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博 士 論 文

令和元年 6 月

神戸大学大学院経済学研究科

経済学専攻

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Three Essays on Household Energy Use in Ghana

(ガーナにおける家計のエネルギー利用に関する研究)

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Chapter 1

Introduction

Energy is a key component of a household consumption basket. Cooking and lighting are two of the main energy uses at the household level. Although households derive satisfaction from cooking, the source of cooking energy can cause disutility. In most developing countries, fuelwood (firewood, charcoal, crop residue and saw dust) is a major energy source for household cooking, as a significant number of people, especially those living in the rural areas, still do not have access to electricity. Unfortunately, the use of these traditional cooking fuels causes indoor air pollution that is harmful to the health of people, and especially to the elderly, women, and children. Dependency on traditional energy services coupled with limited access to electricity is generally termed energy poverty. According to Gonzalez-Eguino (2015), energy poverty is among the three main challenges facing the energy sector in the coming decades, along with energy security and climate change.

One of the solutions for reducing energy poverty is to encourage households to switch from traditional energy sources to cleaner and modern energy. However, access to modern energy services continues to be a challenge for many developing countries, particularly those in sub-Saharan African (SSA). Access to energy was not on political agendas until the United Nations (UN) included access to energy in its Sustainable Development Goals in 2012. The UN General Assembly's "International Year for Sustainable Energy for All" also emphasized the importance of access to energy. In most

developing countries, however, lower purchasing power and an inadequate supply of modern energy services are barriers to that goal.

In Ghana, biomass fuels are the primary cooking fuels for more than 70% of households. Household air pollution as a result of these biomass fuels causes 16,600 deaths and the loss of 502,000 disability-adjusted life-years annually (Asante et al., 2018). Ghana has made some progress in reducing the dependence on traditional energy as part of its goal to reduce energy poverty. Programs such as the Rural Liquefied Petroleum Gas (LPG) Promotion Program, the Self-Help Electrification Program (SHEP) and the distribution of efficient cooking stoves have contributed to reducing energy poverty. Taking Ghana as an example of SSA and developing countries, this thesis consists of three essays (Chapters 2, 3 and 4) that cover issues related to energy poverty, energy expenditure, and rural electrification in Ghana.

The first essay (Chapter 2) investigates the dynamics of energy poverty in Ghana using two nationwide cross-sectional datasets (Ghana Living Standards Surveys V and VI). Employing the Multidimensional Energy Poverty Index (MEPI) as a measure of energy poverty, the estimates show that the share of people in energy poverty decreased from 87.3% in 2005/2006 to 80.3% in 2012/2013. The results indicate that although there has been a significant decline in the overall energy poverty during the study periods, the incidence of energy poverty remains high. Moreover, the study findings show a large gap between urban and rural energy poverty over the two periods; the energy poverty in rural areas is almost twice that in urban areas. These findings suggest the need to incorporate energy-poverty reduction strategies into income-poverty reduction strategies to improve access to modern energy and affordability.

The second essay (Chapter 3) examines the factors affecting household energy expenditures in Ghana. The double-hurdle model is used to investigate whether the factors affecting fuel choice differ from those affecting fuel expenditures. The following results are obtained using a nationwide representative household dataset. First, the results show that the factors influencing a household's decision to participate in either the LPG or charcoal market differ from those influencing how much money is spent. Second, households that already use and, therefore spend money to acquire LPG or charcoal are indifferent to the prices of other fuels. Similarly, households using and spending positive amounts of money on multiple cooking fuels (charcoal and LPG) are insensitive to the prices of other fuels. Third, although income plays a role in rural and urban residents' expenditures on LPG, it is insignificant in terms of urban residents' spending on charcoal. These findings suggest that different programs and policies may be necessary for households that already use modern cooking fuels and those that do not and, as well as for households in urban and rural areas.

The third essay (Chapter 4) examines why some rural households and communities remain without power despite Ghana's progress in rural electrification. The objectives are to analyze the role of socio-economic factors in household electrification and to also examine the welfare impacts of one of Ghana's flagship rural electrification programs. Using the most recent two household datasets constructed from two nationwide household surveys (GLSS VI and GLSS VII samples) combined with other community datasets, the following results were obtained. First, household expenditure, employment status, and gender of the head of the household are significant predictors of rural household electrification in Ghana. Second, these robust predictors tend to persist

over the two sample periods. Third, using one of Ghana's flagship rural electrification programs called the Self-Help Electrification Programme (SHEP) as a proxy for public policy, the results indicate that SHEP correlates with improvements in electrification rates of rural communities. Lastly, although rural electrification improves community welfare, its impact is skewed towards rural communities with higher average household expenditure.

Chapter 5 presents the concluding remarks of the thesis.

Chapter 2

Energy Poverty in Ghana: Any Progress So Far?

2.1 Introduction

Every developed economy ensures access to modern energy sources as the underpinning of its economic prosperity. Although energy was not included in the United Nation's Millennium Development Goals (MDGs), it played an important role in reducing poverty and attaining the MDGs. This was emphasized by the former Secretary-General of the United Nations (UN), Ban-Ki-moon: 'Development is not possible without energy, and sustainable development is not possible without sustainable energy.'¹ The importance of energy in this modern era has led the UN to include energy in its Sustainable Development Goals (SDGs). Specifically, goal seven of the SDGs is to ensure universal access to affordable, reliable, sustainable, and modern energy by the year 2030.

Access to modern energy services is a persistent challenge to many developing countries, particularly sub-Saharan African (SSA) countries. Among the 1.2 billion people in developing countries who do not have access to electricity, more than 634 million people live in SSA countries (International Energy Agency (IEA), 2015). The IEA reports that more than 2.7 billion people in developing countries depend on traditional biomass (e.g., wood, agricultural residues, and animal dung) for cooking. In

¹ A Framework for Action on Sustainable Energy for All by "The Secretary-General's High Level Group on Sustainable Energy for All," January 2012.
http://www.se4all.org/sites/default/files/l/2013/09/SE_for_All_-_Framework_for_Action_FINAL.pdf

SSA countries alone, more than 753 million people rely on traditional biomass for cooking. The heavy reliance on traditional biomass exposes people to indoor pollution that causes several respiratory diseases.

Reddy (2000, p.44) defined energy poverty as “the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe, and environmentally benign energy services to support economic and human development.” In the energy poverty literature, the terms “energy poverty” and “fuel poverty” are used almost interchangeably. While fuel poverty is often used in the context of developed and relatively wealthy countries (e.g., New Zealand and the United Kingdom), energy poverty is typically used in studies that focus on developing and relatively poor countries (e.g., Ghana, India and SSA countries).² One of the differences between these two is that the former entails fuel use for heating. This chapter addresses only energy poverty and not fuel poverty because there is no need for heating fuel in Ghana.

There are studies that address various aspects of energy poverty. Examples include the examination of household determinants of energy poverty (Ismail and Khembo, 2015; Ogwumike and Ozughalu, 2016), the estimation of an energy poverty line (Barnes et al., 2010; Foster et al., 2000), and the construction of various energy poverty measures (Nussbaumer et al., 2012; Pachauri and Spreng, 2004; Wang et al., 2015). However, none of these studies examined the dynamics of energy poverty, i.e., the change of energy poverty between time periods.

In Ghana, several programs have been undertaken over the years to reduce the high dependence on traditional biomass. Notable among them is the National Liquefied

² For a comprehensive review of the differences between energy poverty and fuel poverty, see Li et al. (2014).

Petroleum Gas (LPG) promotion campaign, which began in the early 1990s with the aim to encourage the use of LPG as an alternative cooking fuel to the traditional biomass. However, after years of implementation, minimal work has been done to ascertain the effectiveness of these programs in reducing the use of traditional biomass. This leads us to an important question: have the various programs engendered any significant transition from the use of traditional biomass to modern energy? This chapter attempts to answer the question by examining the dynamics of energy poverty in Ghana during the period from 2005 to 2013.

This chapter serves three purposes. First, this chapter examines the dynamics of energy poverty in Ghana using two nationally representative cross-sectional datasets: the Ghana Living Standards Survey conducted in 2005/2006 (GLSS V) and 2012/2013 (GLSS VI). By comparing energy poverty in two periods, this chapter assesses the effect of energy poverty alleviation policies for SDG attainment. Second, we compare energy poverty between rural and urban areas. Of those who depend on traditional biomass, 80% live in rural areas; therefore, they are more energy poor than those living in urban areas (IEA, 2015). By comparing urban and rural areas in two time periods, this chapter can examine the differences in energy poverty between these areas and determine whether the energy poverty gap is widening. Third, this chapter compares regional differences in energy poverty. In terms of income poverty, there are wide differences between the three northern regions and the remaining regions.³ Therefore, it is expected that energy poverty in the three northern regions will be highest among all regions.

³ Ghana has 10 administrative regions. The three northern regions are the Upper East region, Upper West region, and the Northern region.

The remainder of the chapter is organized as follows. Section 2.2 discusses three consequences of energy poverty, including its impacts on health, the environment, and the economy. Section 2.3 provides an overview of policy interventions relating to energy poverty in Ghana. Section 2.4 explains the data and the methodology used to measure energy poverty. Section 2.5 presents the results while section 2.6 concludes and offers some policy recommendations.

2.2 Consequences of Energy Poverty

2.2.1 Impacts on Health

In general, households in developing countries are highly dependent on traditional biomass for cooking. Traditional biomass is usually burnt in homes, thereby exposing household members to indoor air pollution. The use of candles and kerosene lamps as sources of lighting also creates indoor air pollution, which contains high levels of particulate matter (PM) and toxins that are hazardous to the respiratory system. The IEA (2015) reports that approximately one-third of the total world population (2.7 billion) relies on traditional biomass for cooking. Out of this number, 754 million people are in Africa and 1.9 billion people are in developing Asia.

Indoor air pollution caused by traditional biomass is characterized by high levels of carbon monoxide, aromatic compounds, and suspended fine particles. These suspended fine particles are known to contain ash, soot, and metal elements. Suspended fine particles with diameters of 2.5 micrometers or less are known as PM_{2.5}, and those with diameters of 10 micrometers or less are known as PM₁₀. The World Health Organization (WHO) estimates that in homes where combustion of traditional biomass

occurs, PM₁₀ concentrations tend to vary daily between 303 and 3,000 µg/m³, which is two to twenty times as high as the U.S. regulation standard of 150 µg/m³ (WHO, 2006).

Zhou et al. (2010) analyzed geo-referenced data on indoor air pollution in four neighborhoods in Accra, Ghana. The study found that PM concentrations vary among neighborhoods and socioeconomic status (SES) of communities. Specifically, PM_{2.5} concentrations from traditional biomass use in high and low-SES neighborhoods vary between 21–29 µg/m³ and 23–33 µg/m³, respectively. However, in two low-SES slums, PM_{2.5} and PM₁₀ concentrations were estimated to vary between 62– 80 µg/m³ and 114–150 µg/m³, respectively.

Medical studies have found that PM engenders health problems, particularly among children, the elderly, and women. Inhaling PM causes asthma, lung cancer, cardiovascular diseases, and respiratory diseases. According to the IEA (2007), there is a causal relationship between exposure to PM and children's acute respiratory infections, particularly pneumonia, which might increase the death rate of children under five years old. The WHO (2006) indicates that indoor air pollution doubles the risk of pneumonia in children under five years old. It also reports that women who use traditional biomass as their source of cooking energy are three times more likely to suffer from chronic obstructive pulmonary disease than those who cook with electricity.

The WHO (2009) estimates that 1.3 million people die prematurely each year from indoor air pollution from the use of solid fuels. It also reports that 85% of these deaths can be attributed to biomass use, with the remaining 15% attributed to the use of coal. The number of premature deaths caused by indoor air pollution is highest in Southeast Asia and SSA.

2.2.2 Impacts on the Environment

High dependence on traditional biomass has positive and negative impacts on the environment. A positive impact is the displacement of fossil fuel use leading to a reduction in air pollution and acid rain. Another positive impact is the recycling of atmospheric carbon dioxide emissions (CO₂). However, overexploitation of biomass use increases deforestation, desertification, and changes in land use.

One-third of the earth's land surface is covered by forests that provide many benefits, e.g., ecosystems provide sources of food and water for the population, and soil conservation brings biodiversity. However, biomass use erodes all these benefits via deforestation. Deforestation is a concern for developing countries because it shrinks tropical forest areas, causing a loss of biodiversity, and enhancing the greenhouse effect (Chakravarty et al., 2012). From 1990 to 2015, the global forest area reduced by approximately 129 million hectares (Food and Agriculture Organization, FAO, 2015). According to Gonzalez-Eguino (2015), a relationship exists between energy poverty and the environment via land use changes, such as when forests are converted to other land uses such as hunting and agriculture. It is estimated that 7 million hectares of forest have been lost per year in tropical climate regions, which increased agricultural land area by 6 million hectares from 2000 to 2010 (FAO, 2015).

Ghana lost an average of 135,000 hectares of forest per year between 1990 and 2000 (FAO, 2007). Moreover, Ghana's forests decreased by 115,000 hectares between the period 2000 and 2005. As a result, Ghana lost 26% of its forest cover from 1990 to 2005 making it one of the countries with the highest deforestation rates in the world at 2% per annum. In Ghana, most wood removals are used for household cooking, with the

remainder used for industrial purposes. Deforestation in Ghana is also driven by other factors, such as slash and burn agriculture, rising demand for fuelwood, timber harvesting, and wildfires (Gyampoh, 2011).

2.2.3 Impacts on the Economy

One of the key components of energy poverty is the lack of access to electricity. According to an IEA (2015) report, approximately one-fifth of the total world population (1.2 billion people) had no access to electricity in 2013. Of this number, 635 million people are in Africa and 526 million people are in developing Asia. In total, 99.8% of the total global population with no access to electricity is in developing countries. The greatest challenge to addressing electricity access is in SSA, where only 32% of the population has access to electricity, representing the lowest level in the world (IEA, 2015). A lack of electricity is a major cause of poverty in most SSA countries (Brew-Hammond and Kemausuor, 2009).

Researchers have attempted to examine the link between access to electricity and economic development. On a macro level, some studies have examined the impact of electricity on different development outcomes, such as productivity, growth, and poverty reduction. Some of these studies found positive relationships between access to electricity and productivity (Fan et al., 2004; Fedderke and Bogetic, 2006; Um et al., 2009), access to electricity and economic growth (Ayogu, 1999; Canning and Pedroni, 2004), and access to electricity and poverty reduction (Fan et al., 2004; Fan et al., 2002). At the micro level, several studies have shown that access to electricity enhances firm productivity, creates employment, and improves household income (Arnold et al., 2008;

Goedhuys and Sieuwaegen, 2010). In terms of education, empirical evidence shows that countries with higher levels of access to electricity tend to have higher literacy rates and lower drop-out rates, and devote significant time to reading and studying (Khandker et al., 2014). These empirical studies emphasize the importance of access to electricity in enhancing economic growth.

The IEA estimates that 7 million people in Ghana are without access to electricity. Although the electrification rate in Ghana (72%) is one of the highest among SSA countries, a major concern is the stability of the electricity supply.⁴ Multiple factors such as the breakdown of thermal power plants, financial difficulties in purchasing gas from Nigeria Gas to power thermal plants, unexplored renewable energy resources, a monopolized distribution regime, distorted tariff systems, and intermittent rainfall patterns, have all accounted for the unstable electricity supply over the past years (Ackah, 2016). Mathrani et al. (2013) indicates that a lack of stable electricity supply is the second most important constraint to business activities in the country and that Ghana lost approximately 1.8% of GDP during the country's 2007 power crisis.⁵ Similarly, a report by the Institute of Statistical, Social, and Economic Research (ISSER, 2015) showed that Ghana loses approximately \$2.2 million daily and \$686.4 million annually (translating into approximately 2% of GDP) due to the crisis.

⁴ Energy poverty does not directly measure power outages. Ghana has been experiencing a power crisis over the past few years.

⁵ Some of the main reasons for the 2007 power crisis include poor rainfall and the non-availability of sufficient reliable thermal power generators.

2.3 Overview of Interventions to Energy Poverty in Ghana

2.3.1 Electricity

Until 1990, hydropower was the only source of electricity generation in Ghana. Because of a rising population and the increasing demand for electricity from households and the industrial sector, Ghana began to use other sources of electricity such as thermal power energy (e.g., light crude oil, natural gas, and diesel fuel) and solar energy. Currently, hydropower accounts for 48.62% of the total electricity generation capacity, while thermal power and solar energy account for 50.69% and 0.69%, respectively (Sakah et al., 2017). Ghana has set a target to achieve universal access to electricity by 2020, which requires sizable investments and policy support. The nation's electrification rate currently stands at 72% compared with 31% in 1990. This increase has been attributed to a combination of policy mechanisms and institutions (IEA, 2015).

Ghana initiated the Economic Recovery Programme (ERP) in 1983 to reverse the continuing economic decline of the 1980s. After the economy recovered in the early 1990s, the government recognized the importance of electricity in sustaining the economy and initiated the 30-year National Electrification Programme (NEP). In 1998, the government of Ghana reduced the import duty and value-added tax (VAT) on solar and wind energy products to promote the use of renewable energy.⁶ The Renewable Energy Service Project (RESPRO) was initiated to manage and extend solar energy to poor and needy communities and was coupled with the design and installation of 2,000 solar panels in schools and households in 1999. The shift from hydropower to other

⁶ As of 2002, a zero import duty has been applied to solar, wind, and thermal generating sets as well as solar cells and panels. (http://www.ghanaweb.com/GhanaHomePage/economy/import_duty.php)

renewable sources was further boosted in 2006 when the target for the use of renewable energy was increased to 10% in the Strategic National Energy Policy, with a plan to further increase it to 30% in rural areas by 2020. In 2010, the Ghana National Energy Policy developed a renewable energy development program to enhance the use of waste for energy production. In 2011, the Renewable Energy Law was passed to provide a legal basis for the promotion of renewable energy use.

During the focus period of this study (2005–2013), there has been a 32% increase in the country's electricity generation capacity, from 1,730 MW in 2006 to 2,280 MW. This can be attributed to investments in thermal and hydropower plants, such as the Tema Thermal 1 and 2 power plants (160 MW), Sunon Asogli Thermal power plant (200 MW), and Bui Hydroelectric power plant (400 MW). In 2013, Ghana began to invest in solar energy by completing the Navrongo solar power plant station, which adds approximately 3 MW to the electricity generation capacity. This chapter expects that energy poverty in Ghana has been reduced due to the significant increase in electricity generation capacity and access to electricity.

