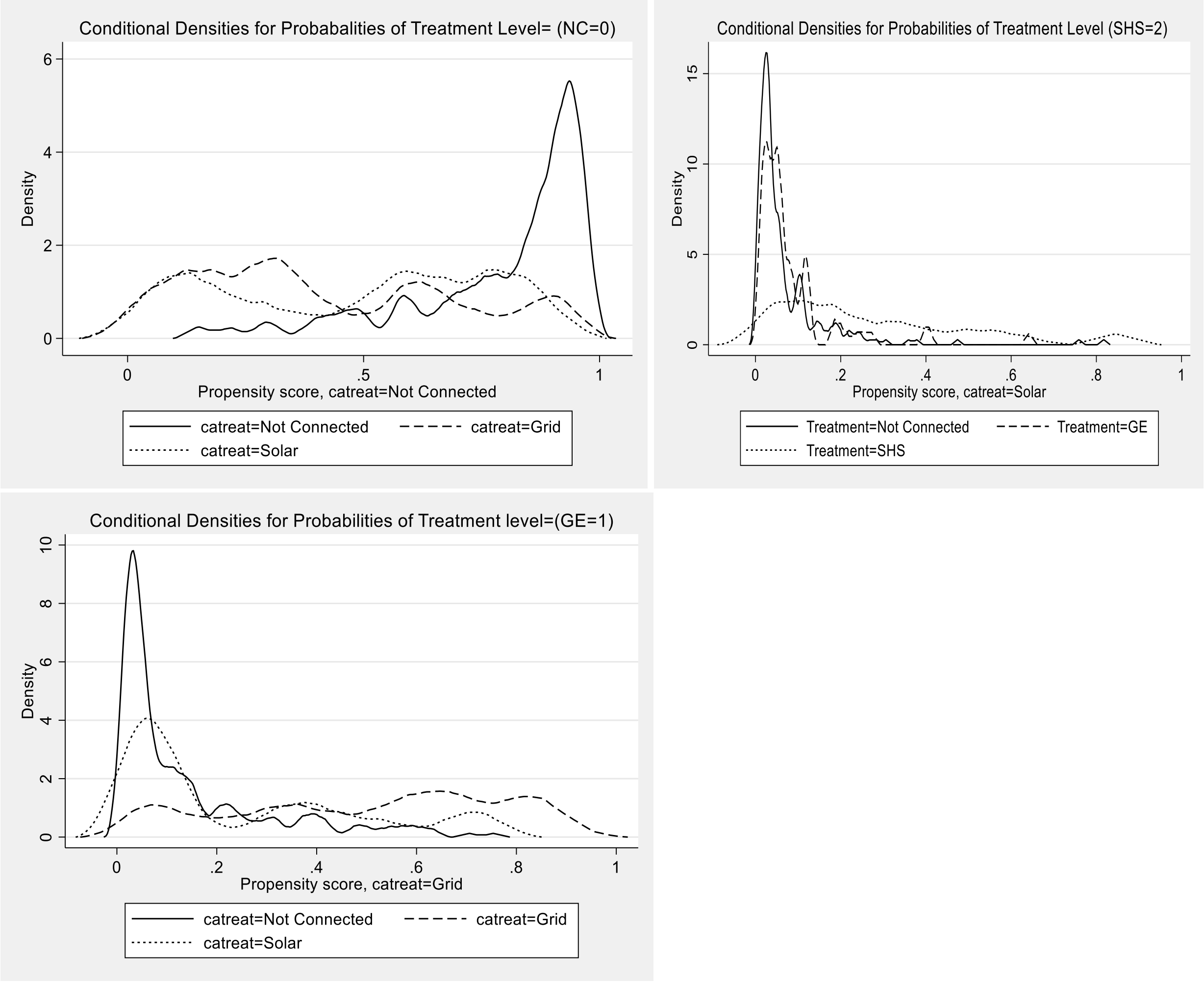
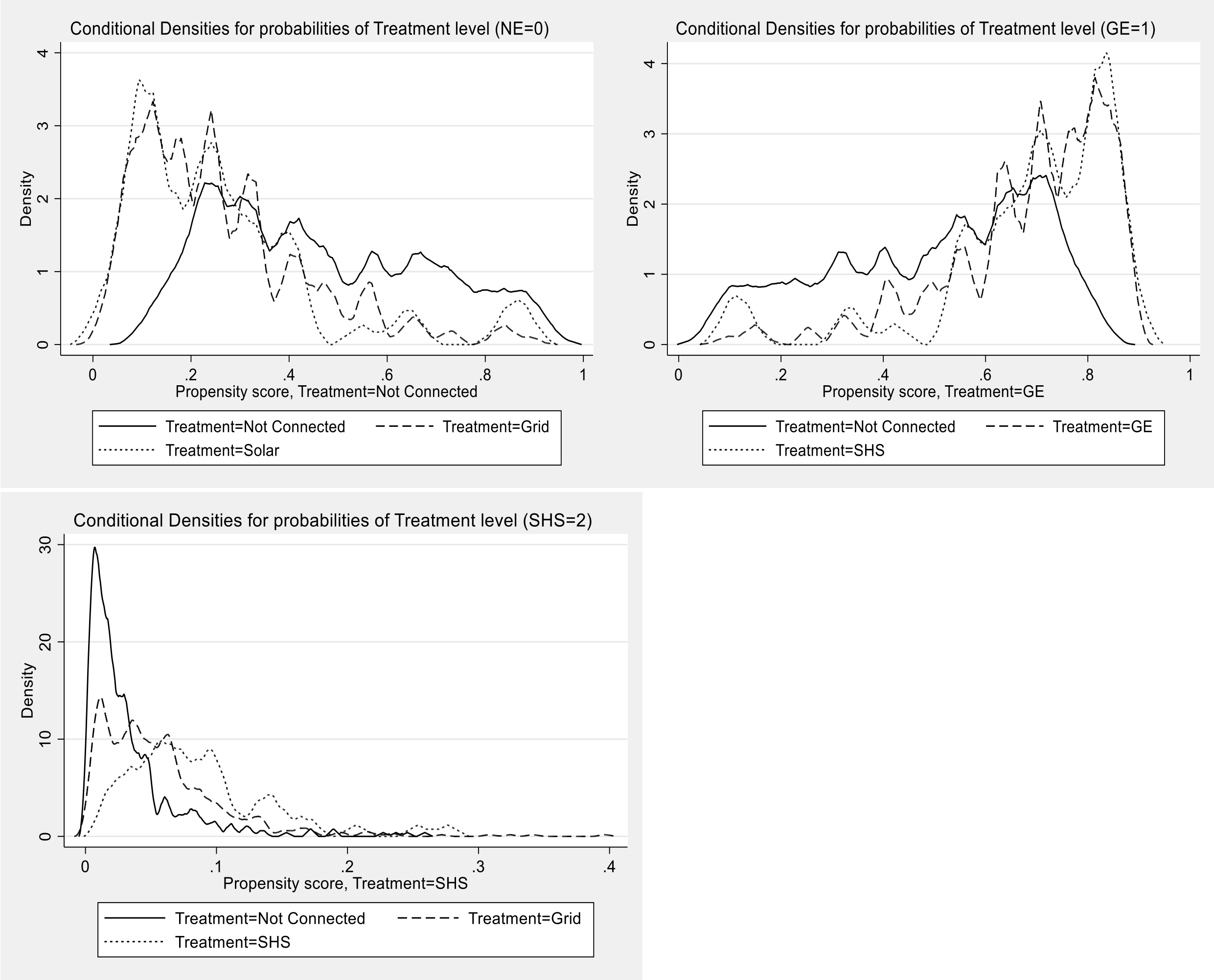


Figure A1.3: Overlap Test for GPS for Categorical Treatment for Urban Areas



Appendix B: Paper Two

Table B2.1: Descriptive Statistics for Covariates used in GPS Estimation

	Multi-Tiers				
Covariates	**1**	**2**	**3**	**4**	**5**
House walls	0.55(0.5)	0.49(0.5)	0.55(0.5)	0.79(0.4)	0.83(0.4)
Electricity service Quality	0.5(0.51)	0.4(0.49)	0.5(0.50)	0.7(0.47)	0.6(0.50)
Area Price of Candle	2.26(0.3)	2.33(0.4)	2.25(0.3)	2.43(0.4)	2.36(0.3)
Household size	5.9 (0.39)	6.3(0.25)	5.8(0.22)	4.7(0.16)	5.2(0.08)
Use of solid fuel	0.37(0.4)	0.54(0.5)	0.31(0.5)	0.14(0.3)	0.13(0.3)
Type of household dwelling	1.44(1.2)	1.36(1.01)	1.32(0.7)	1.29(0.7)	1.37(0.9)
Asset ownership	0.28(0.4)	0.18(0.3)	0.10(0.3)	0.03(0.2)	0.06(0.2)
Household head gender	0.89(0.3)	0.77(0.4)	0.79(0.4)	0.72(0.4)	0.75(0.3)
Running water in the house	0.37(0.5)	0.43(0.4)	0.53(0.5)	0.78(0.4)	0.79(0.4)
Access to mobile money	0.31(0.5)	0.34(0.4)	0.27(0.4)	0.29(0.5)	0.35(0.4)
Household marital status	0.73(0.4)	0.73(0.4)	0.81(0.4)	0.57(0.5)	0.61(0.5)
Monthly expenditure on food	861.79(882)	871.72(951)	879.09(1267)	1674(1650)	1572(1803)
Household head years of schooling	9.03(0.4)	7.95(4.4)	9.16(3.9)	10.32(0.3)	10.28(4.3)
Hectares of land owned	3.91(11.4)	6.29(35.62)	14.76(13.5)	0.59(1.8)	4.06(1.7)

**Parenthesis represents standard deviations*

Table B2.2: Results of GLM Estimation for the Continuous Treatment on Covariates

Variables	Coefficients	Robust Standard Error
House walls	1.0474***	0.2256
Electricity service Quality	0.5604***	0.1319
Area Price of Candle	0.5001***	0.1769
Household size	-0.0573**	0.0250
Use of solid fuel	1.0014***	0.1402
Type of household dwelling	0.0327	0.0790
Animal asset ownership	-0.3458	0.2369
Household head gender	-0.1016	0.1954
Running water	0.7212***	0.1389
Access to mobile money	-0.0714	0.1507
Ox-cart ownership	0.6061	0.4405
Household marital status	0.0277	0.0794
Monthly expenditure on food	0.0004***	0.00009
Monthly expenditure on food squared	-1.79e-08***	5.78e-09
Household head years of schooling	0.0577***	0.0136
Total hectares of land owned by household	-0.0081**	0.0040
Total hectares of land owned by household squared	8.38e-06**	4.07e-06

Constant	3.0197***	0.6766
Log Pseudolikelihood	-410.6392	
Number of observations	**1, 349**	

*, **, *** indicate 10%, 5% and 1% significance level

Table B2.3: Covariates Balancing for Continuous Treatment (Bayes Factor for Means Equality)

	Groups				
Covariates	**1 [0.042-0.125]**	**2 [0.167-0.292]**	**3 [0.333-0.625]**	**4 [0.667-0.916]**	**5 [0.958-1]**
House walls	1.636	2.717	4.025	1.085	5.425
Electricity service Quality	1.482	**0.953**	3.603	2.535	6.921
Area Price of Candle	1.302	1.020	1.933	1.921	5.249
Household size	2.004	1.258	4.012	**0.810**	2.151
Use of solid fuel	1.810	3.022	3.737	4.472	**0.893**
Type of household dwelling	**0.535**	3.382	3.853	2.913	5.978
Animal asset ownership	1.447	3.271	4.012	**0.871**	5.624
Household head gender	1.220	2.641	2.237	2.680	6.708
Running water	1.620	3.111	1.608	4.764	2.895
Access to mobile money	1.290	1.586	4.001	2.077	3.421
Ox-cart ownership	2.100	3.323	3.236	1.254	6.716
Household marital status	1.620	2.306	3.157	3.092	6.901
Monthly expenditure on food	2.095	2.034	2.870	3.902	2.038
Monthly expenditure on food squared	2.108	3.361	4.088	3.566	4.037
Household head years of schooling	2.045	2.000	3.716	3.961	6.379
Hectares of land	2.115	3.171	4.081	3.212	6.782
Hectares of land squared	2.061	3.000	4.090	3.924	6.689

*Bold numbers indicate Bayes factor less than 1:

Table B2.4: Regression Results for Conditional Expectation for Outcomes Variables

	Outcome Variables						
	Time allocation (Minutes/day)				**Employment in non-Agric**	**Household Expenditure**	
	Children studying (6-15 years)		**Working away from home for pay/self**			**Expenditure on alternative energy**	**Expenditure per capita (logs)**
	Boys	***Girls***	***Men***	***Women***			
Treatment	22.68	186.02	**1475.41****	823.25	10.68	191.44	-3.065
	(171.19)	(196.69)	(746.28)	(607.9)	(7.86)	(190.65)	(2.315)
Treatment squared	-289.74	-491.27	**-3206.4****	**-2295.2****	-18.92	-173.65	**6.996***