2.3.2 Biomass

Traditional biomass has been the main source of energy for household cooking in Ghana. Figure 2.1 shows the trend in biomass consumption in Ghana from 2000 to 2015. Total biomass consumption decreased by 23.2% from 3,432 ktoe in 2000 to 2,784.7 ktoe in 2015. The consumption of firewood also decreased during this period, while that of charcoal increased. The decline in the consumption of biomass, particularly from 2000

to 2010, can be attributed to several programs and policies (e.g., the National LPG Programme) that have been initiated by successive governments.

A continuous increase in charcoal consumption from 2000 to 2015 might be attributed to the diffusion of efficient charcoal-burning stoves. In the early 1990s, an Ahibenso stove was introduced as an efficient stove that could reduce the consumption of biomass and indoor pollution. Available data indicate that by 1993, almost 40,000 Ahibenso stoves had been sold to households, which could save up to 18.4% of charcoal consumption. After the success story of Ahibenso stoves, the Gyapa stove was introduced in 2002, and over 200,000 stoves were sold. This stove can save households \$37 per year and conserve more than 27,606 hectares of forest (Kemausuor et al., 2011). In addition, the use of Gyapa stoves could decrease the average PM_{2.5} and carbon monoxide (CO) concentrations by 52% and 40%, respectively (Pennise et al., 2009).

[Figure 2.1]

The UN advocates that developing countries intensify programs that encourage the use of modern cooking energy services to meet the SDGs.⁷ One such cooking service involves the access to Liquefied Petroleum Gas (LPG). The government of Ghana began promoting the use of LPG as an alternative cooking fuel to traditional biomass in the early 1990s by establishing the National LPG Programme. The main targets of this program were urban households, public institutions requiring mass catering facilities, and small-scale food vendors. Although the main targets were urban households, rural

⁷ <http://www.unfoundation.org/what-we-do/issues/energy-and-climate/clean-energy-development.html>

households were not completely excluded. The government initiated a Unified Petroleum Price Fund (UPPF) to compensate oil companies that transport petroleum products such as LPG, to rural areas outside a radius of 200 km. Although there has been an increase in the National LPG penetration share from 6% in 2000 to 18% in 2010, Ghana failed to achieve the National LPG target of 50% in 2016 because of limited distribution outlets nationwide. In 2014, the government of Ghana launched the LPG cookstove program to freely distribute 350,000 LPG cylinders and stoves in the rural districts by the end of 2016.⁸ It is expected that energy poverty in Ghana in relation to biomass use has been reduced because of the various programs outlined above.

2.4 Data and Methodology

2.4.1 Data

Data for this study were extracted from the fifth and sixth rounds of the Ghana Living Standards Survey (GLSS V and GLSS VI) conducted by the Ghana Statistical Service in 2005/06 and 2012/13, respectively. The GLSS V and VI are nationwide household surveys designed to collect detailed information including demographic characteristics, education, health, employment and time use, migration and tourism, fuel use, housing conditions, household agriculture, access to financial services, and asset ownership [38]. The GLSS V covered a nationally representative sample of 8,687 households, whereas the GLSS VI covered 16,772 households. This study uses 8,312 households from GLSS V and 14,918 households from GLSS VI because these

⁸ <http://www.graphic.com.gh/news/general-news/govt-launches-lpg-cook-stove-programme.html>

households have complete information on main cooking fuel, electricity access, and household appliance ownership.

Several studies have used the GLSS to investigate household fuel choice in Ghana (Akpalu, 2011; Karimu, 2015; Karimu et al., 2016; Mensah and Adu, 2015). However, these studies mainly focused on cooking fuel choice and its determinants. In contrast to these studies, this chapter addresses energy poverty including cooking fuel, access to electricity, and ownership of home appliances and mobile phones.

2.4.2 Methodology

This study employs the Multidimensional Energy Poverty Index (MEPI) constructed by Nussbaumer et al. (2012) as a measure of energy poverty. The MEPI captures a set of energy deprivations that may affect a household. The methodology of MEPI is based on the Oxford Poverty and Human Development Initiative (Alkire and Foster, 2007) inspired by Amartya Sen's contribution to the discussion on deprivations and capabilities (Sen, 1999). The index is originally composed of five dimensions representing basic energy services with six indicators (Table 2.1).

In constructing the MEPI, the five dimensions can be equally weighted so that each dimension is given a 0.2 weight. However, because of the importance of the cooking and lighting dimensions to energy poverty, these two dimensions are given higher weights compared with the other three dimensions. In addition, because cooking is one, if not the most basic, energy need in a typical Ghanaian household, it is given a slightly higher weight compared with lighting. Thus, each indicator in the cooking dimension is weighed slightly higher than the indicator for lighting. This leads to a weight of 0.205 for

each of the two indicators in the cooking dimension and a weight of 0.20 for lighting. The remaining weight of 0.39 is shared equally among the last three dimensions, which are contingent on electricity access.⁹ A sensitivity analysis with regards to the choice of weight is discussed in Section 2.5.4.

Let us assume that there are n individuals and d dimensions. Then, $Y = [y_{ij}]$ represents the $d * n$ matrix of achievements for individuals across variables. Each row vector $y_i = (y_{i1}, y_{i2}, \dots, y_{id})$ represents individual i 's achievement in the different variables, and each column vector $y_j = (y_{1j}, y_{2j}, \dots, y_{nj})$ gives the distribution of achievements in the variable j across individuals. A weighting vector w is defined as $\sum_{j=1}^d w_j = 1$. We define z_j as the deprivation cut-off in variable j to identify all individuals deprived in any of the variables. Let $g = [g_{ij}]$ denote the deprivation matrix with an element defined as $g_{ij} = w_j$ when $y_{ij} < z_j$, and $g_{ij} = 0$ when $y_{ij} \geq z_j$. A column vector c_i represents the i th entry of deprivation and is defined as the sum of weighted deprivations suffered by individual i : $c_i = \sum_{j=1}^d g_{ij}$. A cut-off, $k > 0$, is set so that a person is considered multidimensionally energy poor if the weighted deprivation count c_i exceeds k . Therefore, $c_i(k) = 0$ when $c_i \leq k$, and $c_i(k) = c_i$ when $c_i > k$.¹⁰ Following Nussbaumer et al. (2012), k is set at 0.33, implying that a person is energy poor if deprived of at least one-third of total deprivations.

⁹ Nussbaumer et al. (2012) argues that the assignment of weights is an arbitrary and value-driven process. In our study, we basically retain the weights used in the Nussbaumer et al. (2012) for the ease of comparison.

¹⁰ $c(k)$ denotes the censored vector of deprivation counts and differs from c in that it counts zero deprivation for persons not identified as multidimensionally energy poor.

[Table 2.1]

The MEPI is computed by multiplying the headcount ratio (share of people identified as energy poor) and the average intensity of energy poverty. The headcount ratio H is defined as $H = q/n$ where q is the number of people that are energy poor, and n is the total number of people.¹¹ On the other hand, the average intensity of energy poverty, A , is defined as $A = \sum_{i=1}^n c_i(k)/q$. The MEPI has advantages compared with other energy poverty metrics. First, it can be decomposed into different sub-groups and dimensions because of its robust functional form. For instance, the MEPI can be calculated for households in the rural and urban areas or for high- and low-income households. The decomposability of the MEPI allows for a wide range of analyses that are not possible with other energy poverty metrics. Moreover, it focuses on the deprivation of energy services as opposed to extracting information indirectly through variables such as energy or electricity consumption (Nussbaumer et al., 2012). More importantly, it can capture both the incidence and intensity of energy poverty.

Since the dataset is obtained from a survey, sampling weights are applied in the estimation of the MEPI to adjust for disproportionate sampling and non-response. This ensures that the MEPI estimates from the sample data are representative of the population.

¹¹ The unit of analysis is the household. However, we include the number of persons per household in the computation of the headcount ratio and the average censored weighted deprivation.

2.5 Results

2.5.1 *Cooking energy sources*

Figure 2.2 shows the distribution of households by each cooking energy source in 2005/2006 and 2012/2013. The figure shows that most households in Ghana use firewood for cooking followed by charcoal, gas, crop residue/sawdust, kerosene, and electricity. The results indicate a decline in the percentage of households that depend on firewood during the two periods (from 57.54% to 53.39%), electricity (from 0.28% to 0.23%), charcoal (from 30.02% to 27.07%), and kerosene (from 0.59% to 0.15%). On the other hand, there was an increase in the percentage of households that depend on gas (from 9.35% to 14.75%) and crop residue/sawdust (from 2.23% to 4.41%). The increase in the percentage of households depending on gas can be attributed to the implementation of the National LPG Programme, which has led to an increase in the National LPG penetration share from 6% in 2000 to 18% in 2010.

In summary, there was a slight decline in the percentage of households depending on traditional cooking energy sources (i.e., firewood, crop residue/sawdust, and charcoal) from 89.79% to 84.88% during the study period. This decline indicates some gains in government efforts to reduce dependence on traditional biomass. On the other hand, there was an increase in the percentage of households depending on modern cooking energy sources (i.e., kerosene, gas, and electricity) from 10.21% to 15.12%, which indicates a gradual transition from the use of traditional cooking energy sources to modern sources.¹²

¹² Some households in Ghana use multiple cooking fuels (fuel stacking). The data used in this study, however, only collect information on the main cooking fuel. Thus, this study omits the complementary use of other cooking fuels.

[Figure 2.2]

The distribution of household cooking energy sources is further decomposed by the locations of households in Table 2.2.¹³ Over 80% of rural households use firewood as their main cooking fuel during the study period. Including charcoal and crop residue/sawdust, most rural households use traditional biomass as the main cooking fuel. In contrast, about half of the urban households use charcoal as their main cooking fuel. Including charcoal and crop residue/sawdust, urban households depend on traditional biomass as their main cooking fuel to a lesser extent than rural households. Moreover, urban households' dependence on traditional biomass decreased from 77% to 70% during the period. A significant number of urban households use gas as their main cooking fuel, with this share increasing from 22% to 30% in the same period.

[Table 2.2]

There are marginal declines in the percentage of rural households using firewood (from 83.11% to 80.33%), electricity (from 0.08% to 0.05%), and kerosene (from 0.16% to 0.13%) between 2005/2006 and 2012/2013. On the other hand, there are increases in the percentage of rural households using charcoal (from 11.83% to 12.62%) and gas (from 1.12% to 3.72%). The biggest change is in rural households' use of gas, which saw an increase of 2.6 percentage points during the study period. For urban households, there are slight declines in the percentages of households using firewood (from 19.35% to

¹³ An "Urban area" is a locality with at least 5,000 inhabitants; otherwise, it is a "rural area."

17.61%), kerosene (from 1.23% to 0.17%), charcoal (from 57.19% to 46.30%), and electricity (from 0.57% to 0.47%). However, there are increases in the percentages of urban households using gas (from 21.63% to 29.38%) and crop residue/sawdust (from 0.03% to 6.08%). An interesting finding is that while firewood is the major cooking fuel for rural households, urban households mainly use charcoal.

In summary, the data show an increase in the use of modern cooking energy sources by urban households (from 23.43% to 30.02%) and rural households (from 1.30% to 3.90%). At the same time, there is a decrease in the use of traditional cooking energy sources by urban households (from 76.57% to 69.98%) and rural households (from 98.70% to 96.10%).¹⁴ This indicates a wide disparity in the use of modern and traditional cooking energy sources between urban and rural households.

Table 2.3 shows the regional differences in the use of modern and traditional cooking energy sources. It indicates a decline in the use of traditional cooking energy sources across all 10 regions from 2005/2006 to 2012/2013. Except for the Greater Accra region, at least 75% of the households in each region depend on traditional cooking energy sources for cooking. Households in the Northern, Upper East, and Upper West regions have the largest shares of households that depend on traditional energy sources compared with the other regions. This is not surprising because the monetary poverty rates in these three regions are the highest in Ghana. Cooke et al. (2016) find that the monetary poverty rates for Northern, Upper East, and Upper West regions are 50.4%, 44.4%, and 70.7%, respectively, which are far higher than the poverty rates in the other

¹⁴ See Table A2.1.

regions.¹⁵ The table also shows an increase in the use of modern cooking energy sources across all regions between the two periods. The Northern, Upper East, and Upper West regions have the lowest shares of households depending on modern cooking energy sources. The Western region had the largest decline in the use of traditional cooking energy sources and the largest increase in the use of modern cooking energy sources. This can be attributed to the decline in monetary poverty levels in the region. Cooke et al. (2016) report that the Western region had the largest drop in monetary poverty levels, from 59.6% in 1992 to 20.9% in 2013.

[Table 2.3]

2.5.2 Access to electricity

Figure 2.3 shows the distribution of households with access to electricity. The figure indicates that access to electricity has improved over the study period. Specifically, the share of households with access to electricity increased from 44.68% to 59.20%. This can be attributed to investments in thermal and hydropower plants such as the Tema Thermal 1 and 2 power plants, the Sunon Asogli Thermal power plant, and the Bui Hydroelectric power plant. Access to electricity in rural areas improved by 16.59 percentage points compared with 8.07 percentage points for urban households during the study period. As expected, households in urban areas have a much higher electrification rate compared with rural households (Figure 2.3). Access to electricity has improved in

¹⁵ The monetary poverty analysis is based on the consumption per adult equivalent using the standard Foster, Greer, and Thorbecke (FGT) poverty indices.

all regions (Figure 2.4). While the Northern, Upper East, and Upper West regions continue to have the lowest share of households with access to electricity, there have been increases in the share of households with access to electricity in these three regions.

[Figure 2.3]

[Figure 2.4]

2.5.3 Construction of MEPI

Table 2.4 shows the percentage of people deprived of each energy service. The results indicate that the cooking dimension has the largest percentage of people deprived of the energy service. Specifically, more than 80% of people in Ghana are deprived of access to modern cooking fuel and modern cooking stoves. This figure declined marginally from 89.8% in 2005/2006 to 84.9% in 2012/2013. The decline between the two periods can also be observed for other indicators. The telecommunication indicator showed the largest improvement, with a drastic decline in deprivation from 81.1% to 25.6%. This can be attributed to the rapid increase in the mobile phone penetration rate in Ghana. According to the International Telecommunication Union (ITU) of the United Nations, mobile phone subscriptions in Ghana increased dramatically from 0.1 million in 2000 to 35 million in 2015 (ITU, 2016).

Table 2.5 also shows the overall energy poverty measure, headcount ratio, and the average intensity of energy poverty in Ghana in 2005/2006 and 2012/2013. The overall energy poverty rates in Ghana are 0.70 in 2005/2006 and 0.57 in 2012/2013. The

results also indicate that the share of people who are energy poor was 88.4% in 2005/2006 and 82.5% in 2012/2013. Although there has been a statistically significant decline in the overall energy poverty in Ghana during these two periods, the incidence of energy poverty remains high.¹⁶

[Table 2.4]

[Table 2.5]

Energy poverty and headcount ratio are further decomposed by the area of residence (Table 2.6). As expected, the results indicate high energy poverty in rural areas compared with urban areas. Specifically, the share of rural people who are energy poor was 98.3% in 2005/2006 and 95.3% in 2012/2013. On the other hand, the proportion of energy poor urban people was 73.5% in 2005/2006 and 65.5% in 2012/2013. Thus, the results suggest greater improvement in the reduction of energy poverty among urban dwellers. Moreover, overall energy poverty rates in the rural areas were 0.838 and 0.706, whereas the overall energy poverty rates in the urban areas were 0.496 and 0.382 in 2005/2006 and 2012/2013, respectively. In other words, energy poverty in rural areas is almost twice that in urban areas.

Energy poverty can be further decomposed by region (Table 2.7). There has been reduction in energy poverty in all regions during the study period. The lowest incidence

¹⁶ A t-test was conducted to ascertain the statistical significance of the decrease in the overall energy poverty rates. A p-value of 0.003 led to the conclusion that the decrease is statistically significant at 5%.

of energy poverty during the two periods is observed in the Greater Accra region, with 61.6% and 54.2% of people estimated as energy poor in 2005/2006 and 2012/2013, respectively. This is not surprising since this region has the highest percentage of households with access to electricity (Figure 2.4) and the highest percentage of households depending on modern cooking energy sources (Table 2.2). At the same time, the Greater Accra region has had the lowest monetary poverty rates among the 10 regions since 1992, which could partly explain the region having the lowest energy poverty rates over these two periods (Cooke et al., 2016). Income has been pointed out as a key determinant for the choice of modern cooking fuel in Ghana (Karimu et al., 2016; Mensah and Adu, 2015). The highest energy poverty rates during the two periods continue to be observed in the Northern, Upper East, and Upper West regions. Energy poverty was highest in the Upper West and Upper East regions in 2005/2006 and 2012/2013, respectively.

[Table 2.6]

[Table 2.7]

This chapter also attempts to examine the relationship between energy poverty and household income. To achieve this, the sum of weighted deprivations suffered by each household is computed and termed as energy poverty score. Households are then grouped into deciles with each decile representing 10% difference in the energy poverty score. The first decile (1) stands for the households having energy poverty score of up to

10% with successive deciles (second decile, third decile and so on) representing 10% incremental energy poverty score. Higher energy poverty score represents higher levels of deprivation. The results are shown on Table 2.8 using both GLSS V and GLSS VI. The results show that the lower the energy poverty score, the higher the household income and household per capita income is. This result suggests that energy poor people are more likely to be income poor.

[Table 2.8]

2.5.4 Sensitivity Analysis

This chapter conduct two different sensitivity analysis to test the robustness of the results. First, the MEPI results may be vulnerable to the cut-off set at 0.33. Following Nussbaumer et al. (2012), the cut-off of multidimensional energy poverty, k , is varied to examine the impact on MEPI and H for all sub-groups (rural, urban, and the 10 administrative regions). To test the robustness, the cut-off, k , is varied using 0.20 and 0.40. The results are presented in Tables A2.3, A2.4, A2.5, and A2.6. The results indicate that changes in the energy poverty cut-offs do not lead to significant changes in the values of MEPI and H (incidence of energy poverty). A key observation is that the values of MEPI and H begin to decrease when the cut-off increases from 0.2 to 0.33 and 0.40.

Also, the MEPI results may be sensitive to the weights assigned to the dimensions. Following Sadath and Acharya (2017), the rank sum method of assigning weights is used. Before assigning the weights, the appliance dimension, education/entertainment dimension and communication dimension are grouped into one main dimension called

the “other measures.” Hence, the five dimensions have now been reduced to only three dimensions which are ordered based on the relative importance of the individual dimensions. To compute the weight using the rank sum method, the following formula is used.

$$w_{ti} = \frac{K - r_i + 1}{\sum_{j=1}^K K - r_i + 1}$$

where r_i is the rank of the i th objective, and K is the total number of objectives. Using the above formula, a weight of 0.50, 0.33 and 0.17 are calculated for the dimensions; cooking, lighting and other measures respectively. Following Sadath and Acharya (2017), two ordering schemes are used– the first, cooking, lighting and other measures: and the second, lighting, cooking and other measures. The weight is equally divided if a dimension has more than one indicator, similar to the assignment of weights in Table 3. The results are presented in Tables A2.7, A2.8, A2.9 and A2.10. The results indicate that changes in the weights of the dimensions do not also lead to significant changes in the values of MEPI and H (incidence of energy poverty). Thus, MEPI and H are robust to the weights and cut-offs used in the index construction.

2.6 Summary and Conclusions

Energy plays a vital role in the development and transformation of every country. Access to modern energy services is a key to achieve the SDGs. Energy poverty is a measure that provides important information on household dependence on both traditional and modern energy services. Thus, it is helpful to measure the extent to which a country has made progress toward sustainable development.

In Ghana, as in many SSA countries, a high percentage of households depend on traditional biomass as their main source of energy for cooking. At the same time, about a quarter of the population of Ghana does not have access to electricity. Given this background, this chapter investigated the dynamics of energy poverty in Ghana using the MEPI as a measure of energy poverty. This study sought to ascertain whether there has been some significant transition from traditional biomass use to modern energy using two nationally representative cross-sectional datasets: the GLSS V in 2005/2006 and GLSS VI in 2012/2013.

The results of this chapter indicate a decline in the use of biomass as a cooking energy source by households between the two study periods. At the same time, there has been an increase in the percentage of households with access to electricity. However, the results show a wide disparity between urban and rural households in the use of traditional cooking energy sources as well as access to electricity. There is also a large gap between urban and rural energy poverty since rural people are almost twice as energy poor as urban people. In terms of regional decomposition, there has been a reduction in energy poverty in all regions between the two periods, although energy poverty is still high in the Upper West and Upper East regions. The chapter's conclusion is that there has been some progress in alleviating energy poverty in Ghana, but much more must be done in terms of policy interventions to reduce energy poverty.

The results of this study showed that cooking dimension had the largest percentage of people deprived of energy service. Also, the cooking dimension contributes more than 49% to energy poverty in Ghana (Table A2.2). This implies that addressing issues regarding cooking fuels could largely help in reducing energy poverty in Ghana.

Ghana has implemented the Rural LPG program which supplies LPG cylinders and cookstoves to rural households with the aim of reducing deforestation and increasing the usage of modern cooking fuels. One of the major challenges of this program is the financial constraint faced by beneficiaries to sustain the use of LPG cylinders and stoves (Karimu et al., 2016; Asante et al., 2018). Therefore, this study recommends a mechanism to identify these group of beneficiaries with the goal of providing some form of financial incentives to help sustain their usage of LPG. Identification of potential beneficiaries would require establishing monitoring and evaluation systems to effectively obtain feedbacks from these beneficiaries. These monitoring and evaluation systems could also facilitate the scaling up of the rural LPG program. Another major challenge with regards to the usage of LPG is supply constraints particularly in the Northern, Upper East and Upper West regions of Ghana. Out of the 641 LPG filling stations in Ghana, only 33 (representing 5%) are located in these three regions (Asante et al., 2018). Hence, there is the need to increase the number of LPG filling stations in these regions to help reduce supply difficulties, thereby reducing energy poverty in Ghana. These energy poverty reduction strategies should be incorporated into income poverty reduction strategies to improve not only access to modern energy but also in terms of affordability.

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List of Tables and Figures

Table 2.1: Dimensions and respective indicators with cut-offs including relative weights in parentheses

Dimension	Indicator (<i>weight</i>)	Variables	Deprivation cut-off (energy poor if...)
Cooking	Modern cooking fuel (0.205)	Type of cooking fuel	Any fuel use besides electricity, LPG, kerosene, natural gas, or biogas.
	Indoor pollution (0.205)	Food cooked on stove or open fire (no hood/chimney), indoor, if using any fuel beside electricity, LPG, natural gas, or biogas.	True
Lighting	Electricity access (0.20)	Has access to electricity	False
Services provided by means of household appliances	Household appliance ownership (0.13)	Has a fridge	False
Entertainment/education	Entertainment/education appliance ownership (0.13)	Has a radio OR television	False
Communication	Telecommunication means (0.13)	Has a phone land line OR mobile phone	False

Source: Nussbaumer et al. (2012)

Table 2.2: Distribution of household cooking energy sources by area of residence (%)

Main cooking fuel	GLSS V (2005/2006)		GLSS VI (2012/2013)	
	Area of residence		Area of residence	
	Rural	Urban	Rural	Urban
Firewood	83.11	19.35	80.33	17.61
Crop residue/saw dust	3.70	0.03	3.15	6.08
Charcoal	11.83	57.19	12.62	46.30
Electricity	0.08	0.57	0.05	0.47
Gas	1.12	21.63	3.72	29.38
Kerosene	0.16	1.23	0.13	0.17
Total	100.00	100.00	100.00	100.00

Source: Author's computation using GLSS V and GLSS VI.

Table 2.3: Distribution of household cooking energy sources by region (%).

Region	GLSS V (2005/2006)		GLSS VI (2012/2013)	
	Modern	Traditional	Modern	Traditional
Western	7.81	92.19	22.47	77.53
Central	14.99	85.01	14.99	85.01
Greater Accra	38.04	61.96	44.10	55.90
Volta	4.92	95.08	9.36	90.64
Eastern	6.00	94.00	10.20	89.80
Ashanti	11.88	88.12	24.54	75.46
Brong Ahafo	3.63	96.37	9.47	90.53
Northern	1.04	98.96	2.33	97.67
Upper East	0.51	99.49	4.67	95.33
Upper West	1.80	98.20	4.24	95.76

Source: Author's computation using GLSS V and GLSS VI.

Table 2.4: Summary of deprivation indicators, 2005 to 2013.

Indicator	Type	Weight	GLSS V (2005/2006) Deprived (%)	GLSS VI (2012/2013) Deprived (%)
<i>Domain 1</i>				
Modern cooking fuel	Binary	0.205	89.8	84.9
Indoor pollution	Binary	0.205	81.2	80.0
<i>Domain 2</i>				
Electricity access	Binary	0.20	55.3	40.8
<i>Domain 3</i>				
Household appliance ownership (fridge)	Binary	0.13	80.2	75.1
<i>Domain 4</i>				
Entertainment/education appliance ownership (radio or television)	Binary	0.13	31.9	25.0
<i>Domain 5</i>				
Telecommunication means (phone land line or mobile phone)	Binary	0.13	81.1	25.6

Source: Authors' estimation

Table 2.5: Summary of MEPI measures, 2005 to 2013.

Index	GLSS V (2005/2006)		GLSS VI (2012/2013)	
	Estimate	Std. Error	Estimate	Std. Error
Main				
MEPI	0.701	0.0034	0.567	0.0026
Additional				
H (Headcount ratio)	0.884	0.0035	0.825	0.0031
A (Average intensity)	0.793	0.0021	0.687	0.0017

Source: Authors' estimation

Table 2.6: Summary of MEPI measures by area of residence, 2005 to 2013.

Index	GLSS V (2005/2006)			GLSS VI (2012/2013)		
	Area of Residence		Total	Area of Residence		Total
	Urban	Rural		Urban	Rural	
Main						
MEPI	0.496	0.838	0.701	0.382	0.706	0.567
Additional						
H (Headcount ratio)	0.735	0.983	0.884	0.655	0.953	0.825
Number of people	9523	23158	32681	17948	42112	60060

Source: Authors' estimation

Table 2.7: Summary of MEPI measures by region, 2005 to 2013.

Region	GLSS V (2005/2006)			GLSS VI (2012/2013)		
	H	MEPI	Number of people	H	MEPI	Number of people
Western	0.918	0.707	2976	0.739	0.468	5050
Central	0.909	0.723	2236	0.845	0.563	5165
Greater Accra	0.616	0.400	2620	0.542	0.308	3569
Volta	0.948	0.794	2746	0.888	0.615	5919
Eastern	0.923	0.737	3125	0.854	0.585	5898
Ashanti	0.840	0.624	5190	0.705	0.425	5249
Brong Ahafo	0.956	0.758	3123	0.872	0.590	6035
Northern	0.982	0.839	4324	0.971	0.718	9233
Upper East	0.990	0.862	3112	0.946	0.737	6407
Upper West	0.978	0.883	3243	0.945	0.730	7439
Total	0.884	0.701	32695	0.825	0.567	59964

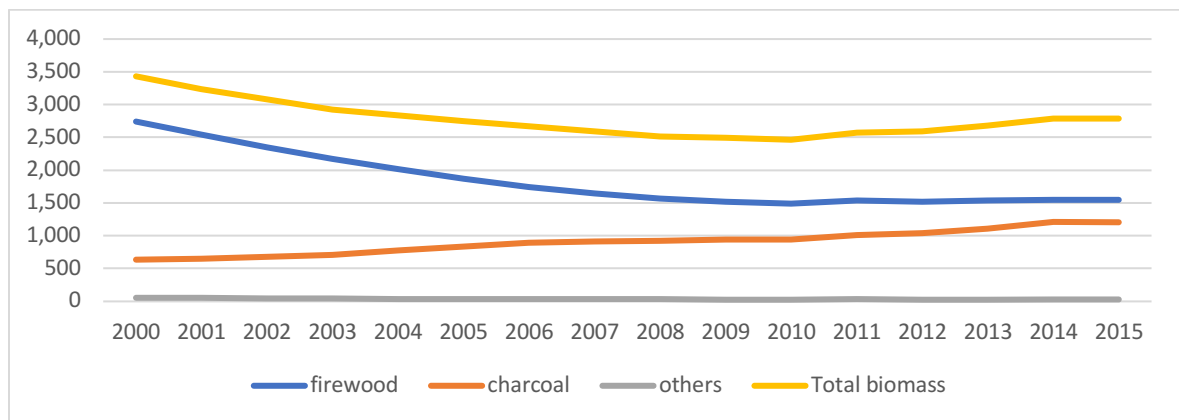
Source: Authors' estimation

Table 2.8: Average Income of Households at different frequencies of energy poverty score.

Deciles	GLSS 5		GLSS 6	
	Average Total Income (Gh¢)	Average per capita Income (Gh¢)	Average Total Income (Gh¢)	Average per capita Income (Gh¢)
1	9576.60	2992.69	12660.79	3956.50
2	8252.34	2171.58	10825.98	2848.94
3	7969.48	1771.0	9937.64	2208.36
4	5891.34	1370.08	7569.45	1760.34
5	5001.33	1282.39	6131.51	1572.18
6	5357.89	992.20	6964.63	1289.75
7	4981.23	1383.68	6544.31	1817.86
8	4210.67	935.70	5083.74	1129.72
9	3001.34	789.83	4091.34	1076.75
10	2109.87	527.47	3720.943	930.24

Source: Authors' estimation

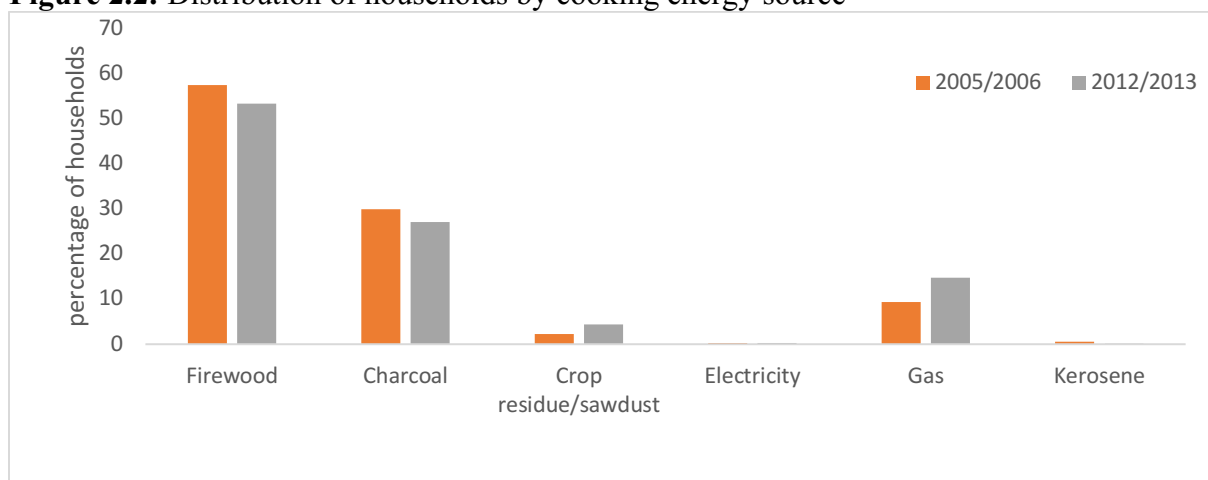
Figure 2.1: Biomass Consumption, 2000–2015 (in ktoe)



Source: Energy Commission (2015)

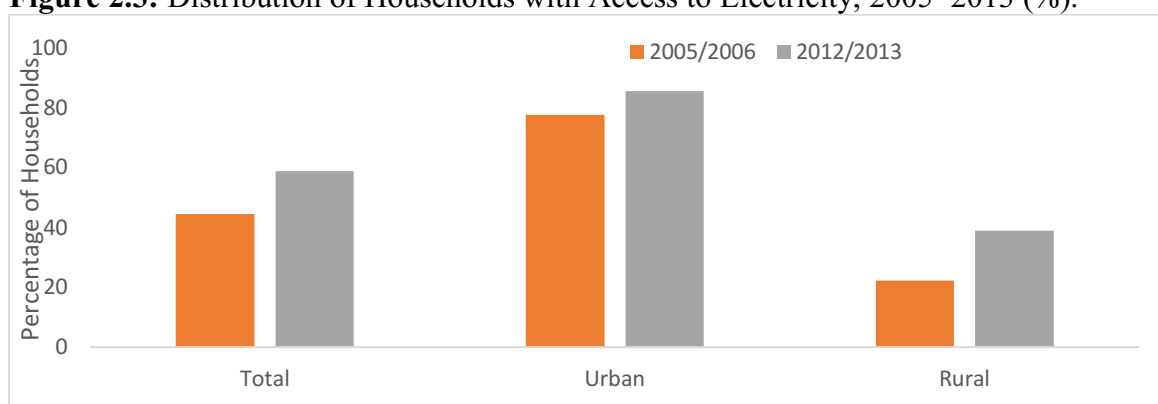
Note: Others include sawdust, saw mill residue, agricultural residue, and animal dung.

Figure 2.2: Distribution of households by cooking energy source



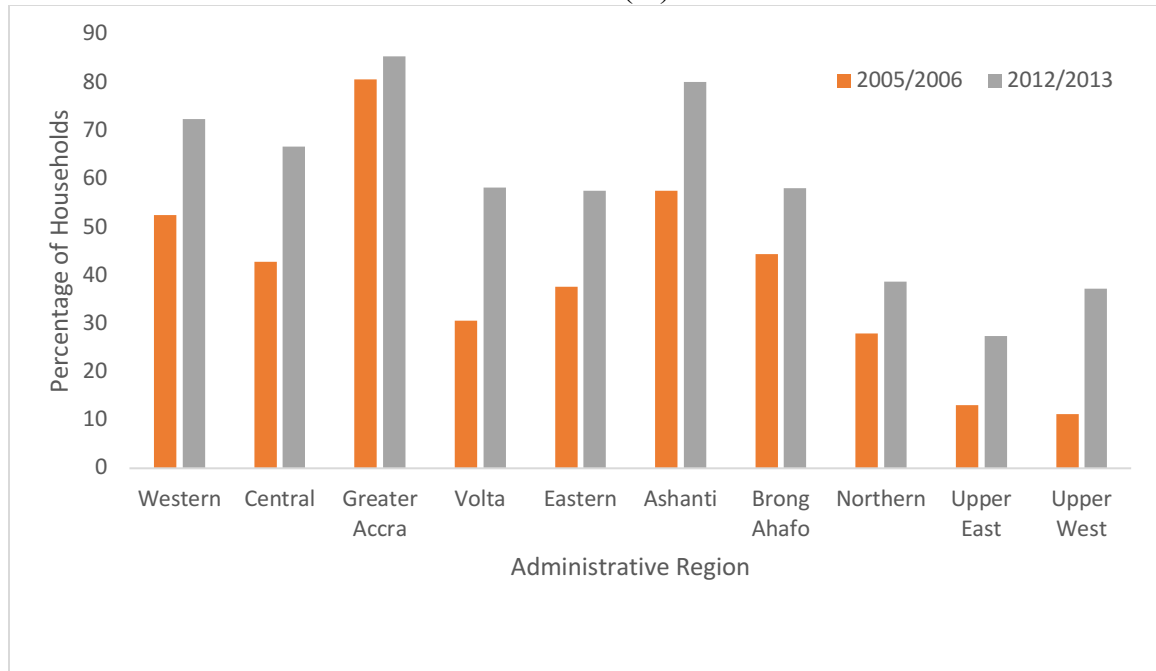
Source: Author's computation using GLSS V and GLSS VI.

Figure 2.3: Distribution of Households with Access to Electricity, 2005–2013 (%).



Source: Author's computation using GLSS V and GLSS VI.

Figure 2.4: Distribution of Households with Access to Electricity by Region, 2005–2013 (%).



Source: Author's computation using GLSS V and GLSS VI.