	(326.66)	(357.08)	(1332.14)	(1090.8)	(14.07)	(336.18)	(4.095)
Treatment cubic	198.06	329.41	**2106.07****	**1501.49****	11.65	99.11	-3.108
	(188.90)	(202.17)	(742.08)	(611.85)	(7.89)	(189.12)	(2.275)
GPS	1992.1	964.40	7410.26	6956.6	145.79	**5818.44****	**88.78*****
	(1360.9)	(1509.6)	(6480.97)	(5260.3)	(116.23)	(2105.60)	(20.3)
GPS squared	-2659.8	-1443.8	-10027.77	-10193.4	-188.03	**-7716.33****	**-132.64*****
	(1862.08)	(2056.7)	(8706.19)	(7061.6)	(153.23)	(2739.50)	(27.17)
GPS cubic	1154.42	703.89	4439.38	4850.7	85.60	**3449.52****	**67.273*****
	(832.77)	(917.23)	(3824.74)	(3101.8)	(66.4)	(1172.88)	(11.87)
Treatment x GPS	109.56	-1.352	-62.15	202.5	-2.111	-135.07	-1.392
	(74.34)	(78.87)	(310.77)	(257.8)	(3.27)	(81.97)	(0.974)
Constant	-412.18	-197.67	-1848.78	-1592.8	-40.55	**-1413.49****	**-12.582****
	(324.48)	(363.3)	(1572.4)	(1277.7)	(28.97)	(531.30)	(4.973)
R^2	***0.0174***	***0.0182***	***0.0552***	***0.0563***	***Loglikelihood= -360.028***	***0.0293***	***0.3935***
No. Obs	**586**	**598**	**1,147**	**1,126**	**1,029**	**1,006**	**1,325**

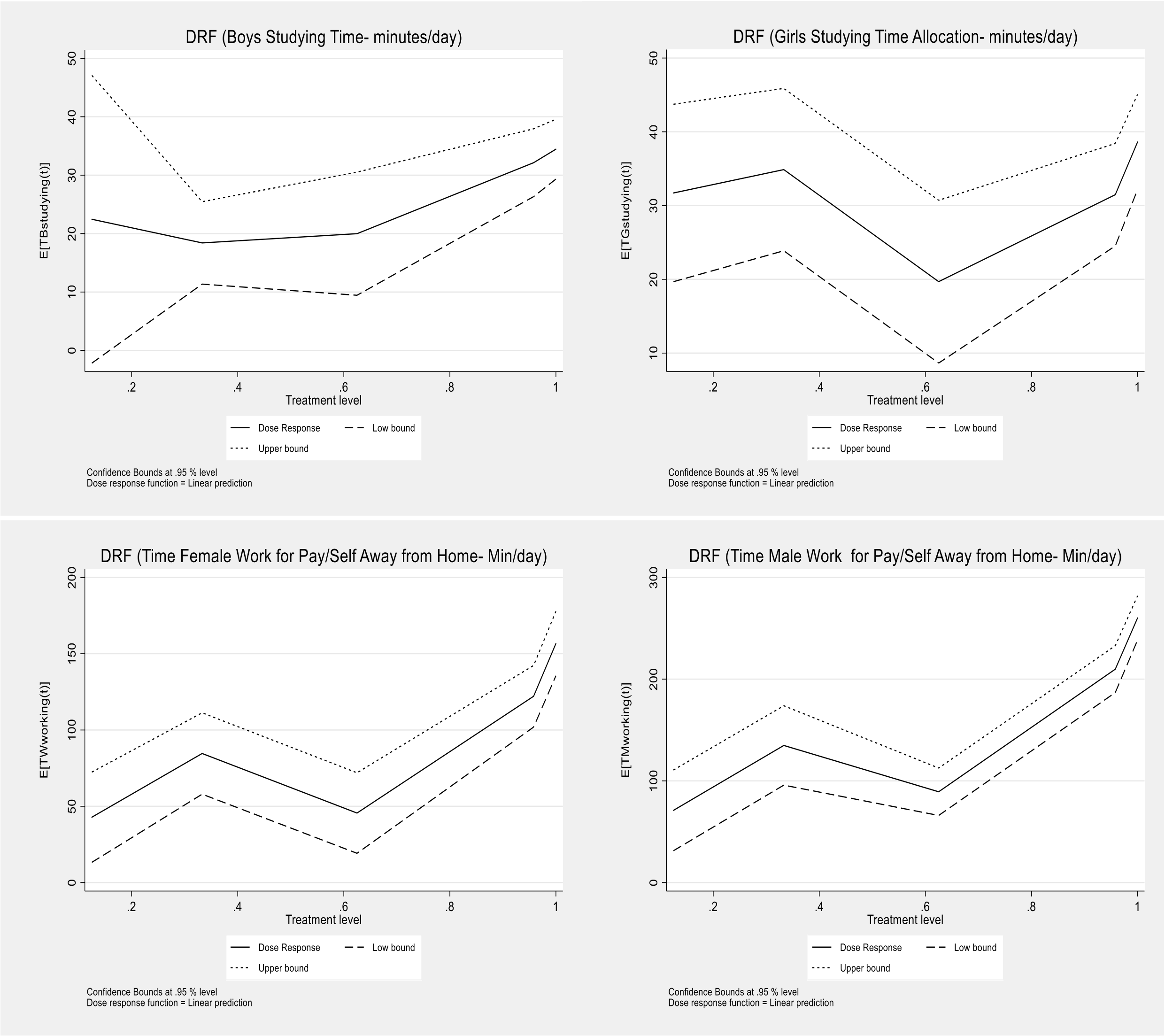
*, **, *** indicate 10%, 5% and 1% significance level

Table B2.5: Treatment Function Estimates for Marginal (Availability) Effect Within Tiers

	Outcome Variables						
Treatment Level (Tier) (With Delta=0.1 (2.4hrs))	**Time allocation (Minutes/day)**				**Employment in non-Agric sector**	**Household Expenditure**	
	Children studying (6-15 years)		**Working away from home for pay/self**			**Expenditure in Alternative Energy**	**Expenditure per- capita (logs)**
	Boys	***Girls***	***Men***	***Women***			
4 -6.4hrs	-2.78	4.39	**49.77*****	**33.79*****	0.05	2.23	**-0.21****
(0.16-0.26)	(5.46)	(5.07)	(15.06)	(9.04)	(0.28)	(8.49)	(0.09)
8-10.4 hrs	-0.41	**-4.57****	**-10.28****	**-9.40***	-0.005	-1.54	-0.03
(0.33- 0.43)	(3.32)	(2.20)	(5.09)	(5.05)	(0.01)	(1.99)	(0.03)
16-18.4hrs	**2.49*****	2.73	-2.35	-4.28	-0.009	-2.49	**0.09*****
(0.66-0.86)	(0.61)	(1.96)	(7.36)	(4.71)	(0.013)	(2.53)	(0.029)
23-25.4hrs	**5.80***	**19.93*****	**138.19*****	**95.31*****	**0.62*****	2.61	0.034
(0.96-1.06)	(3.26)	(4.71)	(9.18)	(14.67)	(0.014)	(6.53)	(0.06)
No. Obs.	**586**	**598**	**1,147**	**1,126**	**1,029**	**1,006**	**1,325**