Appendix

Table A2.1: Distribution of households' type of cooking energy source by area of residence

Main cooking fuel	GLSS V (2005/2006)		GLSS VI (2012/2013)	
	Area of residence		Area of residence	
	Rural (%)	Urban (%)	Rural (%)	Urban (%)
Modern	1.30	23.43	3.90	30.02
Traditional	98.70	76.57	96.10	69.98
Total (%)	100.00	100.00	100.00	100.00

Table A2.2: Each indicator's contribution to MEPI

Indicator	GLSS V (2005/2006) MEPI	GLSS VI (2012/2013) MEPI
<i>Domain 1</i>		
Modern cooking fuel	0.254	0.294
Indoor pollution	0.237	0.285
<i>Domain 2</i>		
Electricity access	0.157	0.143
<i>Domain 3</i>		
Household appliance ownership (fridge)	0.146	0.165
<i>Domain 4</i>		
Entertainment/education appliance ownership (radio or television)	0.059	0.056
<i>Domain 5</i>		
Telecommunication means (phone land line or mobile phone)	0.148	0.057
Total	1	1

Table A2.3: Robustness results of MEPI measures, 2005 to 2013.

k (cut-off)	GLSS V (2005/2006)		GLSS VI (2012/2013)	
	H	MEPI	H	MEPI
0.20	0.942	0.713	0.883	0.579
0.33	0.884	0.701	0.825	0.567
0.40	0.844	0.681	0.795	0.557

Note: 0.33 is the baseline cut-off used in the main results.

Table A2.4: Robustness results of MEPI measures by area of residence, 2005 to 2013.

k (cut-off)	GLSS V (2005/2006)				GLSS VI (2012/2013)			
	Rural H	Urban H	Rural MEPI	Urban MEPI	Rural H	Urban H	Rural MEPI	Urban MEPI
0.20	0.990	0.841	0.843	0.519	0.974	0.761	0.711	0.405
0.33	0.983	0.735	0.838	0.496	0.953	0.655	0.706	0.382
0.40	0.970	0.682	0.834	0.479	0.940	0.602	0.702	0.365

Note: 0.33 is the baseline cut-off used in the main results.

Table A2.5: Robustness results of MEPI measures by region, 2005/2006

k (cut-off)	0.20		0.33		0.40	
	H	MEPI	H	MEPI	H	MEPI
Western	0.923	0.721	0.918	0.707	0.904	0.717
Central	0.931	0.734	0.909	0.723	0.909	0.726
Greater Accra	0.620	0.438	0.616	0.400	0.603	0.420
Volta	0.952	0.815	0.948	0.794	0.930	0.800
Eastern	0.943	0.754	0.923	0.737	0.929	0.747
Ashanti	0.852	0.703	0.840	0.624	0.836	0.644
Brong Ahafo	0.964	0.802	0.956	0.758	0.944	0.768
Northern	0.990	0.902	0.982	0.839	0.880	0.849
Upper East	0.993	0.932	0.990	0.862	0.890	0.872
Upper West	0.981	0.914	0.978	0.883	0.965	0.893

Note: 0.33 is the baseline cut-off used in the main results.

Table A2.6: Robustness results of MEPI measures by region, 2012/2013.

k (cut-off)	0.20		0.33		0.40	
	H	MEPI	H	MEPI	H	MEPI
Western	0.812	0.484	0.739	0.468	0.709	0.458
Central	0.897	0.574	0.845	0.563	0.799	0.588
Greater Accra	0.664	0.335	0.542	0.308	0.478	0.478
Volta	0.923	0.623	0.888	0.615	0.865	0.608
Eastern	0.920	0.598	0.854	0.585	0.823	0.574
Ashanti	0.807	0.447	0.705	0.425	0.654	0.408
Brong Ahafo	0.927	0.602	0.872	0.590	0.850	0.583
Northern	0.982	0.720	0.971	0.718	0.969	0.717
Upper East	0.965	0.741	0.946	0.737	0.931	0.732
Upper West	0.967	0.735	0.945	0.730	0.936	0.727

Note: 0.33 is the baseline cut-off used in the main results.

Table A2.7: MEPI measures based on rank sum weighted method (2005–2013)

	Energy Poverty (Equally Weighted)		Energy Poverty (Rank Sum Weighted)-1		Energy Poverty (Rank Sum Weighted)-2	
	H	MEPI	H	MEPI	H	MEPI
GLSS V (2005/2006)	0.811	0.734	0.873	0.677	0.803	0.608
GLSS VI (2012/2013)	0.813	0.589	0.803	0.541	0.799	0.518

Note: Energy Poverty (Rank Sum Weighted)-1 is based on the cooking, lighting and other measures ordering of dimensions and Energy Poverty (Rank Sum Weighted)-2 is based on lighting, cooking and other measures.

Table A2.8: MEPI measures based on rank sum weighted method by area of residence (2005–2013)

	Energy Poverty (Equally weighted)		Energy Poverty (Rank Sum Weighted)-1		Energy Poverty (Rank Sum Weighted)-2	
	H	MEPI	H	MEPI	H	MEPI
<i>GLSS V (2005/2006)</i>						
Rural	0.976	0.843	0.964	0.804	0.914	0.801
Urban	0.781	0.473	0.704	0.432	0.702	0.423
<i>GLSS VI (2012/2013)</i>						
Rural	0.944	0.715	0.904	0.714	0.900	0.704
Urban	0.608	0.358	0.592	0.340	0.584	0.324

Note: Energy Poverty (Rank Sum Weighted)-1 is based on the cooking, lighting and other measures ordering of dimensions and Energy Poverty (Rank Sum Weighted)-2 is based on lighting, cooking and other measures.

Table A2.9: MEPI measures based on rank sum weighted method by region
(2005/2006)

	Energy Poverty (Equally Weighted)		Energy Poverty (Rank Sum Weighted)-1		Energy Poverty (Rank Sum Weighted)-2	
	H	MEPI	H	MEPI	H	MEPI
Western	0.901	0.711	0.898	0.698	0.754	0.700
Central	0.920	0.715	0.897	0.710	0.804	0.720
Greater Accra	0.625	0.414	0.605	0.396	0.500	0.404
Volta	0.952	0.799	0.931	0.790	0.875	0.782
Eastern	0.931	0.729	0.908	0.725	0.809	0.706
Ashanti	0.833	0.613	0.823	0.609	0.732	0.682
Brong Ahafo	0.951	0.737	0.949	0.708	0.890	0.725
Northern	0.979	0.829	0.973	0.824	0.965	0.806
Upper East	0.991	0.865	0.988	0.858	0.907	0.884
Upper West	0.968	0.890	0.963	0.879	0.924	0.859

Note: Energy Poverty (Rank Sum Weighted)-1 is based on the cooking, lighting and other measures ordering of dimensions and Energy Poverty (Rank Sum Weighted)-2 is based on lighting, cooking and other measures.

Table A2.10: MEPI measures based on rank sum weighted method by region
(2012/2013)

	Energy Poverty (Equally Weighted)		Energy Poverty (Rank Sum Weighted)-1		Energy Poverty (Rank Sum Weighted)-2	
	H	MEPI	H	MEPI	H	MEPI
Western	0.724	0.469	0.709	0.461	0.717	0.444
Central	0.828	0.574	0.834	0.559	0.804	0.543
Greater Accra	0.550	0.315	0.534	0.300	0.502	0.298
Volta	0.879	0.621	0.876	0.609	0.818	0.606
Eastern	0.832	0.590	0.804	0.569	0.796	0.543
Ashanti	0.714	0.428	0.700	0.408	0.690	0.414
Brong Ahafo	0.881	0.581	0.868	0.576	0.846	0.531
Northern	0.979	0.720	0.970	0.711	0.954	0.704
Upper East	0.957	0.741	0.938	0.731	0.921	0.727
Upper West	0.949	0.732	0.941	0.728	0.923	0.711

Note: Energy Poverty (Rank Sum Weighted)-1 is based on the cooking, lighting and other measures ordering of dimensions and Energy Poverty (Rank Sum Weighted)-2 is based on lighting, cooking and other measures.

Chapter 3

Household Energy Expenditure in Ghana: A Double-Hurdle Model Approach

3.1 Introduction

In most developing countries, the primary household cooking energy source is fuelwood. According to the International Energy Agency (IEA, 2015), more than 2.7 billion people in developing countries rely on traditional biomass (i.e., wood, agricultural residues, and animal dung) for cooking. In sub-Saharan Africa (SSA) alone, more than 753 million people use traditional biomass for cooking. Such overdependence on traditional biomass combined with the use of inefficient cooking stoves cause indoor air pollution, which is harmful to human health particularly for the elderly, women, and children. The World Health Organization (WHO, 2009) estimates that 1.3 million people die prematurely every year as a result of indoor air pollution from the use of solid fuels. In fact, 85% of these deaths can be attributed to biomass usage, with the remaining 15% caused by the use of coal.

Many governments and development agencies have proposed various measures to reduce such overdependence on traditional biomass use. One measure is encouraging households to adopt a modern cooking fuel, such as liquefied petroleum gas (LPG) and electricity. However, in most developing countries, lower purchasing power prevents the adoption of modern cooking fuels. Modern fuels are generally expensive, and therefore, households in developing countries that choose to adopt them would have to expend a

significant portion of their income on energy. Although some measures have led to an increased adoption rate of modern cooking fuels,¹⁷ considerable efforts are still needed to achieve Goal 7 of the Sustainable Development Goals (SDGs): ensure universal access to affordable, reliable, sustainable, and modern energy by 2030.

Empirical studies on developing countries tend to focus on households' access to modern cooking fuels and factors influencing their choice of fuel (Heltberg 2004; Chambwera and Folmer, 2007; Akpalu et al. 2011; Ouedraogo, 2006; Barnes et al. 2005). While decision making regarding fuel choice is undoubtedly important, it is also key for policy makers to consider how much households spend on these fuels after the decision to adopt them. For example, households that spend a large proportion of their income on a modern cooking fuel will be forced to forgo other consumption opportunities and thus, policies should focus on ways to improve fuel affordability. As modern fuels become increasingly available, households must decide whether to adopt them and the amount they are willing to spend. Understanding household energy expenditure is critical for a smooth transition from traditional cooking fuels to cleaner and modern ones.

Using household survey data for Ghana, this chapter examines the role of demographic and economic characteristics in explaining household energy expenditure in a developing country. More concretely, a research question can be stated as follows: Do the factors determining a household's decision to participate in a fuel market differ from those influencing how much it will spend? Several empirical studies have explored factors influencing fuel choice in Ghana (Heltberg, 2004; Akpalu et al., 2011; Karimu, 2015; Karimu et al., 2016; Kwakwa et al., 2013; and Mensah and Adu, 2015). However,

¹⁷ The national LPG penetration share for Ghana increased from 6% in 2000 to 18% in 2010. However, Ghana's Energy Commission failed to achieve the national LPG penetration target of 50% for 2016.

the factors identified in these studies may vary from those that determine how much a household will spend on these fuels. A unique feature of this chapter is that it addresses these two decisions separately by using the double-hurdle model, which is uncommon in the extant literature. Understanding the effect of household demographic and economic characteristics on energy spending in Ghana will reveal the implications of policies that not only address household decisions to adopt a cooking fuel, but also work toward making such fuels affordable for most households.

This chapter classifies LPG as a modern fuel and charcoal as a transition fuel, in line with the energy ladder hypothesis (van der Kroon et al., 2013). This hypothesis characterizes the development of fuel use evolution into three stages. First, there is universal dependence on traditional biomass fuels, such as firewood, crop residue, and animal dung. Second, fuel switching occurs from traditional biomass to transition fuels, such as kerosene, charcoal, and coal as a result of higher incomes. Third, the switch from transition to modern fuels, such as LPG and electricity occurs. The hypothesis identifies household income as the main and sole determinant of household fuel choice and fuel switching, respectively (Heltberg, 2004). This chapter focuses on LPG and charcoal, because in addition to firewood, they are the most frequently used cooking fuels in Ghana. Therefore, sufficient data are available on cooking fuel expenditure to enable our analysis. As an extension, this chapter also examine the behavior of households who spend a positive amount on LPG and charcoal based on the fuel stacking model (Masera et al., 2000). In contrast to the energy ladder hypothesis, the fuel stacking model assumes that households use multiple fuels at the same time.

The remainder of this chapter is organized as follows. Section 3.2 briefly reviews the relevant literature. Sections 3.3 and 3.4 describe the data and methodology adopted in this chapter. Section 3.5 presents the results. Section 3.6 concludes the paper and provides policy implications.

3.2 Literature Review

Given the lack of sufficient data on energy prices and expenditures, few studies on household energy spending in developing countries have been carried out. Consequently, most of the studies have tended to focus on the determinants of household cooking fuel choice. These studies can be grouped mainly into research investigating (1) the determinants of household energy demand and energy choices (Heltberg et al. 2000; Chambwera and Folmer, 2007; Akpalu et al. 2011; Ouedraogo, 2006; Barnes et al. 2005), and (2) works exploring the validity of the energy ladder hypothesis (Hosier and Dowd, 1987; Bello, 2011; Farsi and Filippini, 2007). Most of these studies identify income, fuel prices, education, household size, and access to modern infrastructure as the key factors determining household choice in cooking fuel.

On the other hand, some studies have attempted to examine the determinants of household energy expenditures. In the developed world, there is evidence of socioeconomic factors explaining energy expenditure patterns among households. For example, Longhi (2015) analyzes whether changes in household socioeconomic circumstances translate into changes in energy expenditure in the United Kingdom (UK). The study found that although socio-economic characteristics have a moderate impact, dwelling characteristics, such as household size have considerably larger impacts. This

evidence highlights the importance of controlling for various socio-demographic and economic factors in explaining energy expenditure patterns, a finding supported by other studies including those of Meier and Rehdanz (2010) and Rehdanz (2007).

In the context of developing nations, Alkon et al. (2016) use nationally representative household data from India for 1987–2010 to reveal that households are willing and able to spend on energy when modern fuels are available. The study also shows that increases in monthly energy spending have not been driven by increases in household income. These results highlight the importance of improving access to modern fuels in both urban and rural areas. In most developing countries, the supply of modern fuels, such as LPG and electricity, is yet to be regulated given the frequent shortages. Further, even the wealthiest households face difficulties in purchasing modern cooking fuels and, thus, choose other fuels, such as charcoal, which is typically available in large quantities. In contrast, Khandker et al. (2012) reveal that income is key in increasing energy expenditures among Indian households in all but the most impoverished section of society. The variation in conclusions regarding income can be explained by the fact that these studies used different periods and datasets.¹⁸

Using a two-stage Heckman model, Kojima et al. (2011) examine the factors influencing household decisions to use LPG and the quantity consumed per person in six developing countries (Guatemala, India, Indonesia, Kenya, Pakistan, and Sri Lanka). Their findings suggest that in all six countries, household expenditure and education were essential in the decision to select LPG. However, the significance of household characteristics, such as urban residence and household size, differs by country. In the

¹⁸ Khandker et al. (2012) used the 2004–2005 wave of the India Human Development Survey (IHDS), while Alkon et al. (2016) adopted five rounds of the National Sample Survey (NSS) data for 1987–2010.

second stage estimation, they find household expenditure and LPG price to be positively and negatively related to the quantity of LPG consumption, respectively. Kojima et al.'s (2011) approach is thus closely related to this current chapter, despite the difference in methodologies adopted. In addition, in contrast to Kojima et al. (2011), this chapter focuses on energy spending in terms of understanding the burden on households' total expenditure, given its significant policy implications.

3.3 Data Description

The data for this chapter are taken from the sixth round of the Ghana Living Standards Survey (GLSS VI), a multi-purpose, nationally representative household survey conducted by the Ghana Statistical Service (GSS) during 2012–2013. The sampling frame for the survey was the population living in private households¹⁹ in Ghana, which was divided into primary and secondary sampling units. Census enumerated areas (EAs) were defined as the primary sampling unit, and households within each EA constituted the secondary sampling unit. According to the population in each region, the EAs were first stratified into the 10 administrative regions in Ghana. The GSS adopted a two-stage stratified random sampling design, in which 1,200 EAs were considered in the first stage to cover a nationally representative sample of 18,000 households. In this chapter, 16,041 out of the 16,772 households that were successfully interviewed are used because of missing data. The data on charcoal prices are adopted from the charcoal price tracking reports produced by the Energy Commission of Ghana. The reports present the

¹⁹ Private households are defined in GLSS as a population that excludes institutional populations, such as schools and hospitals.

findings of a series of surveys on charcoal pricing in selected charcoal markets across the 10 regions in Ghana for June 2012–December 2013.²⁰ The data on LPG and kerosene prices are taken from the National Petroleum Authority (NPA) of Ghana.

3.3.1 Patterns of Household Energy Use and Expenditure

Table 3.1 reports the patterns of energy use and energy expenditures in Ghana. In particular, it shows that firewood is the most frequently used cooking fuel among Ghanaian households, followed by charcoal and LPG.²¹ In addition, the results also indicate differences in energy use patterns between urban and rural households. Rural areas are highly reliant on traditional fuels, with about 80% of rural households using firewood as the primary cooking fuel. By contrast, 17% of urban households use traditional biomass. Use of modern fuels, such as LPG, among urban households is 32%, compared to 4% among rural households. As it will be discussed in more detail in Section 3.5.4, the table also reports the share of households who spend a positive amount on both LPG and charcoal. According to our definition, only a small percentage of households use multiple fuels at the same time. It is clear from these patterns of energy expenditure that urban households spend more than rural households on cooking fuels. For both urban and rural households, electricity is the highest energy expenditure, followed by LPG. For rural households, expenditures on firewood might be the highest energy expenditure,

²⁰ It is assumed that households living in and around the same charcoal market face the same charcoal price. Also, households were interviewed from October 2012–October 2013 and at different months. Hence, households are assigned a price depending on the month and year they were interviewed. The same technique is used for kerosene and LPG prices.

²¹ The GLSS VI collects data on the main cooking fuels used by households.

although data supporting this viewpoint are unavailable.²² Data on firewood expenditure are difficult to collect, because the bulk of the firewood in Ghana is collected for free from its forests.

[Table 3.1]

This chapter focuses on LPG and charcoal expenditure for two reasons. First, LPG and charcoal are among the three main cooking fuels used in Ghana (Table 3.1). Second, data are readily available for these two fuels. Although there exists data on electricity and kerosene expenditures, they are among the least used cooking fuels in Ghana. Thus, any analysis results regarding kerosene and electricity expenditure will have limited implications. Tables A3.1 and A3.2 list all variables used in this study along with their respective definitions and descriptive statistics.

3.4 Methodology

Survey data for expenditures in particular tend to contain zero values. Failure to choose an appropriate statistical or econometric method to deal with these zeros can lead to biased and inconsistent results. There are numerous econometric approaches that deal with the issue of the preponderance of zeros in survey data. Humphreys (2013) summarizes the key elements that should be considered when choosing an appropriate econometric methodology (Figure 3.1). Suppose the variable of interest, y_i has a mass of

²² Although the bulk of firewood is collected for free from forests without any direct cost, it is anticipated that imputing the value of biomass fuel using market prices will render firewood expenditure as the highest energy-based expenditure.

zero observations. Then, the first step is to identify the reasons for the zeros in the data. There are three possible reasons: (1) genuine zeros resulting from a choice made by the agents in the survey; (2) the zeros represent a decision over which the agent has no control for a certain reason, and (3) the zeros represent missing or non-response outcomes. If the zeros in the data are attributable to reasons (1) and (2), then, the Tobit model is an appropriate estimator. If the Tobit model fails to work, either the double-hurdle or two-part models are preferred. However, if the zeros in the data result from the third reason, then the Heckman sample selection model is preferred.

In the GLSS VI data set, the observations of zero expenditure result from (1) the respondents' inability or unwillingness to respond to a particular question, (2) failure in data entry by the operator for a given question, or (3) a non-applicable question. These three reasons for a zero observation coincide with the first two reasons provided by Humphreys (2013), which fall under the "Genuine zeros" category in Figure 3.1. Accordingly, this chapter first employs the Tobit model, followed by the double-hurdle model. The Heckman sample selection model is employed as a robustness check. Thus, three different methodologies were utilized to explore the factors influencing energy spending on LPG and charcoal. All analyses were conducted using Stata 14.0 (StataCorp, College Station, TX).

[Figure 3.1]

3.4.1 Tobit Model

The standard Tobit specification is defined as

$$y_i^* = x_i\beta + \varepsilon_i \text{ with } \varepsilon_i \sim N(0, \sigma^2) \text{ and } i = 1, 2 \dots n \quad (1)$$

$$y_i = \begin{cases} y_i^*, & \text{if } y_i^* > 0 \\ 0, & \text{if } y_i^* \leq 0 \end{cases} \quad (2)$$

where y_i^* is a latent endogenous variable representing a household's desired level of expenditure and y_i is the actual observed level of expenditure. x_i is a set of household characteristics that explain the expenditure decision and β is the corresponding vector of parameters to be estimated. ε_i is assumed to be a homoscedastic, normally distributed error term. Eq. (2) states that the observed level of expenditure becomes a positive continuous value only if a positive expenditure amount is desired and is zero otherwise:

$$LL = \sum_0 \ln \left[1 - \Phi\left(\frac{x_i\beta}{\sigma_i}\right) \right] + \sum_+ \ln \left[\frac{1}{\sigma_i} \phi\left(\frac{y_i - x_i\beta}{\sigma_i}\right) \right] \quad (3)$$

where “0” indicates summation over the zero observations in the sample ($y_i = 0$) and “+” denotes summation over positive observations ($y_i > 0$). Φ and ϕ are the cumulative distribution functions for the standard normal random variable and standard normal probability density functions.

3.4.2 Double-Hurdle Model

Cragg (1971) formulated the double-hurdle model, which offers an effective way of modeling the pattern of household expenditures on commodities. The model postulates that households must pass two separate hurdles before they are observed with a positive

level of expenditure. The first hurdle is the decision to choose positive or zero spending (participation decision) and the second hurdle is deciding the amount to be spent conditional on having decided to spend the positive amount (expenditure decision). The double-hurdle model can be specified as follows:

$$y_{i1}^* = w_i\alpha + u_i \quad \text{Participation Decision} \quad (4)$$

$$y_{i2}^* = x_i\gamma + v_i \quad \text{Expenditure Decision} \quad (5)$$

$$y_i = x_i\gamma + u_i \quad \text{if } y_{i1}^* > 0 \text{ and } y_{i2}^* > 0. \quad (6)$$

$$y_i = 0 \quad \text{otherwise} \quad (7)$$

where y_{i1}^* is a latent endogenous variable representing a household's participation decision, y_{i2}^* is a latent endogenous variable denoting a household's expenditure decision; y_i is the observed level of expenditure; w_i is a set of household characteristics explaining the participation decision; x_i is a set of individual characteristics explaining the expenditure decision; and u_i and v_i are independent, homoscedastic, normally distributed error terms. As in the Tobit model, the log likelihood function of the double hurdle model in Eq. (8) is estimated by using maximum likelihood techniques:

$$LL_{DoubleHurdle} = \sum_0 \ln \left[1 - \Phi(w_i\alpha) \Phi\left(\frac{x_i\gamma}{\sigma_i}\right) \right] + \sum_+ \ln \left[\Phi(w_i\alpha) \frac{1}{\sigma_i} \phi\left(\frac{y_i - x_i\gamma}{\sigma_i}\right) \right] \quad (8)$$

The results obtained from the maximum likelihood estimation are used to compute the marginal effects of each regressor on the dependent variable. Three different marginal effects can be calculated: the overall effect of each of the regressors on the dependent variable, which is the expected value of y_i for values of the regressors x , denoted by

$E[y_i|x]$,²³ the conditional expectation, which is the expected value of y_i for values of the regressors x , conditional on $y_i > 0$ and denoted by $E[y_i|x, y_i > 0]$; and the probability of a positive value of y_i for all values of the regressors, indicated by $P[y_i > 0|x]$.

The probability of participation and the level of expenditure conditional on participation are shown in Eq. (9) and Eq. (10), respectively:

$$P[y_i > 0|x] = \Phi(w_i\alpha) \Phi\left(\frac{x_i\gamma}{\sigma_i}\right) \quad (9)$$

$$E[y_i|x_i > 0, x] = x_i\gamma + \sigma_i \left(\frac{\phi\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)} \right) \quad (10)$$

The marginal effects are estimated by taking the first derivative of Eq. (9) and Eq. (10) with respect to each regressor in Eq. (11) and Eq. (12).

$$\frac{\partial P[y_i > 0|x]}{\partial x_j} = \alpha_j \phi(w_i\alpha) \Phi\left(\frac{x_i\gamma}{\sigma_i}\right) + \gamma_j \Phi(w_i\alpha) \phi\left(\frac{x_i\gamma}{\sigma_i}\right) \quad (11)$$

$$\frac{\partial E[y_i | y_i > 0, x]}{\partial x_j} = \gamma_j - \gamma_j * \left[\frac{\phi\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)} \right] * \left[\frac{x_i\gamma}{\sigma_i} + \frac{\phi\left(\frac{x_i\gamma}{\sigma_i}\right)}{\Phi\left(\frac{x_i\gamma}{\sigma_i}\right)} \right] \quad (12)$$

where α_j and γ_j are the coefficients of the regressor x_j from the participation and expenditure equations, respectively.

3.4.3 Heckman Sample Selection Model

As Figure 3.1 shows, the Heckman model is a better choice if the zero expenditures result from non-observable responses. The Heckman model assumes that the participation decision (first hurdle) dominates the expenditure decision (second hurdle), which is also

²³ The overall effect, also known as the unconditional expectation, $E[y_i|x]$, is decomposed into the conditional expectation, $E[y_i|x, y_i > 0]$ and the probability of a positive value of y_i , for all values of the regressors, $P[y_i > 0|x]$.

known as the first hurdle dominance. This dominance implies that zero expenditures reflect the household's decision to not participate in the fuel market. For example, the Heckman model assumes that a household's expenditure on LPG is zero only because the household does not use LPG. The key difference between the Heckman model and double-hurdle models is that the former does not account for households with zero expenditure even though they participate in the market, whereas the latter model includes such households. The Heckman sample selection model states that the expenditure variable (y_{i2}^*) is only observed if the participation variable (y_{i1}^*) is positive. In the Heckman model, a probit model is estimated in the first stage. Then, the unbiased estimates from the first stage are used to obtain the second stage. The Heckman model specification takes the same form as the double-hurdle model, except for the expenditure decision, which is as follows:

$$y_i^{***} = \begin{cases} y_{i2}^*, & \text{if } y_{i2}^* > 0 \\ \text{not observed} & \end{cases} \quad (13)$$

The Heckman model assumes that the error terms in the participation and expenditure decisions are dependent. Hence, $u_i \sim N(0,1)$ and $v_i \sim N(0, \sigma^2)$ have a bivariate normal distribution:

$$\begin{pmatrix} u_i \\ v_i \end{pmatrix} \sim N \left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 1 & \rho\sigma \\ \rho\sigma & \sigma^2 \end{pmatrix} \right) \quad (14)$$

where ρ is the correlation coefficient between the error terms u_i and v_i . A sample selection bias in the OLS estimator emerges if ρ is non-zero. The log likelihood for Heckman's selection model is

$$LL_{Heckman} = \sum_0 \ln[1 - \varphi(w_i\alpha)] + \sum_+ \ln \left[\Phi \left(\frac{(w_i\alpha) + \frac{\rho}{\sigma}(y_i - x_i\gamma)}{\sqrt{1-\rho^2}} \right) \frac{1}{\sigma} \phi \left(\frac{y_i - x_i\gamma}{\sigma} \right) \right] \quad (15)$$

3.5 Results and Discussions

3.5.1 Diagnostic Tests on Tobit Model

This chapter begins the empirical estimations by employing the Tobit model.²⁴ The main restrictions of the Tobit model are its strong normality and homoscedasticity assumptions, which bias the results if violated. According to Cameron and Trivedi (2010), failure of the normality and homoscedasticity assumptions have serious consequences for the Tobit model estimates. Table 3.2 presents the results for the normality and homoscedasticity tests using the Lagrange multiplier test. For both the LPG and charcoal expenditure models, the null hypothesis of the normality and homoscedasticity assumptions is rejected. This outcome suggests that the Tobit model is not appropriate for analyzing these data. Failure of the normality and homoscedasticity assumptions also implies that a single process does not determine the choice between $y = 0$ and $y > 0$ as well as the value of y , given $y > 0$. Thus, it is necessary to use a model that separately deals with both decisions. Therefore, we employ the double hurdle model instead of the Tobit model.

[Table 3.2]

²⁴ Table A3.3 reports the full results of the Tobit model for both LPG and charcoal expenditures.

3.5.2 Double-Hurdle Model Results

Table 3.3 reports the results for the double-hurdle model for both LPG and charcoal; all reported values are marginal effects. Comparison of the second and third columns shows clearly that the factors influencing the decision of households to participate in the LPG market differ from those influencing how much to spend on LPG. Similarly, comparison of the fifth and sixth columns reveals that the factors influencing the decision to participate in the charcoal market vary from those influencing how much households spend on charcoal. All of the marginal effects except for the kerosene price are significant in terms of a household's decision to participate in the LPG market. However, variables such as the charcoal and kerosene prices, reliable firewood supply, and employment and occupancy status are not significant in influencing LPG expenditure once the decision to participate in the LPG market is made. In the case of charcoal expenditure, variables such as LPG and kerosene prices, gender and age of household head, income, and employment and occupancy status are not significant in a household's decision to participate in the charcoal market. In contrast, variables such as charcoal price, reliable charcoal supply, reliable LPG supply, age of household head, urban residence location, electricity, number of rooms, and household size are significant in influencing charcoal expenditure once the decision to participate in the charcoal market is made. These findings mean that the Tobit model is not appropriate because it assumes that the variables influencing the decision to participate in a fuel market are the same as those influencing how much to spend.

Income is a statistically significant factor influencing the probability of a household participating in the LPG market and LPG expenditure once the decision to

participate is made. For example, income increases the probability of participating in the LPG market by 1% and LPG expenditure by 4.5% conditional upon LPG market participation. This is in line with our expectations because LPG is one of the most expensive cooking fuels in Ghana; consequently, market participation and spending will be highly influenced by household income. In the charcoal expenditure model, however, income is found to be insignificant. This outcome reflects the different role income plays in the uptake of modern fuels, such as LPG, compared with transition fuels (e.g., charcoal).

The household head often controls decisions regarding expenditures, and this influence might, therefore affect fuel adoption and spending. We find that having a male as a household head decreases the probability of participating in the LPG market by 1.4% and increases LPG expenditure by 6.9% conditional on LPG market participation. This is consistent with the findings of Karimu et al. (2016), who finds evidence that female-headed households in Ghana are more likely to adopt LPG than male-headed households. Karimu et al. (2016) explain that this negative relationship reflects the differences in decision making by female and male-headed households in terms of preferences, welfare, and opportunity cost of time. In the case of charcoal, the gender of the household head negatively affects only charcoal expenditure conditional on charcoal market participation. Once the decision to use charcoal is made, female-headed households are more likely to increase charcoal expenditure by 6.9% compared to male-headed households.

In addition, this chapter also examined the effects of supply-side constraints on the probability of household participation in the LPG and charcoal markets as well as expenditure for both fuels. As expected, the results show that a reliable LPG or charcoal

supply increases the probability of participating in these markets as well as expenditure. In particular, the estimated marginal effects indicate that the reliable supply of LPG increases a household's probability of participating in the LPG market by 13% and increases its LPG expenditure by 24% conditional on LPG market participation. Similarly, the results indicate that the reliable supply of charcoal increases the likelihood of a household's charcoal market participation by 47.1% and increases its charcoal expenditure by 30.9%, also conditional upon market participation. On the other hand, reliable supplies of substitute fuels generally decrease the probability of both participation and expenditure. For example, reliable firewood and kerosene supplies decreases the probability of participating in the LPG market and LPG expenditure, and similarly, a reliable LPG supply decreases the probability of a household participating in the charcoal market and its charcoal expenditure. In the LPG case, however, the estimated marginal effects on the reliable charcoal supply are positive and significant. A possible reason is that richer households are more likely to use LPG and will continue to use and spend on LPG despite an available supply of charcoal. However, this is not the case in the charcoal model because the marginal coefficient on the reliable LPG supply is found to be negative.

The results also show that education levels have significant and positive effects on the probability of participating in the LPG market and LPG expenditure. The estimated marginal effects on basic, secondary, and tertiary levels of education increase the probability of LPG market participation by 3.7%, 5.8%, and 8.9%, respectively. Furthermore, the estimated marginal effects on basic, secondary, and tertiary levels of education increase LPG expenditure, conditional on LPG market participation, by 19.8%,

17.3%, and 27.6%, respectively. These findings imply that a household in which the head is educated has a high likelihood of participating in the LPG market and increase its LPG expenditure. In the case of charcoal, a higher level of education, i.e., education beyond the secondary level, decreases the probability of household participation in the charcoal market. None of the three education levels affect charcoal expenditure. These results suggest that highly educated household heads are more likely to participate in the LPG market than in the charcoal market. A possible explanation could be knowledge about the opportunity costs, such as health and time costs, associated with using charcoal.

This chapter finds a negative relationship between the LPG price and the probability of household participation in the LPG market. In particular, a 1% increase in the LPG price decreases the probability of households participating in the LPG market by 3.9%. The price effect of LPG on LPG expenditure is also negative and statistically significant, suggesting that a 1% increase in the price leads to a 15.3% decrease in expenditure. The results imply that a fall in the price of LPG will increase the probability of households using LPG as well as increase the expenditure of households. Therefore, a price subsidy to promote usage of LPG might lead to an increase in expenditure burden on households. Among the price effects of various fuels on LPG expenditure, only the LPG price is statistically significant. This result indicates that households with positive LPG expenditures are indifferent to the prices of other fuels. Similarly, in the case of charcoal, only charcoal price is the only significant price variable influencing both participation in the charcoal market and expenditure on charcoal. These results indicate that any policy targeting fuel prices will affect both the participation and expenditure of the fuel in question, but will have no impact on household decisions regarding other fuels.

[Table 3.3]

3.5.3 Fuel Stacking Model Results

Analyses so far considered households using only one cooking fuel, i.e. using only LPG or charcoal. In this sub-section, the attempt is made to explore the households that use multiple cooking fuels based on the fuel stacking model (Masera et al., 2000). In Ghana, some households, especially those in the urban areas, have been observed to use more than one cooking fuel (Mensah and Adu, 2015). Therefore, it is important to extend the analysis to include these households. However, the dataset used in this paper (GLSS VI) elicits information on only the main cooking fuel of households, and thus, does not allow us to investigate household behavior that uses several cooking fuels at the same time. Notwithstanding this limitation, a different approach is used to identify households using multiple cooking fuels. This chapter interprets that households reporting positive amounts for both charcoal and LPG expenditure in the dataset are using multiple cooking fuels. With this assumption, this chapter is able to identify 1,123 households that use multiple cooking fuels. Since this sample represents only 7% of the total number of households, the relative share of multiple cooking fuel users is small based on the definition. Among multiple cooking fuel users, 84% are urban households and 16% are rural households, which coincides with the observation that fuel stacking is mostly practiced by urban households in Ghana.

This chapter then investigate factors that affect multiple cooking fuel users and their total expenditure on LPG and charcoal, by using the double-hurdle model. Table 3.4 shows the results of the analysis. Similar to the results in the previous subsection,

multiple cooking fuel users are responsive to only LPG and charcoal prices, and indifferent to the prices of other fuels, like kerosene. Moreover, key factors, such as income, residential location, and reliable fuel supply are all significant in the fuel stacking model. Nevertheless, this chapter observes some notable differences between the analysis based on the energy ladder model and the fuel stacking model. First, a comparison of Tables 3.3 and 3.4 reveal that the marginal effects on reliable fuel supply in the former are larger than those in the latter. Specifically, the results in Table 3.3 indicate that the reliable supply of charcoal and LPG increases its charcoal and LPG expenditure by 30.9% and 24%. In Table 3.4, on the other hand, the reliable supply of charcoal and LPG increases the total expenditure on LPG and charcoal by 13.5% and 18.5%, respectively. The smaller marginal effects can be attributed to the easier substitution between LPG and charcoal in the case of multiple fuel users as compared to single fuel users. Multiple fuel users can easily substitute LPG for charcoal or vice versa, and hence, the availability of one fuel has less effect on total expenditure.

Second, the marginal effects of the income variable in Table 3.4 are much larger than that in Table 3.3. For example, in Table 3.3, income increases the probability of participating in the LPG market by 1% and LPG expenditure by 4.5% conditional upon LPG market participation. On the other hand, in Table 3.4, income increases the probability of participating in the multiple fuel use by 6.45% and total expenditure to LPG and charcoal by 8.2% conditional upon participation. The larger marginal effects indicate the importance of income in the adoption and spending behaviors of multiple cooking fuel users. Last but not least, only a level of education beyond a secondary education has a statistically significant and positive effect in Table 3.4, in contrast to

Table 3.3 that illustrates the significant positive effect of all three levels of education. The implication is that a household head education level below tertiary education has no effect on the adoption and expenditure for multiple fuels. It suggests that only highly educated households use multiple cooking fuels.