Note: *, **, * indicate significance level of 1%, 5% and 10%**

Figure B2.1: Dose Response Functions (DRF) for Household Outcome Variables



DRF (Boys Studying Time- minutes/day)

Confidence Bounds at .95 % level
Dose response function = Linear prediction

DRF (Girls Studying Time Allocation- minutes/day)

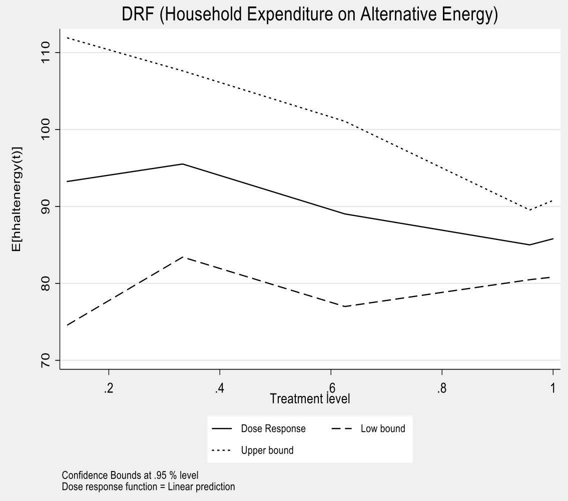
Confidence Bounds at .95 % level
Dose response function = Linear prediction

DRF (Time Female Work for Pay/Self Away from Home- Min/day)

Confidence Bounds at .95 % level
Dose response function = Linear prediction

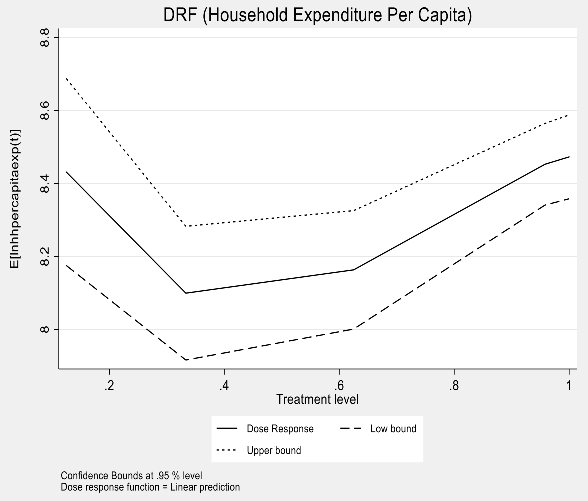
DRF (Time Male Work for Pay/Self Away from Home- Min/day)

Confidence Bounds at .95 % level
Dose response function = Linear prediction



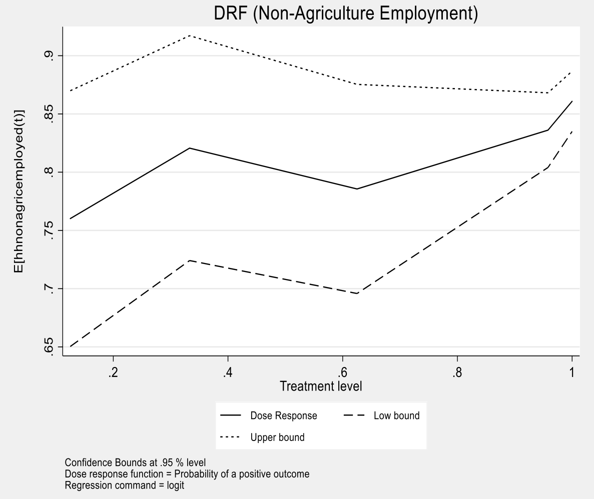
DRF (Household Expenditure on Alternative Energy)

Confidence Bounds at .95 % level
Dose response function = Linear prediction



DRF (Household Expenditure Per Capita)

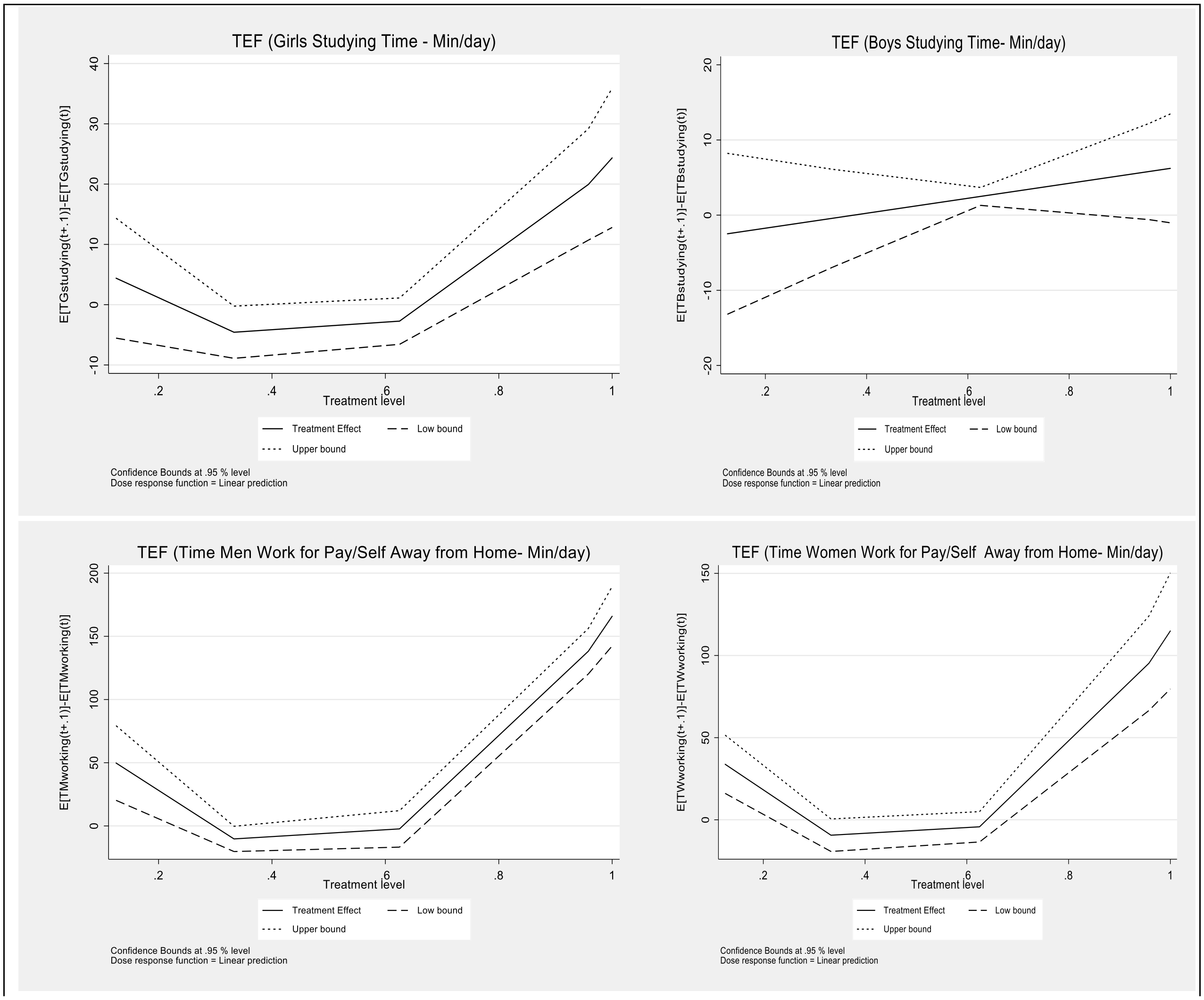
Confidence Bounds at .95 % level
Dose response function = Linear prediction