[Table 3.4]

3.5.4 Rural and Urban Households

Consistent with previous studies on Ghana, such as those by Karimu (2015) and Karimu et al. (2016), the results in Table 3.3 indicate that, on average, urban households have a higher probability of participating in the charcoal and LPG markets compared with rural households. In this subsection, to investigate the differences in the factors explaining energy expenditure, this chapter further decompose the full sample into rural and urban households. The results of the double hurdle model are presented for the urban sample (Table 3.5) and rural sample (Table 3.6). The findings are similar to the full sample model reported in Table 3.3, albeit with certain differences. Comparing the marginal effects of fuel prices reveals higher effects for the urban sample than the rural sample. For example, a 1% increase in the LPG price decreases urban households' participation in the LPG market by 12.4%, whereas the drop in rural household's participation is only 0.8%. Similarly, a 1% increase in the charcoal price decreases urban households' participation in the charcoal market by 17.2%, but it decreases rural households' participation only by 3.4%. These results suggest that in terms of participation, urban households are more responsive than rural households to changes in

the fuel price. Therefore, promotion of modern energy sources via price-related policies might be more effective for urban residents than for rural residents.

The results also indicate income may play different roles in expenditure decisions between rural and urban residents. For rural households, income is highly significant in both LPG and charcoal expenditure decisions. However, for urban households, income is only significant in LPG expenditure decisions. A possible explanation is that, because LPG is far more expensive to use than charcoal, household income will play a significant role in LPG expenditure decisions, irrespective of household location. On the other hand, because charcoal is cheaper and the purchase of this fuel constitutes a smaller share of the income of urban households, it does not play a significant role in charcoal expenditure decisions by urban households.

[Table 3.5]

[Table 3.6]

3.5.5 Robustness checks

The Heckman model is used in this section to carry out robustness checks. As explained in Section 3.4, the Heckman model can be used if zero expenditure represents missing or non-response outcomes. Thus, this chapter exclude all households that use LPG or charcoal, but have no positive expenditure. The final dataset reduces from 16,041 to 15,346 households. For these remaining households, zero expenditure clearly represents the non-usage of a particular fuel, which is consistent with the Heckman

model's assumptions. The results reported in Table 3.7 are largely consistent with those of the double hurdle model. For example, income is statistically insignificant in the charcoal case, a finding consistent with the results of the double-hurdle model. As the third and fifth columns of Table 3.7 show, households are indifferent to prices of other fuels when they make expenditure-related decisions.

To further confirm the robustness of the results, this chapter conducts diagnostic tests to compare the results of the double-hurdle and Heckman models. The double-hurdle model is tested against the Heckman model using Vuong's test.²⁵ The results in Table 3.2 indicate that the Vuong test does not reject the null hypothesis that the two models are equivalent. The Tobit model results were also tested against those of the double hurdle model using the likelihood ratio (LR) test statistic. This chapter found that the Tobit model was rejected in favor of the double-hurdle model.

[Table 3.7]

3.6 Conclusions

This chapter attempted to investigate whether the factors determining a household's decision to participate in a fuel market differ from those determining how much to spend on that fuel after the participation decision is made. To answer this question, three estimation methodologies were used: the Tobit, double-hurdle, and Heckman models. Diagnostic checks led to the rejection of the Tobit model, because both

²⁵ The Vuong test is used to test one non-nested model against another. More specifically, it tests the null hypothesis that the expected value of the log-likelihood ratio of the two non-nested models equals zero.

the normality and homoscedasticity assumptions were violated. This chapter's main discussion drew on the results from the double-hurdle, with the Heckman model used as robustness check.

The analysis yielded several interesting results. First, the factors influencing the household decision to participate in either the LPG or charcoal market differ from those influencing how much is spent. Therefore, to be able to adequately address these differences in decision-making, a methodology capable of addressing these decisions should be adopted. Second, households already using and spending positive amounts on LPG or charcoal are indifferent to prices of other fuels. The finding suggests that any policy that affects the price of a cooking fuel will have impact on its own users, but not on users of other fuels. Third, although income plays a role in the LPG expenditure of rural and urban residents, it is insignificant in terms of charcoal expenditures of urban residents. This result indicates the critical role that income plays in modern cooking fuel choice and spending, as compared to transition fuels.

The results have several policy implications regarding the transition to modern fuels. First, different policy designs might be necessary for households that use LPG and those that do not. For example, it is necessary to focus on making LPG affordable to encourage households already using LPG to maintain its usage and increase related spending. In other words, LPG price is key in motivating LPG users to maintain their spending. To enhance the uptake of LPG and spending among those that do not use LPG, a possible solution is policy measures to improve their livelihoods, which could encourage charcoal users to switch to a modern fuel such as LPG. This can be achieved by intensifying poverty reduction schemes to improve with the goal of reducing poverty.

Second, the results showed that there are positive returns to education for both single fuel users (LPG or charcoal) or multiple fuel users (LPG and charcoal). It suggests that intensifying awareness on the positive effects of LPG use and spending could affect behavioral patterns, thereby increasing the uptake of cleaner cooking fuels. Third, policies that increase access to modern fuels should be mainly focused on urban households. Urban households have a considerably higher purchasing power, and thus, are more likely to adopt and spend on LPG contingent on a more reliable supply. In contrast, such policies might not be sufficient for rural households given their access to firewood, which is freely available in most cases. Here, a free supply of LPG cylinders might be helpful for rural households especially when the free supplies are associated with frequent visits to the beneficiaries to address challenges in their quest to maintain the use of LPG. Although the free supply of LPG cylinders might not be typically sustainable, it helps reduce the fixed costs associated with using LPG. In the case of charcoal use, particularly among urban households, policies should be designed to limit the fuel supply to reduce its use and spending. Such tailor-made policies are important to increase the usage of modern fuels in Ghana.

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Table 3.1: Household Energy Use Patterns

	Main Cooking Fuels					Multiple Fuels
	Traditional	Transition		Modern		LPG & Charcoal
	Firewood	Kerosene	Charcoal	LPG	Electricity	
Ghana (N = 16,041)						
Household users (%)	48.08	0.16	35.41	16.09	0.26	7.00
Average energy expenditure	-	4.82	4.47	10.36	20.50	19.44
Urban Areas (N =6,886)						
Household users (%)	17.25	0.22	44.58	32.14	0.54	13.66
Energy expenditure (GH¢/month)	-	5.28	5.92	12.60	24.36	19.90
Rural Areas (N = 9,155)						
Household users (%)	80.01	0.12	12.82	4.01	0.05	1.99
Energy expenditure (GH¢/month)	-	4.20	1.98	9.08	13.92	17.08

Source: Authors' calculations. GH¢1= US \$0.60.²⁶

²⁶ The authors employ an average of the official exchange rate for 2011 and 2012:
https://data.worldbank.org/indicator/PA.NUS.FCRF?end=2012&start=2011&year_low_desc=false.

Table 3.2: Model Diagnostics

Test Type	Computed χ^2	p-value/critical χ^2	Decision
<i>LPG Expenditure</i>			
Normality	8,341.32	prob > chi2 = (0.000)	Reject null
Homoscedasticity	2,432.87	prob > chi2 = (0.000)	Reject null
Tobit vs. double hurdle	4,712.31	$\chi^2(0.05, 2) = [5.991]$	Reject Tobit
Double hurdle vs. Heckman	0.001	N (0,1) = [1.96]	Double = Heckman
<i>Charcoal Expenditure</i>			
Normality	7,492.10	prob > chi2 = (0.000)	Reject null
Homoscedasticity	2,097.75	prob > chi2 = (0.000)	Reject null
Tobit vs. double hurdle	3,822.67	$\chi^2(0.05, 3) = [7.815]$	Reject Tobit
Double hurdle vs. Heckman	0.004	N (0,1) = [1.96]	Double = Heckman

Note: p-values are in round parenthesis and critical values are in square parenthesis.

Table 3.3: Estimated Elasticities for the Double Hurdle Model

Variable	LPG Expenditure			Charcoal Expenditure		
	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$
Log LPG price	-0.039*** (0.01)	-0.153* (0.08)	-0.221*** (0.07)	-0.076 (0.14)	0.019 (0.12)	-0.04 (0.07)
Log charcoal price	0.041*** (0.01)	0.183 (0.17)	0.285*** (0.05)	-0.102** (0.02)	-0.053** (0.01)	-0.172*** (0.05)
Log kerosene price	-0.008 (0.03)	-0.324 (0.29)	-0.097 (0.23)	-0.142 (0.17)	0.086 (0.17)	-0.267 (0.17)
Reliable charcoal supply	0.012* (0.01)	0.136*** (0.05)	0.093*** (0.03)	0.471*** (0.01)	0.309*** (0.07)	0.815*** (0.02)
Reliable firewood supply	-0.04*** (0.004)	-0.058 (0.04)	-0.253*** (0.02)	-0.096*** (0.01)	0.073 (0.02)	-0.143*** (0.02)
Reliable kerosene supply	-0.02** (0.004)	-0.116*** (0.03)	-0.117*** (0.02)	0.072*** (0.01)	0.033 (0.03)	0.152*** (0.02)
Reliable LPG supply	0.130*** (0.006)	0.238*** (0.05)	0.108*** (0.04)	-0.463*** (0.03)	-0.090*** (0.03)	-0.177*** (0.02)
Male head	-0.014*** (0.003)	-0.069** (0.04)	-0.099*** (0.02)	-0.110 (0.009)	-0.069* (0.03)	-0.221*** (0.02)
Age head	-0.0004** (0.0001)	0.004* (0.002)	-0.002*** (0.001)	0.0004 (0.0003)	0.002*** (0.001)	0.002*** (0.001)
Log income	0.010*** (0.001)	0.045*** (0.01)	0.070*** (0.008)	0.005 (0.003)	0.011 (0.01)	0.014 (0.01)
Employment status	0.065*** (0.024)	-0.042 (0.26)	0.337*** (0.099)	0.091 (0.07)	-0.091 (0.15)	0.094 (0.14)
Urban	0.012*** (0.003)	0.036* (0.01)	0.080*** (0.02)	0.211*** (0.01)	0.240*** (0.02)	0.555*** (0.02)
Electricity	0.065*** (0.005)	0.239* (0.09)	0.398*** (0.03)	0.170*** (0.01)	0.139*** (0.03)	0.374*** (0.02)
Occupancy status	-0.022*** (0.004)	-0.019 (0.04)	-0.138*** (0.02)	-0.016 (0.02)	-0.015 (0.03)	-0.156*** (0.02)
Number of rooms	0.012*** (0.002)	0.049*** (0.02)	0.083*** (0.01)	-0.021*** (0.004)	0.022** (0.01)	-0.031*** (0.01)
Household size	-0.002*** (0.001)	0.075*** (0.01)	-0.004 (0.005)	0.021*** (0.002)	0.060*** (0.005)	0.063*** (0.004)
Basic education	0.037*** (0.004)	0.198*** (0.06)	0.262*** (0.03)	0.053*** (0.01)	0.042 (0.03)	0.116*** (0.02)
Secondary education	0.058*** (0.005)	0.173* (0.07)	0.445*** (0.04)	0.044*** (0.158)	-0.010 (0.04)	0.074* (0.03)
Tertiary education	0.089*** (0.006)	0.276*** (0.06)	0.773*** (0.05)	-0.027** (0.01)	-0.010 (0.04)	-0.057 (0.04)
N	16,041	2,412	16,041	16,041	5,621	16,041

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.4: Estimated Elasticities for the Fuel Stacking Model

Charcoal and LPG expenditure			
Variable	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$
Log LPG price	-0.019*** (0.006)	-0.118** (0.009)	0.568 (0.110)
Log charcoal price	-0.331*** (0.067)	-0.309*** (0.060)	-0.322*** (0.068)
Log kerosene price	-0.023 (0.016)	0.246 (0.192)	0.163 (0.204)
Reliable charcoal supply	0.372*** (0.122)	0.135*** (0.046)	0.027** (0.007)
Reliable firewood supply	-0.017*** (0.002)	-0.163*** (0.031)	-0.117*** (0.033)
Reliable kerosene supply	-0.020 (0.075)	-0.116 (0.128)	-0.115*** (0.034)
Reliable LPG supply	0.122*** (0.091)	0.185*** (0.026)	0.159*** (0.029)
Male head	0.096 (0.073)	0.094*** (0.031)	0.066** (0.027)
Age head	0.004* (0.002)	-0.001 (0.001)	0.00004 (0.001)
Log income	0.064*** (0.023)	0.082*** (0.009)	0.093*** (0.012)
Employment status	3.618 (5.223)	0.219 (0.191)	0.095 (0.183)
Urban	0.291*** (0.074)	0.207*** (0.029)	0.262*** (0.032)
Electricity	0.153* (0.079)	0.278*** (0.028)	0.301*** (0.035)
Occupancy status	0.006** (0.002)	0.108*** (0.031)	0.160*** (0.029)
Number of rooms	0.021 (0.041)	0.115*** (0.013)	0.114*** (0.015)
Household size	0.024 (0.017)	0.027*** (0.006)	0.032*** (0.007)
Basic education	0.003 (0.078)	0.207 (0.127)	0.197*** (0.039)
Secondary education	0.041 (0.124)	0.352 (0.246)	0.344*** (0.045)
Tertiary education	0.477*** (0.159)	0.641*** (0.042)	0.708*** (0.047)
N	16,041	1,123	16,041

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.5: Estimated Elasticities for the Double Hurdle Model for Urban Households

Variable	LPG Expenditure			Charcoal Expenditure		
	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$	Prob $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$
Log LPG price	-0.124** (0.035)	-0.159* (0.088)	-0.406*** (0.145)	-0.058 (0.051)	-0.026 (0.128)	0.035 (0.125)
Log charcoal price	0.168** (0.031)	0.198 (0.159)	0.672** (0.123)	-0.172*** (0.034)	-0.054*** (0.049)	-0.386*** (0.081)
Log kerosene price	0.111 (0.106)	-0.417 (0.361)	0.281 (0.318)	-0.218 (0.115)	-0.316 (0.196)	-0.610* (0.263)
Reliable charcoal supply	0.018 (0.019)	0.110*** (0.042)	0.095* (0.056)	0.675*** (0.031)	0.492*** (0.147)	1.317*** (0.027)
Reliable firewood supply	-0.126*** (0.012)	-0.075* (0.045)	-0.497*** (0.047)	-0.104*** (0.015)	0.020 (0.024)	-0.192*** (0.032)
Reliable kerosene supply	-0.073*** (0.013)	-0.101*** (0.038)	-0.300*** (0.058)	0.037* (0.016)	0.065** (0.031)	0.138*** (0.030)
Reliable LPG supply	0.409*** (0.012)	0.164*** (0.063)	1.640*** (0.043)	-0.090*** (0.014)	-0.129*** (0.028)	-0.265*** (0.034)
Male head	-0.028** (0.012)	-0.080** (0.041)	-0.128*** (0.047)	-0.082*** (0.015)	-0.046* (0.026)	-0.181*** (0.036)
Age head	-0.014*** (0.001)	0.004** (0.002)	-0.004** (0.002)	0.001* (0.001)	0.004*** (0.001)	0.005*** (0.001)
Log income	0.025*** (0.004)	0.044*** (0.013)	0.106*** (0.016)	0.002 (0.005)	0.013 (0.009)	0.012 (0.013)
Employment status	0.228** (0.078)	-0.182 (0.333)	0.695*** (0.211)	0.070 (0.085)	-0.001 (0.147)	0.093 (0.175)
Electricity	0.185*** (0.025)	0.086 (0.154)	0.637*** (0.072)	0.059*** (0.020)	0.139*** (0.037)	0.199 (0.044)
Occupancy status	-0.048 (0.013)	-0.001 (0.047)	-0.173*** (0.051)	-0.064*** (0.015)	-0.018 (0.031)	-0.153*** (0.038)
Number of rooms	0.046*** (0.007)	0.045** (0.020)	0.180*** (0.023)	-0.037*** (0.008)	0.027 (0.018)	-0.062*** (0.018)
Household size	-0.005 (0.003)	0.087*** (0.011)	0.008 (0.011)	0.048*** (0.003)	0.086*** (0.005)	0.149*** (0.009)
Basic education	0.107 (0.015)	0.165*** (0.059)	0.437*** (0.055)	-0.014 (0.016)	-0.022 (0.028)	0.034 (0.034)
Secondary education	0.150*** (0.184)	0.077 (0.072)	0.598*** (0.071)	0.006 (0.023)	-0.025 (0.047)	-0.014 (0.049)
Tertiary education	0.235*** (0.017)	0.220*** (0.063)	1.044*** (0.081)	0.126 (0.122)	-0.036 (0.050)	-0.288*** (0.060)
N	6,886	2,028	6,886	6,886	3,776	6,886

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.6: Estimated Elasticities for the Double Hurdle Model for Rural Households

Variable	LPG Expenditure			Charcoal Expenditure		
	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$	Prob $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Uncond. Mean $E[y_i x]$
Log LPG price	-0.008*** (0.005)	-0.153** (0.077)	-0.219*** (0.073)	-0.117 (0.074)	0.343 (0.328)	0.147 (0.121)
Log charcoal price	-0.001 (0.004)	0.183 (0.168)	0.278*** (0.051)	-0.034*** (0.010)	-0.381*** (0.102)	-0.488*** (0.020)
Log kerosene price	-0.031 (0.01)	-0.314 (0.296)	-0.072 (0.235)	-0.139* (0.077)	0.734 (0.295)	-0.484 (0.314)
Reliable charcoal supply	0.003 (0.002)	0.137*** (0.049)	0.101*** (0.026)	0.270*** (0.013)	0.184*** (0.093)	1.138*** (0.058)
Reliable firewood supply	-0.005*** (0.002)	-0.063 (0.420)	-0.268*** (0.025)	-0.076*** (0.010)	0.167*** (0.047)	-0.308*** (0.035)
Reliable kerosene supply	0.002 (0.001)	-0.115*** (0.034)	-0.111*** (0.023)	0.054*** (0.009)	-0.002 (0.043)	0.207*** (0.035)
Reliable LPG supply	0.024*** (0.003)	0.248*** (0.048)	1.152*** (0.035)	0.007 (0.013)	0.103 (0.056)	0.028 (0.052)
Male head	-0.005*** (0.002)	-0.070* (0.039)	-0.102*** (0.025)	-0.096*** (0.010)	-0.156*** (0.046)	-0.361*** (0.040)
Age head	-0.0001 (0.00004)	0.004** (0.002)	-0.002*** (0.001)	-0.001** (0.0003)	-0.002 (0.001)	-0.001 (0.001)
Log income	0.003*** (0.001)	0.045*** (0.011)	0.070*** (0.008)	0.011*** (0.003)	0.070*** (0.015)	0.047*** (0.013)
Employment status	-0.006 (0.013)	-0.042 (0.261)	0.335*** (0.100)	0.062 (0.138)	-0.853 (0.587)	0.206 (0.561)
Electricity	0.012*** (0.002)	0.249*** (0.092)	0.418*** (0.025)	0.141*** (0.008)	0.110** (0.044)	0.563*** (0.035)
Occupancy status	-0.008*** (0.002)	-0.021 (0.042)	-0.146*** (0.018)	-0.057*** (0.009)	-0.002 (0.042)	-0.244*** (0.037)
Number of rooms	0.002*** (0.001)	0.048*** (0.018)	0.082*** (0.010)	-0.00003 (0.004)	0.036 (0.020)	0.002 (0.016)
Household size	-0.001** (0.0003)	0.076*** (0.010)	-0.004 (0.005)	0.003 (0.002)	0.016* (0.010)	0.011 (0.008)
Basic education	0.007*** (0.002)	0.198*** (0.055)	0.266*** (0.027)	0.049*** (0.010)	0.107** (0.046)	0.207 (0.039)
Secondary education	0.015*** (0.003)	0.173*** (0.068)	0.453*** (0.039)	0.065 (0.018)	0.009 (0.080)	0.260 (0.073)
Tertiary education	0.023*** (0.003)	0.276*** (0.059)	0.784*** (0.051)	0.114 (0.018)	0.051 (0.074)	0.445 (0.072)
N	9155	2412	9155	9155	1845	9155

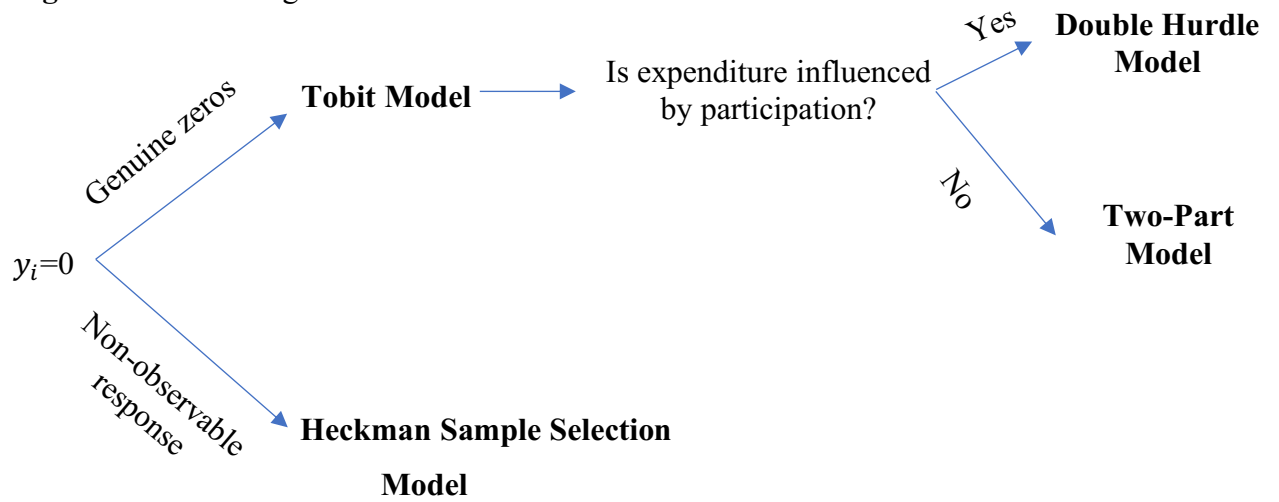
Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 3.7: Estimated Elasticities for the Heckman model

Variable	LPG Expenditure		Charcoal Expenditure	
	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$	Prob. $P[y_i > 0 x]$	Cond. Mean $E[y_i x, y_i > 0]$
Log LPG price	-0.062*** (0.01)	-0.284** (0.11)	-0.071 (0.02)	0.241 (0.15)
Log charcoal price	0.046*** (0.01)	0.081 (0.153)	-0.282*** (0.07)	-0.261*** (0.10)
Log kerosene price	-0.086 (0.35)	-0.355 (0.32)	-0.173 (0.01)	-0.255 (0.25)
Reliable charcoal supply	0.008** (0.004)	0.114** (0.05)	0.474*** (0.01)	1.837*** (0.28)
Reliable firewood supply	-0.037*** (0.005)	0.027 (0.06)	-0.092*** (0.01)	-0.083 (0.06)
Reliable kerosene supply	-0.018*** (0.004)	-0.078* (0.04)	0.070*** (0.01)	0.216*** (0.05)
Reliable LPG supply	0.132*** (0.01)	0.131* (0.01)	-0.076*** (0.01)	-0.272*** (0.05)
Male head	-0.015*** (0.003)	-0.035 (0.04)	-0.108*** (0.01)	-0.244*** (0.06)
Age head	-0.001*** (0.0001)	0.005*** (0.001)	0.001 (0.0002)	0.004*** (0.001)
Log income	0.010*** (0.001)	0.021** (0.001)	0.005 (0.03)	0.021 (0.04)
Employment status	0.052** (0.004)	-0.160 (0.31)	0.086 (0.07)	-0.100 (0.25)
Urban	0.015*** (0.004)	0.013** (0.001)	0.228*** (0.01)	0.799*** (0.12)
Electricity	0.063*** (0.004)	0.057 (0.13)	0.170*** (0.01)	0.536*** (0.10)
Occupancy status	-0.021** (0.003)	-0.028 (0.05)	-0.073 (0.01)	-0.192*** (0.05)
Number of rooms	0.013*** (0.001)	0.024 (0.02)	-0.020*** (0.004)	-0.022 (0.02)
Household size	-0.003*** (0.001)	0.082*** (0.01)	0.021*** (0.002)	0.103*** (0.01)
Basic education	0.035*** (0.004)	0.094** (0.001)	0.052** (0.01)	0.164*** (0.04)
Secondary education	0.058*** (0.01)	0.016** (0.002)	0.044*** (0.02)	0.079 (0.06)
Tertiary education	0.096*** (0.006)	0.052** (0.01)	-0.025*** (0.01)	-0.077 (0.70)
constant		4.016*** (0.61)		-2.056 (0.70)
Lamda		-0.319* (0.17)		1.109*** (0.249)
N	15,346	2,412	15,942	5,621

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Figure 3.1. Choosing an Estimator



Source: Humphreys (2013)

Appendix

Table A3.1: List of variables and definitions

Variables	Definition
Dependent Variables:	
<i>Binary Dep. Variable (First Hurdle)</i>	
LPG	Dummy (participant=1, others=0)
Charcoal	Dummy (participant=1, others=0)
<i>Monthly Expenditure (Second Hurdle)</i>	
Log monthly LPG expenditure	Monthly amount spent in Ghana cedi
Log monthly charcoal expenditure	Monthly amount spent in Ghana cedi
Independent Variables	
<i>Household Characteristics</i>	
Sex of household head (Male head)	Dummy (male=1, female=0)
Age of household head	Continuous
Log monthly household income	Continuous
Household size	Continuous
Employment status	Dummy (employed=1, otherwise=0)
Basic education	Dummy (basic=1, no formal education=0)
Secondary education	Dummy (secondary=1, no formal education=0)
Tertiary education	Dummy (tertiary=1, no formal education=0)
Urban	Dummy (urban=1, rural=0)
Electricity	Dummy (yes=1, no=0)
Occupancy status	Dummy (owning=1, otherwise=0)
Number of rooms	Number of rooms the household occupies
<i>Fuel Characteristics</i>	
Reliable LPG supply	Dummy (yes=1, no=0)
Reliable kerosene supply	Dummy (yes=1, no=0)
Reliable firewood supply	Dummy (yes=1, no=0)
Reliable charcoal supply	Dummy (yes=1, no=0)
Log charcoal price (cedi/kg)	Continuous
Log LPG price (cedi/kg)	Continuous
Log kerosene price(cedi/liter)	Continuous

Table A3.2: Summary Statistics of Variables

Variable	Obs.	Mean	S.D.	Min.	Max.
LPG	16,041	0.16	0.37	0.00	1.00
Charcoal	16,041	0.35	0.44	0.00	1.00
Log LPG expenditure	2,412	4.46	0.83	0.69	8.25
Log Charcoal expenditure	5,621	2.41	0.83	0.18	5.63
Log charcoal and LPG expenditure	1,123	4.66	0.73	2.07	7.63
Age head	16,041	45.61	15.52	15.00	99.00
Male head	16,041	0.72	0.45	0.00	1.00
Log income	16,041	8.16	1.39	-3.00	14.03
Household size	16,041	4.26	2.78	1.00	29.00
Basic education	16,041	0.30	0.46	0.00	1.00
Secondary education	16,041	0.08	0.28	0.00	1.00
Tertiary education	16,041	0.10	0.30	0.00	1.00
Urban	16,041	0.43	0.49	0.00	1.00
Electricity	16,041	0.60	0.49	0.00	1.00
Occupancy status	16,041	0.54	0.50	0.00	1.00
Number of rooms	16,041	1.90	1.29	1.00	17.00
Reliable LPG supply	16,041	0.30	0.46	0.00	1.00
Reliable kerosene supply	16,041	0.49	0.50	0.00	1.00
Reliable firewood supply	16,041	0.58	0.49	0.00	1.00
Reliable charcoal supply	16,041	0.80	0.40	0.00	1.00
Log charcoal price	16,041	0.42	0.06	0.20	0.63
Log LPG price	16,041	0.47	0.09	0.26	0.86
Log kerosene price	16,041	0.03	0.05	-0.09	0.39

Note: “S.D.” denotes standard deviation, “Obs.” represents number of observations, and “Min.” and “Max.” are minimum and maximum.

Table A3.3: Tobit Estimation Results

Variables	LPG expenditure	Charcoal expenditure
Log LPG price	-1.120*** (0.34)	-0.520 (0.37)
Log charcoal price	1.574*** (0.34)	-0.735*** (0.20)
Log kerosene price	-0.500 (1.09)	-1.188** (0.65)
Reliable charcoal supply	0.600*** (0.17)	4.889*** (0.15)
Reliable firewood supply	-1.367*** (0.13)	-0.737*** (0.08)
Reliable kerosene supply	-0.550*** (0.13)	0.698*** (0.08)
Reliable LPG supply	5.180*** (0.14)	-0.704*** (0.09)
Male head	-0.505*** (0.121)	-0.968*** (0.08)
Age head	-0.014*** (0.004)	0.006* (0.003)
Log income	0.378*** (0.04)	0.054* (0.03)
Employment status	2.328** (0.870)	0.582 (0.61)
Urban	0.519*** (0.14)	2.18*** (0.09)
Electricity	2.764*** (2.03)	1.720*** (0.09)
Occupancy status	-0.785*** (0.126)	-0.682*** (0.08)
Number of rooms	0.434*** (0.06)	-0.173*** (0.04)
Household size	0.015 (0.02)	0.212*** (0.02)
Basic education	1.586*** (0.15)	0.506*** (0.09)
Secondary education	2.328*** (0.19)	0.415*** (0.14)
Tertiary education	3.342*** (0.17)	-0.164 (0.13)
Constant	-11.55*** (1.00)	-9.868*** (0.70)
Sigma	3.631*** (0.06)	3.651*** (0.04)
<i>N</i>	16,041	16041

Note: Standard errors are in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table A3.4: Collinearity Diagnostics

Variable	VIF	VIF
	LPG expenditure	Charcoal expenditure
Log LPG price	1.09	1.02
Log charcoal price	1.02	1.07
Log kerosene price	1.08	1.02
Reliable charcoal supply	1.32	1.06
Reliable firewood supply	1.42	1.26
Reliable kerosene supply	1.50	1.28
Reliable LPG supply	1.15	1.27
Male head	1.12	1.19
Age head	1.40	1.22
Log income	1.16	1.17
Employment status	1.01	1.01
Urban	1.16	1.27
Electricity	1.05	1.17
Occupancy status	1.32	1.27
Number of rooms	1.85	1.72
Household size	1.67	1.59
Basic education	2.70	1.37
Secondary education	2.20	1.29
Tertiary education	2.84	1.30

Chapter 4

Determinants and Welfare Impacts of Rural Electrification in Ghana

4.1 Introduction

Electricity is an essential input for socio-economic development. Electricity brings improvements in health delivery, education, environmental sustainability and agricultural development (Kemausuor et al., 2014). Despite its importance, access to electricity is limited in many developing countries. In 2015, 1.2 billion people did not have access to electricity. In SSA alone, more than 600 million people lacked access to electricity (IEA, 2015). In Ghana, where this study focuses, more than 7 million people do not have access to electricity (IEA, 2015). Even for communities connected to the national grid, the electricity supply is insufficient and households and businesses often endure blackouts.

Notwithstanding a serious lack of access to electricity, there have been some signs of progress in Ghana and other developing countries. Between 2000 and 2016, the percentage of people with access to electricity increased from 64% to 82% in developing countries, and from 23% to 43% in SSA (IEA, 2017). In Ghana, it increased from 45% to 84%. The trend is confirmed by Ghana's census data, which show that the percentage of households with access to electricity increased from 45% in 2006 to 61% in 2013 and 74% in 2017 (Ghana Living Standards Survey V, VI and VII rounds) as shown in Figure 4.1. Even in rural areas where access to electricity is more limited, the same census data

show that the percentage of rural households with access to electricity increased from 23% in 2006 to 40% in 2013 and 61% in 2017, as shown in Figure 4.1. Available data also indicates that an increasing number of rural communities are being connected to the grid. For instance, about 1,900 rural communities were connected to the national grid between 2009 to 2015 (Ministry of Energy, 2017).

In spite of these encouraging trends in electricity access, many questions are yet to be answered: Despite the increase in access to electricity, why do some households and communities continue to remain without electricity? Which households or communities have benefited from improved access to electricity? What is the role of public policy in improving access to electricity? What are the impacts of rural community electrification programs on the welfare of communities?

[Figure 4.1]

The aim of this chapter is to investigate the dynamics of rural electrification in Ghana. Particularly, this chapter focuses on key determinants of electricity access for rural households in Ghana. Moreover, this chapter examines the role of public policy in community electrification and their impact on community welfare in Ghana. To achieve this purpose, this chapter explores how one of Ghana's flagship rural electrification programs called the Self-Help Electrification Programme (SHEP) helped electricity access and poverty alleviation.

This chapter contributes to extant literature in two ways. First, it introduces dynamic aspects to the study of rural household electrification in developing countries.

While many previous studies on electrification (e.g. Oda and Tsujita, 2011; Onjeji et al., 2012; Kemmler, 2006; Khandker et al., 2012) is based on cross-sectional analysis and ascertain the factors explaining rural electrification at a given time, they do not show how these factors have changed over time. Building on these studies, this chapter investigate whether factors explaining rural household electrification have changed or not from the period 2012-2017. Second, this study evaluates the impact of a public policy to increase access to electricity on the welfare of rural community. While several literatures have estimated the benefits of rural electrification on employment and welfare (e.g. Grogan and Sadanand, 2012; Salmon and Tanguy 2016; Dasso and Fernandez, 2015; Adu et al., 2018), they do not directly assess the impact of rural electrification programs. Although the success of Ghana's electrification drive has been credited to programs like SHEP, no attempts have been made to empirically examine this assertion and its associated impacts. In directly examining the impact of SHEP, this chapter empirically ascertains the role of public policy in increasing access to electricity, improving welfare and reducing poverty.

The remainder of this chapter is composed as follows: Section 4.2 gives a brief overview and history of electrification in Ghana. Section 4.3 describes the data used in this study. Section 4.4 presents the econometric models employed. Section 4.5 discusses the results. Finally, Section 4.6 concludes and provides some policy implications.

4.2 Overview and History of Electrification in Ghana

In the colonial days of the Gold Coast (before Ghana's independence in 1957), the electricity was mostly supplied from isolated diesel generation plants dispersed across the country (Kumi, 2017). The plants were owned by industries and institutions such as hospitals, schools, municipalities, and factories. In 1914, the first public electricity generation system was set up by the Gold Coast Railway Administration in Sekondi (ISSER, 2005). Although the goal was to supply electricity only to the railways sector in Sekondi, it was extended to major cities in the country including Takoradi, Accra, Nsawam, Kumasi, Tema, Tamale, and Bolgatanga by the year 1955.

Ghana began to move away from these diesel generation plants to hydroelectricity in 1972 with the completion of the Akosombo Dam Project over the Volta River that provides a total installed capacity of 912 MW for electricity generation. Although the primary goal of the project was to supply electricity only to the aluminum industry in Ghana, electricity supply was extended to neighboring countries including Togo and Benin (Kumi, 2017). The Kpong Hydroelectric Power Station was commissioned in 1982 to supplement the supply from the Akosombo Dam Project, increasing the installed generation capacity from 912 MW to 1072 MW.

Ghana experienced its first electricity crisis in 1984, when a severe drought in the previous year caused a 15% reduction in the expected long-term inflow into the Akosombo Dam. The crisis called for an immediate action, as the country could not rely solely on hydropower. As a result, several thermal power plants were introduced into Ghana's generation mix. The first of these was a 550 MW facility (Tapco and Tico) at the Takoradi Thermal Plant completed in 2000. Since then, the total installed capacity of

thermal power plants has increased to 2,785 MW as of the end of 2017 (Energy Commission of Ghana, 2018). Currently, the electricity generation mix in Ghana is mainly dominated by hydro and thermal sources. Figure 4.2 depicts the historical electricity generation mix from 2000 to 2017. It shows that hydro had been the main source of electricity until 2015, when thermal sources took over. By the end of 2016, the share of thermal power in the generation mix stood at 57.21% while hydro stood at 42.79%. Although Ghana introduced renewable energy sources such as solar in 2013, they have yet to play a significant role in the generation mix. Presently, renewable energy sources contribute less than 1% of the total power supply (Figure 4.2).