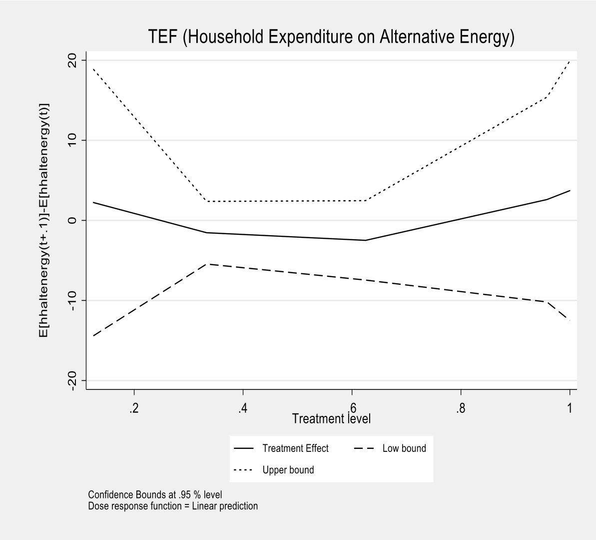


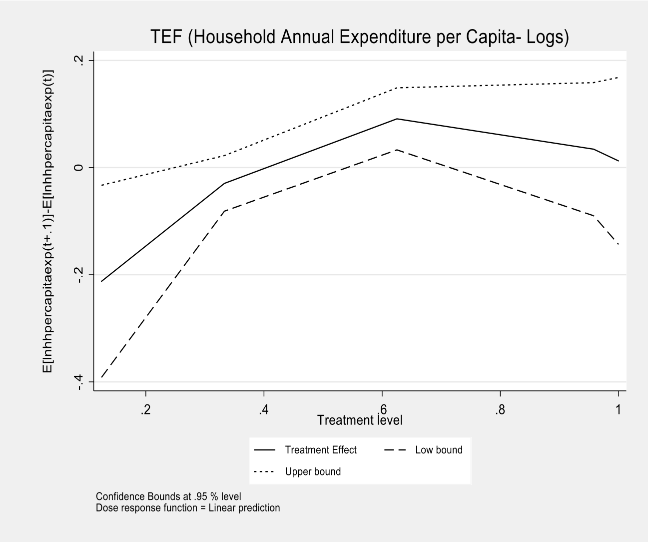
DRF (Non-Agriculture Employment)

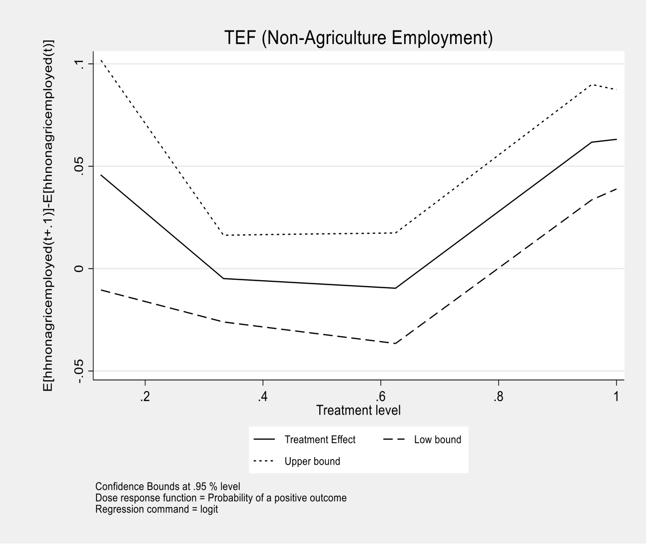
Confidence Bounds at .95 % level
Dose response function = Probability of a positive outcome
Regression command = logit

Figure B2.2: Derivative Treatment Effect Function (TEF) for Household Outcome Variables




TEF (Household Expenditure on Alternative Energy)
E[hhaltenergy(t+.1)]-E[hhaltenergy(t)]
20
10
0
-10
-20
.2
.4
.6
.8
1
Treatment level
Treatment Effect
Low bound
Upper bound
Confidence Bounds at .95 % level
Dose response function = Linear prediction


TEF (Household Annual Expenditure per Capita- Logs)
E[lnhhpercapitaexp(t+.1)]-E[lnhhpercapitaexp(t)]
.2
0
-.2
-.4
.2
.4
.6
.8
1
Treatment level
Treatment Effect
Low bound
Upper bound
Confidence Bounds at .95 % level
Dose response function = Linear prediction


TEF (Non-Agriculture Employment)
E[hhnonagricemployed(t+.1)]-E[hhnonagricemployed(t)]
.1
.05
0
-.05
.2
.4
.6
.8
1
Treatment level
Treatment Effect
Low bound
Upper bound
Confidence Bounds at .95 % level
Dose response function = Probability of a positive outcome
Regression command = logit

Appendix C: Paper Three

Table C3.1: Descriptive Statistics of the Non-Connected Household Characteristics

Variables	Observation	Mean	Standard Deviation	Min	Max
Bids (Grid electricity)	2140	764.88	445.24	297	2124
Bid (SHS Lower Capacity)	545	723.67	324.99	412	1250
Bid (SHS High Capacity)	1570	3533.76	1391.64	1534	4650
Household income	2140	1569	1620.73	0	15000
Distance to the grid	2140	9.28	15.89	1	200
No. of phones owned by household members	2140	0.70	1.06	0	8
Asset ownership	2140	0.19	0.39	0	1
Household head gender	2140	0.74	0.44	0	1
Household head years of schooling	2140	6.15	3.94	0	18
House roof (iron sheets)	2140	0.47	0.49	0	1
Access to finance	2140	1.22	0.58	1	3
Household location (rural)	2140	0.77	0.42	0	1
Household head employment status	2140	0.77	0.41	0	1
Household Grid connection price category	2140	1.26	0.52	1	4

Table C3.2: WTP Results for Grid Electricity Connection- Rural Areas

Variables	Upfront	3 months	6 months	12 months
Mean WTP	*K3361.5**** *(1098.4)*	*K4598.4**** *(1562.9)*	*K4920.3**** *(1694.8)*	*K6071.8**** *(2242.8)*
%($\frac{WTP-MP}{MP}$)	58.3%	116.5%	131.7%	185.8%

MP is market price (K2124); ***Note: ***, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent Robust Standard Error***: Source: Author's computations from World Bank/ESMAP (2018) dataset.

Table C3.3: WTP Results for Low-Capacity SHS- Rural Areas

Variables	Upfront	6 months	6 months	12 months
Mean WTP	*K540.9* *(365.04)*	*K513.6* *(344.4)*	*K977.9** *(508.3)*	*K2202*** *(1237.3)*
$\%(\frac{WTP-MP}{MP})$	-56.4%	-58.6%	-21. %	77.6%

MP is market price (K1240); ***Note: ***, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent Robust Standard Error***: Source: Author's computations from World Bank/ESMAP (2018) dataset.

Table C3.4: WTP Results for High-Capacity Solar Electricity- Rural Areas

Variables	Upfront	3 months	6 months	12 months
Mean WTP	*K3134.5**** *(1169.5)*	*K4370.1**** *(1040.8)*	*K4199.7**** *(1176.9)*	*K4382.8**** *(978.2)*
$\%(\frac{WTP-MP}{MP})$	-32.6%	-6.02%	-9.7%	-5.7%

MP is market price (K4650); ***Note: ***, **, * indicate significance level of 1%, 5% and 10%. Parentheses represent Robust Standard Error***: Source: Author's computations from World Bank/ESMAP (2018) dataset.

Table C3.5. Determinants of WTP for Grid Electricity Services with credit facility

Variables	3 months	6 months	12 months
Bids (Price)	-0.000262***	-0.00025***	-0.00023***
	(0.00006)	(0.00007)	(0.00007)
Household income	0.00004***	0.00060***	0.0019***
	(4.39e-06)	(7.94e-06)	(0.0002)
Distance to the grid	0.0056***	0.0059***	0.0046***
	(0.0016)	(0.0017)	(0.0017)
No. of phones	0.222***	0.227***	0.171***
	(0.038)	(0.036)	(0.035)
Asset ownership	-0.106	-0.044	-0.061
	(0.079)	(0.078)	(0.078)
Household head gender	-0.130	-0.153*	-0.099
	(0.081)	(0.083)	(0.083)
Household head years of schooling	0.035***	0.021***	0.023***
	(0.007)	(0.008)	(0.009)
House roof (iron sheets)	0.469***	0.452***	0.357***
	(0.075)	(0.074)	(0.075)
Access to finance			
2. mobile money	-0.192	-0.009	-0.028
	(0.137)	(0.133)	(0.134)

3. bank account	-0.402**	-0.222*	-0.252**
	(0.126)	(0.122)	(0.122)
Household location			
2. urban low cost	-0.113	0.119	-0.171*
	(0.016)	(0.096)	(0.097)
3.urban medium cost	0.858**	0.832**	0.745***
	(0.303)	(0.291)	(0.273)
4. urban high cost	0.593	0.733*	-0.110
	(0.420)	(0.416)	(0.399)
Household employment status (employed)	0.332***	0.292***	0.230***
	(0.079)	(0.079)	(0.080)
Constant	0.923***	0.966***	0.984***
	(0.110)	(0.109)	(0.109)

Note: ***, **, * indicate significance level of 1%, 5% and 10%;

Table C3.6. Determinants of WTP for Low-capacity SHS Electricity with Credit Facility

Variables	**6 months**	**12 months**	**24 months**
Bids	-0.00093***	-0.00054***	-0.00035**
	(0.00018)	(0.00017)	(0.00017)
Household income	0.00011**	0.00012**	0.00011**
	(0.00044)	(0.00065)	(0.00046)
Distance to the grid	-0.003	0.009**	0.005
	(0.003)	(0.004)	(0.004)
No. of phones	0.234**	0.169**	0.146*
	(0.079)	(0.075)	(0.075)
Asset ownership	-0.204	-0.256*	-0.365**
	(0.153)	(0.148)	(0.147)
Household head gender	-0.035	-0.139	-0.133
	(0.172)	(0.163)	(0.163)
Household head years of schooling	-0.002	0.019	0.018
	(0.015)	(0.015)	(0.016)
House roof (iron sheets)	0.391**	0.297**	0.275*
	(0.151)	(0.147)	(0.148)
Access to finance			
2. mobile money	-0.339	-0.314	-0.457
	(0.295)	(0.289)	(0.282)
3. bank account	0.054	0.070	0.060
	(0.234)	(0.231)	(0.232)
Household location (rural)	0.262	0.284	0.273
	(0.199)	(0.194)	(0.191)

Household employment status (employed)	0.273	0.163	0.178
	(0.168)	(0.162)	(0.161)
Constant	0.773**	0.663**	0.729**
	(0.311)	(0.286)	(0.289)

Note: ***, **, * indicate significance level of 1%, 5% and 10%.

Table C3.7. Determinants of WTP for High-capacity SHS Electricity with Credit Facility

Variables	6 months	12 months	24 months
Bids	-0.000099***	-0.00012***	-0.00013***
	(0.000017)	(0.000018)	(0.000019)
Household income	0.00014 ***	0.00019	0.00018
	(0.000019)	(0.000018)	(0.0000184)
Distance to the grid	0.0049**	0.0038**	0.0042**
	(0.0017)	(0.0018)	(0.0018)
No. of phones	0.148**	0.149***	0.185***
	(0.034)	(0.033)	(0.034)
Asset ownership	-0.144*	-0.218**	-0.196**
	(0.085)	(0.079)	(0.077)
Household head gender	0.170*	0.151*	0.150*
	(0.095)	(0.085)	(0.083)
Household head years of schooling	0.018**	0.044***	0.051***
	(0.008)	(0.008)	(0.008)
House roof (iron sheets)	0.259***	0.158**	0.264***
	(0.079)	(0.075)	(0.074)
Access to finance			
2. mobile money	-0.092	-0.274*	-0.458**
	(0.147)	(0.141)	(0.138)
3. bank account	0.023	-0.152	-0.271**
	(0.121)	(0.118)	(0.118)
Household location (rural)	0.032	0.065	0.094
	(0.099)	(0.097)	(0.093)
Household employment status (employed)	0.281***	0.342***	0.258***
	(0.081)	(0.075)	(0.071)
Constant	0.547***	0.701***	0.841***
	(0.065)	(0.067)	(0.069)

Note: ***, **, * indicate significance level of 1%, 5% and 10%.

Table C3.8: Mean Difference Test for Solar PV Electricity – t-value

Variables	Mean (Standard Deviation)		Mean Difference (t-value -/+)
	Low-capacity solar PV	High -capacity Solar PV	
Household income	1517.32 (1424.18)	1553.31(1615.60)	-35.99 (0.48)
Distance to the grid	10.39 (14.99)	9.14 (16.24)	1.26* (1.65)
No. of phones owned by household members	0.55 (0.97)	0.69 (1.04)	-0.15** (2.96)
Asset ownership	0.19 (0.39)	0.17 (0.38)	-0.02 (1.08)
Household head gender	0.73 (0.44)	0.74 (0.01)	-0.01 (0.74)
Household head years of schooling	6.192 (3.98)	6.195 (3.86)	-0.003 (0.017)
House roof (iron sheets)	0.44 (0.47)	0.47 (0.49)	-0.03 (1.12)
Access to finance	1.23 (0.59)	1.22 (0.58)	0.01 (0.44)
Household location (rural)	0.76 (0.43)	0.76 (0.43)	0.00 (0.08)
Household head employment status	0.83 (0.38)	0.76 (0.42)	0.07 ***(3.28)

Note: ***, **, * indicate significance level of 1%, 5% and 10%.

Appendix D: Paper Four

Figure D4.1: Open Fire/ 3stone Stoves

Source: Luzi et al. (2019). This type relies on firewood and are usually used in an open space. It has high smoke emission and inefficient form of cookstove.

Figure D4.2: Traditional Mbaula Stoves

Source: Luzi et al. (2019). This type of the cookstove is deemed inefficient and uses charcoal as the fuel.

Figure D4.3: Improved Mbaula Stoves

Source: Luzi et al. (2019). The cookstove is improved mbaula because it uses less charcoal to cook the same meal that can be cooked with the traditional Mbaula. It is deemed more efficient compared to the traditional mbaula and it is little bit expensive. Both (traditional and improved mbaula) use charcoal as the fuel.

Figure D4.4: Modern Cookstove (Electric and LPG Stoves)

Source: Luzi et al. (2019). The picture shows two types of cookstoves: electric stove in the first picture and the LPG stove (second) in the second picture. Based on the MTF, households who adopt these cookstoves are usually in Tier 4/5 based on the attributes of cooking energy solutions.

Table D4.1: Distribution of Household Primary Cookstove Choice

Type of Cookstove	Obs	Percentage
3stones/firestove	1,384	39.35
Mbaula	1,644	46.73
Electric stove	490	13.92
Total	***3,****518*	***100***

Table D4.2: Distribution of Household Primary Cooking Energy Fuel Choices

Cooking Energy Fuel	Obs	Percentage
Firewood	1,393	39.61
Charcoal	1,634	46.43
Electricity	491	13.96
Total	***3,****518*	***100***

Table D4.3: Bivariate Probit Results for Cooking Energy Solution Choice

Variables	**Traditional Cooking Energy**		**Intermediate Cooking Energy**		**Modern Cooking Energy**	
	Firewood (=1)	Fire stove/3stone (=1)	Charcoal (=1)	*Mbaula* Stove (=1)	Electricity (=1)	Electric stove (=1)
Household Characteristics						
Number of rooms	0.012**	0.008*	0.076***	0.078***	-0.096***	0.105**
	(0.034)	(0.034)	(0.028)	(0.028)	(0.044)	(0.044)
Household head age	-0.020	-0.026	0.026*	0.032***	-0.013	0.021
	(0.016)	(0.016)	(0.015)	(0.015)	(0.028)	(0.028)
Household head age squared	0.0002	0.003	-0.0003	-0.0003	1.1e-04	2.06e-04
	(0.002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	0.0003
Access to finance service						
2. mobile account	-0.345**	0.367***	0.567***	0.567***	-0.128	-0.457
	(0.155)	(0.154)	(0.133)	(0.133)	(0.264)	(0.265)
3. Bank account	-0.693***	-0.752***	0.074	0.103	0.860***	0.854***
	(0.114)	(0.113)	(0.089)	(0.089)	(0.146)	(0.146)
Household size	0.070***	-0.065	-0.023	-0.020	-0.157***	-0.156***
	(0.018)	(0.018)	(0.016)	(0.016)	(0.031)	(0.031)
Monthly household expenditure	-0.0001***	-1.3e-05	3.94e-05***	-6.16e-04***	7.01e-05**	6.99e-05**
	(3.9e-05)	(3.9e-05)	(1.4e05)	(1.4e-04)	(2.14e-05)	(2.41e-05)
Area price of candle	0.048	0.058	-0.120***	-0.132***	0.185	0.183
	(0.058)	(0.058)	(0.056)	(0.056)	(0.102)	(0.103)
Number of mobile phones	-0.219***	-0.213***	0.188***	0.184***	0.034	0.038
	(0.039)	(0.039)	(0.029)	(0.029)	(0.047)	(0.046)
Location (urban)	-1.549***	-1.583***	-1.248***	1.273***	1.009***	0.996***
	(0.082)	(0.082)	(0.077)	(0.077)	(0.139)	(0.139)
Dwelling ownership (yes)	0.632***	0.609***	-0.414***	-0.389***	-0.253**	-0.249**
	(0.092)	(0.092)	(0.075)	(0.075)	(0.125)	(0.125)

Agric land ownership (Yes)	0.562**	0.472***	-0.389***	-0.318***	0.043	0.064
	(0.083)	(0.083)	(0.079)	(0.078)	(0.157)	(0.156)
Fuel availability						
2. mostly available	0.254***	0.168*	-0.043	0.026	0.119	0.091
	(0.088)	(0.088)	(0.073)	(0.073)	(0.122)	(0.122)
3. sometimes available	-0.432	-0.465*	-0.839***	0.861***	-0.838**	-0.849**
	(0.270)	(0.270)	(0.205)	(0.205)	(0.307)	(0.308)
4.rarely available	0.234	0.224	0.432	0.447	-7.074	-7.059
	(0.049)	(0.503)	(0.417)	(0.417)	(3667)	(3666)
Cooking place						
1. Outdoors	-0.097	-0.079	1.447***	1.428***	-3.136***	-3.036***
	(0.081)	(0.081)	(0.075)	(0.075)	(0.188)	(0.172)
Duration preparing cookstove and fuel	-0.022***	-0.023**	0.064***	0.065***	-0.083	-0.158
	(0.009)	(0.009)	(0.008)	(0.008)	(0.604)	(0.016)
Female Decision-Making Indicator						
Women Social Network	-0.223**	-0.231**	0.042	0.053	0.183***	0.210**
	(0.061)	(0.061)	(0.061)	(0.061)	(0.074)	(0.074)
Female cooking daily (Yes)	0.461***	0.441***	0.085	0.081	-0.168*	-0.150*
	(0.079)	(0.079)	(0.097)	(0.097)	(0.098)	(0.098)
Female employment (Yes)	0.088	0.081	-0.958	-0.958	0.052	0.051
	(0.556)	(0.056)	(0.648)	(0.648)	(0.072)	(0.072)
Female economic activity						
2. Housewife	0.422***	0.433***	-0.247***	-0.223***	-0.055	-0.047
	(0.061)	(0.061)	(0.078)	(0.078)	(0.089)	(0.089)
3. Self-employed	0.638***	0.657***	0.483	0.534	-0.064	-0.054
	(0.072)	(0.072)	(0.654)	(0.065)	(0.123)	(0.122)
4. Salaried Employed	-0.634***	-0.635***	0.781	0.790	0.477**	0.468***
	(0.103)	(0.103)	(0.641)	(0.641)	(0.123)	(0.123)
Female years Schooling	-0.128***	-0.129***	0.064***	0.046***	0.167***	0.165***
	(0.006)	(0.006)	(0.007)	(0.007)	(0.010)	(0.009)
Educated Female (Yes)	-0.701***	-0.680***	0.047	0.028	1.392***	1.393***
	(0.056)	(0.056)	(0.053)	(0.053)	(0.901)	(0.901)
Male Decision-Making Indicators						
Male cooking daily (yes)	0.131	0.155	-0.081	-0.105	0.226**	0.227
	(0.121)	(0.121)	(0.062)	(0.062)	(0.068)	(0.068)
Male employment (yes)	-0.216	-0.231	-0.635	-0.627	0.208	0.197
	(0.711)	(0.711)	(0.602)	(0.599)	(0.071)	(0.071)
Male economic activity						

2. Self-employment	0.639	0.652	0.123	0.127	-0.132*	-0.131*
	(0.714)	(0.714)	(0.605)	(0.602)	(0.081)	(0.081)
3. Salary employee	-0.490	-0.460	0.855	0.843	0.658***	0.642***
	(0.709)	(0.709)	(0.602)	(0.599)	(0.073)	(0.073)
Male years of schooling	-0.127***	-0.129***	0.042***	0.043***	0.140***	0.139***
	(0.009)	(0.009)	(0.006)	(0.006)	(0.009)	(0.009)
Educated male (yes)	-0.331**	-0.297**	0.032	0.012	1.283***	1.282***
	(0.126)	(0.128)	(0.068)	(0.068)	(0.073)	(0.073)
Constant	-0.088	-0.070	-1.314***	-1.383***	-0.732***	-0.770***
	(0.569)	(0.569)	(0.488)	(0.487)	(0.243)	(0.242)
Rho (ρ)	0.994***		0.995***		1***	
	(0.0005)		(0.00037)		(4.19e-05)	
Loglikelihood	-468.679		-634.50		-165.59	

Note: *, **, * indicate significance level of 1%, 5% and 10%**

Table D4.4: Gender Effect of Access to Cooking Energy Solution Across Tiers (Rural Area)

	Health Outcomes		**Time spent on (min/day**							
Tiers	**Respiratory Illness**		**Cooking**		**Fuel Collection and Preparation**		**Studying**		**Income Generation**	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1 vs 0	0.020	-0.008	-32.16***	-9.68**	-5.73	2.85	2.78	-3.46	**19.72****	**19.68****
	(0.018)	(0.021)	(7.18)	(4.39)	(5.21)	(5.62)	(5.76)	(5.87)	(5.49)	(7.95)
2 vs 1	**-0.062***	**-0.059****	**-28.64*****	**-23.77****	9.07	2.31	-8.63	**10.86****	8.43	**19.16***
	(0.035)	(0.027)	(7.03)	(4.57)	(7.89)	(7.46)	(6.31)	(5.72)	(7.45)	(11.56)
3 vs 2	**-0.078****	0.012	**-13.27****	**-9.05****	**-14.49****	7.83	**13.69****	**19.45****	**21.33*****	**27.78****
	(0.032)	(0.013)	(6.14)	(3.72)	(7.58)	(7.02)	(6.56)	(5.50)	(7.78)	(9.33)
4 vs 3	**-0.075****	0.003	**-33.55*****	**-7.25****	**-13.75***	**-17.73****	**14.52****	6.03	**27.35*****	**33.07*****
	(0.033)	(0.022)	(8.89)	(3.66)	(7.09)	(5.97)	(6.81)	(6.19)	(7.12)	(8.95)
5 vs 4	**-0.031****	-0.023	**-15.62****	**-6.75***	**-14.6*****	**-8.67****	6.61	1.37	**15.93****	11.84
	(0.014)	(0.019)	(5.73)	(3.90)	(4.88)	(3.68)	(5.63)	(6.61)	(7.58)	(9.31)

Note: *, **, * indicate significance level of 1%, 5% and 10%**

Table D4.5: Gender Effect of Access to Cooking Energy Solution Across Tiers (Urban Area)

	Health Outcomes		Time spent on (min/day)							
Tiers	Respiratory Illness		Cooking		Fuel Collection and Preparation		Studying		Income Generation	
	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male
1 vs 0	**-0.158***	**-0.147****	-13.03	**-21.68****	**-26.70****	**-32.76****	-2.67	-18.31	7.24	10.34
	(0.091)	(0.076)	(10.62)	(9.06)	(9.73)	(10.32)	(11.27)	(15.50)	(10.38)	(10.38)
2 vs 1	0.047	0.014	**-16.56****	**-25.02*****	**-4.72****	-0.194	-2.55	2.27	**15.08****	9.24
	(0.064)	(0.022)	(5.28)	(6.27)	(2.25)	(3.90)	(4.13)	(3.45)	(6.62)	(7.20)
3 vs 2	-0.024	-0.188*	**-7.37***	**-14.83****	-1.13	-2.41	**8.72***	**19.55****	**9.89****	3.12
	(0.088)	(0.110)	(4.12)	(5.97)	(2.83)	(1.69)	(5.24)	(8.18)	(3.78)	(6.98)
4 vs 3	-0.055	-0.195	**-19.99****	-10.43	-2.49	-1.64	**19.05***	**15.78***	7.07	**13.27***
	(0.081)	(0.107)	(7.55)	(10.90)	(5.05)	(7.52)	(10.85)	(8.89)	(11.18)	(7.38)
5 vs 4	-0.108	0.113	**-23.27****	-3.33	**-10.95****	-7.75	**13.24***	16.17	4.93	12.42
	(0.218)	(0.224)	(7.86)	(8.33)	(4.42)	(6.39)	(7.71)	(9.92)	(12.53)	(12.85)

Note: *, **, * indicate significance level of 1%, 5% and 10%**