The share of rural people with access to electricity has improved considerably, increasing from 6% in 1990 to 60% in 2015 (World Bank, 2016). This is a testament to Ghana's commitment to achieving universal access to electricity, a journey that began with the establishment of the National Electrification Scheme (NES) in 1989 (Ministry of Energy, 2010). This scheme serves as the key instrument to extend electricity to all parts of the country by 2020. Within the first ten years of the NES, about 2,350 communities were connected to the national grid (Kemausuor and Ackom, 2017). Although the universal access target will not be achieved by 2020, judging from the annual growth in electricity access of 2.6% over the period, it is likely that this scheme has contributed to a rapid increase in electricity access. The two pillars of the NES are the National Electrification Program (NEP) and SHEP. Under the first phase of the NEP, electricity was extended to all district capitals in the country. Under the second phase, plans to electrify communities were based on the most economically viable projects.

[Figure 4.2]

SHEP was established to support the NES and encourage community participation with the goal of accelerating the country's electrification process. Under the initial SHEP, households in communities without electricity were expected to mobilize resources to provide a number of utility poles, with the government providing the remaining poles, transmission equipment, materials, and construction work. Rural communities within 20 kilometers from an existing 33kV or 11kV sub-transmission line qualified for electrification if they were willing to pay for the cost of standard low-voltage poles needed for the distribution network in the community. Unelectrified communities that could not afford to pay for the low-voltage poles could request financial assistance from their respective local governments (Kemausuor and Ackom, 2017).²⁷ Under the revised SHEP that began in 2008, the government of Ghana covers 100% of the capital cost for all necessary electricity poles and electricity meters. Figure 4.3 shows the number of communities connected to the national grid under SHEP from the year 2009 to 2016. The figure shows an increasing number of communities under SHEP although the number of new communities joining SHEP has been declining after 2012 due to financial challenges.

[Figure 4.3]

²⁷ Ghana is a constitutional republic with two spheres of government: national and local. At the highest levels of local government, there are three types of assemblies: metropolitan, municipal and district. The local government assemblies are responsible for the setting and collecting of local revenue, public health, environmental protection and sanitation and the provision of basic education.

4.3 Data and Descriptive Statistics

Data were extracted from the sixth and seventh rounds of the Ghana Living Standards Survey (GLSS VI and GLSS VII) conducted by the Ghana Statistical Service (GSS) in 2012/2013 and 2016/2017, respectively. These are nationwide household surveys designed to collect detailed information including demographic characteristics, education, health, employment, migration, tourism, fuel use, housing conditions, household agriculture, access to financial services, and asset ownership (GSS 2014, 2018). The sampling frame for the survey was people living in private households²⁸ in Ghana and was divided into primary and secondary sampling units. Census enumerated areas (EAs) were defined as the primary sampling unit and households within each EA constituted the secondary sampling unit. According to the population in each administrative region, the EAs were first stratified into Ghana's ten administrative regions.

In the 2012/2013 sample, the GSS adopted a two-stage stratified random sampling design in which 1,200 EAs were considered in the first stage to cover a nationally representative sample of 18000 households. In the 2016/2017 sample, however, 1,000 EAs were considered in the first stage to cover a nationally representative sample of 15,000 households. This chapter also uses data from the Ghana Ministry of Energy that contains electrified and unelectrified communities, years of connection, and the number of people in the community. The data extracted from the 2012/2013 and 2016/2017 samples are matched with the data from the Ghana Ministry of Energy.

²⁸ Private households are defined in GLSS as excluding institutional populations such schools and hospitals.

Because this chapter focuses on rural households living in electrified communities, a final sample used is 2,235 (out of 9,214 households) and 3,807 (out of 7,651) rural households from the 2012/2013 and 2016/2017 samples, respectively. Data on communities in SHEP were collected from the Ghana Energy Development and Access Project (GEDAP) of the Ministry of Energy.

Table 4.1 lists all the variables used in this study and their respective definitions. Table 4.2 provides the descriptive statistics of all the variables used in the study. Using the 2012/2013 sample, 76% of the household heads are male and their average age is approximately 47 years old. In the 2016/2017 sample, 70% of the household heads are male and the average age is the same. The average household size in both samples is approximately five members. Merging communities from the 2012/2013 sample and 2016/2017 sample yields a total of 415 communities common to both samples. Of this number, 144 communities were connected to the national grid through on SHEP during 2012-2017.

[Table 4.1]

[Table 4.2]

4.4 Econometric Models

4.4.1 Household Model

This chapter estimates a model of household choice on electrification by assuming that a household's decision to connect to the electricity grid is influenced by their characteristics such as expenditure (expenditure), age of household head (age), household size (size), gender of household head (gender), and employment status of the household head (job). The household choice of connecting to the electricity grid (A) in general is expressed as:

$$A = A(\text{expenditure}, \text{age}, \text{size}, \text{gender}, \text{job}) \quad (1)$$

Suppose representative household i has to choose between b alternatives (where $b = 1, 2$; the first alternative is having access to grid electricity and the second is the use of private generator, solar and rechargeable battery for lighting as well as households without electricity. The indirect utility derived from not having access to grid electricity is defined by M_{ib} . M_{ib} is composed of two parts; an observable part, $x_i' \beta^b$, and an unobservable part $\varepsilon_{i,b}$, where x_i is a vector of all the variables in Eq. (1) and β^b is a vector of parameters to be estimated. The indirect utility function for alternative b for household i can then be expressed as:

$$M_{ib} = x_i' \beta^b + \varepsilon_{i,b} \quad (2)$$

The unobserved part, $\varepsilon_{i,b}$, is assumed to be jointly normally distributed with mean 0, and variance Σ . i.e. $\varepsilon \sim N [0, \Sigma]$.

Then, the probability that household i chooses the first alternative (i.e., chooses to have access to grid electricity) is:

$$P_{i1} = \Pr(\varepsilon_{i2} - \varepsilon_{i1} < x_i' \beta_1 - x_i' \beta_2) = \Pr [\dot{\varepsilon}_{i,21} < x_i' (\beta_1 - \beta_2)] \quad (3)$$

where $\dot{\varepsilon}_{i,21} = \varepsilon_{i2} - \varepsilon_{i1}$.

A similar expression can be obtained for the probability, P_{i2} that household i chooses the second alternative (i.e. chooses not to have access to grid electricity). It is assumed that ε_{ib} has a joint normal density function defined as $f(\varepsilon_{ib}) = f(\varepsilon_{i1}, \varepsilon_{i2})$. Let y_{ib} denote a discrete choice outcome variable that takes a value of 1 if household i has access to grid electricity and 0 otherwise. The cumulative probability for the choice of the first alternative (having access to grid electricity) for household i can now be expressed as:

$$P_{i1} = pr[y_i = 1] = \int_{-\infty}^{\dot{V}_{i,12}} f(\dot{\varepsilon}_{i,21}) d\dot{\varepsilon}_{i,21} \quad (4)$$

where $\dot{V}_{i,12} = x'_i(\beta_1 - \beta_2)$. The expression in Eq. (4) is specific to the first alternative.

In a more general case, the choice probability for household i choosing alternative b is given by $P_{ib} = pr[y_i = b] = h_b(x'_i\beta_b)$, where $h_b(x'_i\beta_b)$ takes a similar expression as in Eq. (4). The log likelihood function for a sample of N independent households with b alternatives can then be expressed as:

$$l = LnL = \sum_{i=1}^N \sum_{b=1}^B y_{ib} Ln(\hat{P}_{ib}) \quad (5)$$

where $\hat{P}_{ib}$ is estimated with a similar expression to that in Eq. (4) using a simulation method that is substituted into the log likelihood function, which is then maximized to obtain the parametric estimates for the β 's.

The primary statistical methods are linear fixed effects regressions and logistic regressions. This chapter estimates both ordinary least squares (OLS) regressions (with community fixed effects) and logistic regressions (with conditional community fixed effects).

4.4.2 Community Model

At the community level, this chapter is interested in (1) the impact of SHEP on improvements in community electrification and (2) the impact of SHEP on community welfare.

The linear regression specification for (1) is given as:

$$Y_{jk} = \alpha_k + \gamma_1 SHEP_{jk} + \gamma_n \theta_{jk} + \varepsilon_{jk} \quad (6)$$

where j denotes communities and k denotes districts. The primary outcome variable of interest Y_{jk} is the change (percentage points) in electrification rates between 2012/2013 sample and the 2016/2017 sample. Communities j are grouped under districts k , implying that α_k is the district fixed effect. γ_1 is the coefficient for the main explanatory variable, SHEP. SHEP takes the value of 1 if a rural community is on SHEP between 2013 and 2016, and 0 otherwise. γ_n is a vector of coefficients for control variables, θ_{jk} . ε_{ij} is the error term that is clustered by district.

This chapter constructs a two-period community panel dataset using the 2012/2013 and 2016/2017 samples to examine the impact of SHEP on community welfare. It exploits the difference-in-difference (DID) method to identify the impact of SHEP on community welfare. Treatment communities are defined as communities on SHEP between 2013 and 2016, while control communities are those without electricity connection. This chapter assumes that the period 2016/2017 is the post-intervention period because SHEP data covers 2012-2017. This chapter uses two outcome variables: average annual household expenditure in a community and the percentage of poor households in a community.²⁹

²⁹ Poverty in Ghana is focused on consumption poverty. In the 2012/2013 and 2016/2017 samples, the upper poverty lines of GH¢1314 and GH¢1760 per adult equivalent per year are calculated, respectively

Given the relatively short period (about four years) between the two data samples, trends between the control and treatment groups are not expected to have changed significantly in the absence of SHEP. The average treatment effect on treated (ATT) is the counterfactual mean difference in the average gains in both treated and control communities which is defined as follows:

$$ATT = E(Y_1 - Y_0 | X, D = 1) = E(Y_1 | X, D = 1) - E(Y_0 | X, D = 1) \quad (7)$$

where $E(.)$ denotes the expectation operator, X is a vector of control variables, D is an indicator variable that takes the value of 1 if a community is treated and 0 otherwise, and Y_1 and Y_0 are the outcome variables for treated and control communities.

This chapter follows the specifications of Angrist and Pischke (2009) and Saing (2018) to estimate the equation below:

$$Y_{jt} = \alpha + \gamma Treat_j + \lambda Post_t + \beta TreatPost_{jt} + \sigma X_{jt} + v_j + \omega_t + \varepsilon_{jt} \quad (8)$$

where Y_{jt} represents the outcome variables of community j at time t . $Treat_j$ is a dummy variable of community j being treated, taking the value of 1 if treated and 0 otherwise. $Post_t$ is the time dummy indicating post-treatment period, taking the value of 1 if the period is post-treatment and 0 otherwise. $TreatPost_{jt}$ is the interaction term between the treatment and time dummies with β as the ATT. X_{jt} , v_j and ω_t are vectors of community-level controls, community and time-specific fixed effects, respectively. ε_{jt} is an idiosyncratic error term.

This chapter uses observational non-randomized data. As a result, this chapter cannot directly observe the counterfactual outcome $E(Y_1 - Y_0)$. Thus, the simple mean value

(GSS: 2014, 2018). Rural households with annual HH expenditure below the upper poverty line are classified as poor.

comparisons between the treated and untreated communities could result in biased estimates. Nilsson (2017) argues that estimating ATT using fixed-effects panel estimations can reduce any selection bias resulting from time-invariant heterogeneity. As a robustness check, this chapter uses Coarsened Exact Matching (CEM) to assign subjects to treatment and control groups before employing the fixed-effects panel estimations that help reduce model dependence (Ho et al., 2007). The matching procedure generates weights that are used in the subsequent weighted fixed-effects panel regressions.

Gains of electricity access might be heterogenous. To consider the distributional consequence across all expenditure groups and poverty classes of communities, this chapter employs unconditional DID quantile panel fixed effect regression. More specifically, this technique is applied to specific welfare quantiles at 25%, 50%, and 75% by estimating a similar equation in Eq. (8) below with q denoting the quantile.

$$Y_{jt}^{(q)} = \alpha^{(q)} + \gamma^{(q)}Treat_j + \lambda^{(q)}Post_t + \beta^{(q)}TreatPost_{jt} + \sigma^{(q)}X_{jt} + v_j^{(q)} + \omega_t^{(q)} + \varepsilon_{jt}^{(q)} \quad (9)$$

4.5 Empirical Results

4.5.1 Household Electrification in Ghana

This subsection explores the determinants of electrification at the household level. Table 4.3 and Table 4.4 reports the regression results using the 2012/2013 sample and the 2016/2017 sample, respectively. The dependent variable in the results presented in Tables 4.3 and 4.4 is a dummy variable for whether or not a rural household has access to grid electricity in an electrified community. To account for the sampling structure and

disproportionate sampling, standard errors are clustered at the community level and sampling weights are applied. Results in models (1) and (3) are results from logistic regressions (conditional community fixed effects) and results from models (2) and (4) are from OLS regressions (community fixed effects) using both Tables 4.3 and 4.4.

Overall, the marginal effects are correctly signed and the statistical significance is typically strong. The household head often controls household decisions especially in the case of expenditures. Having a male as a household head increases the probability of having electricity by 0.3%–0.6% (Table 4.3) and 0.50%–1.60% (Table 4.4). Electrifying a household is a key household decision, because of not only the many uses of electricity in the household but also because of the monetary costs involved. Most household decisions in Ghana are made by the head of the household, who is male in many cases, as shown in Table 4.2.

The tables also reveal that an employed household head is 7%–15% (Table 4.3) and 10%–21% (Table 4.4) more likely to have an electricity connection compared to an unemployed one. This is not surprising, since most unemployed household heads do not have enough financial resources to electrify their households.³⁰ Tables 4.3 and 4.4 also show that household expenditure is the strongest predictor of rural electrification in Ghana, which is to be expected, since the use of electricity is associated with connection costs and monthly electricity bills. Also, higher expenditure households are more likely to migrate from unelectrified rural communities to electrified rural communities than those with lower household expenditures. This result is consistent with the findings of

³⁰ In the GLSS VI and GLSS VII datasets, the share of electricity expenditure in the household budget is 11.4% and 23.8%, respectively.

Dugoua et al. (2017), who showed that an increase in household expenditure by one percent is associated with a 11%–20% point increase in household electricity access rate in rural India. Hence, expenditure plays a vital role in the decision to electrify a household.

The predictors of rural household electrification persist over the two samples, as both Tables 4.3 and 4.4 indicate that expenditure, employment status and gender of the household head are significant predictors of household electrification in Ghana. Also, the size of each of the significant marginal effects in Table 4.4 (2016/2017 sample) is larger than those in Table 4.3 (2012/2013 sample). The implication of these larger marginal effects is to increase positive signed marginal effects or decrease negative signed marginal effects. For instance, comparing models (1) of Tables 4.3 and 4.4, employed household heads have an approximately 14% probability of having an electricity connection in the 2012/2013 sample, while the probability increases to 15% in the 2016/2017 sample. These changes in the marginal effects are likely to occur at the aggregate level and not at the individual level since the 2012/2013 and 2016/2017 samples are repeated cross-sectional datasets.

There are possible issues with endogeneity and selection bias in this sub-section. For instance, lower expenditure households could live in areas where there is poor electricity because of budget constraints. This could mean that property values in a community incorporates the quality of electricity, translating to lower rents which are attractive to lower expenditure households. The use of both ordinary least squares (OLS) regressions (with community fixed effects) and logistic regressions (with conditional community fixed effects) as well as the DID framework and CEM technique should help reduce the effects of endogeneity and selection bias on the results.

[Table 4.3]

[Table 4.4]

4.5.2 Impact of Rural Electrification Program on Community

Electrification

This subsection extends the analysis from the household level to the community level and seeks to answer an important question: Does public policy improve rural community electrification rates in Ghana? To measure public policy, SHEP data taken from the GEDAP covering 2009-2017 is used. The dataset is combined with the 2012/2013 and 2016/2017 samples using community names to arrive at a final number of 415 communities common to both samples. Of these, 144 were on SHEP between 2013 and 2016.

First, this chapter investigates whether SHEP targeted rural communities with low electrification rates. In other words, this chapter tests whether a correlation exists between SHEP and a community's electrification rate. To achieve this objective, a dummy variable is created which is equal to 1 if a rural community joined SHEP between 2013 and 2016 (between 2012/2013 and 2016/2017 samples), and 0 otherwise. The key independent variable is electrification rate defined as the percentage of rural households with access to electricity in a community. This variable is constructed using the 2012/2013 sample. Table 4.5 reports the estimated results of OLS and logistic regressions.

Standard errors are clustered at the district level throughout the analysis to control for intra-district error correlation. Models (1) and (2) are first estimated without controls using logit and OLS regressions, respectively. In models (3) and (4), control variables such as log average expenditure, average household size and log population are included.

The coefficient estimates of electrification rate from models (1) and (2) in Table 4.5 are strongly negative, indicating that the lower the electrification rate of a rural community, the higher the probability that it will be selected for SHEP. The negative relationship holds with the inclusion of the control variables as reported in models (3) and (4). The smaller coefficient estimates (in absolute terms) in models (3) and (4) compared to models (1) and (2) suggest the importance of taking into account key control variables to prevent the coefficient estimates from being overstated. Specifically, a 1% point decrease in the electrification rate of a community will lead to a 0.2%–1.6% points increase in the probability of been selected to SHEP on average. In terms of the control variables, only population (used as a proxy for the size of a community) was found to be statistically significant. The coefficient estimates indicate that the smaller the population of a community, the higher the chances that it will be selected to SHEP. This could be counterintuitive but in practice, rural communities on SHEP are selected based on many factors that this chapter is not able control for all.

[Table 4.5]

Based on the above result, this chapter further examines the impact of SHEP on community electrification-rate improvements. In other words, it tests whether SHEP correlates with actual improvements in electricity access. Improvement in electricity access is defined as the difference in community electrification rates between 2016/2017 and 2012/2013 samples. This definition implies that a community's electrification rate has improved if the difference is positive. On the other hand, if a community's electrification rate decreased from the 2012/2013 sample to the 2016/2017 sample, then the negative difference implies that the community's electrification rate has worsened. The key independent variable is the SHEP dummy variable. The results are shown in Table 4.6.

Models (1) and (2) are estimated without controls while models (3) and (4) include all control variables. The estimated coefficient of SHEP from models (1) and (2) are strongly positive, indicating that the program positively correlates with actual improvements in electricity access. The positive relationship holds with the inclusion of the control variables reported in models (3) and (4). Specifically, rural communities on SHEP between the period 2012 and 2017 improved their community electrification rates by about 15%–17% on average. Because the rural electrification rates increased by 21% from 2013 to 2017 (Figure 4.1), the results suggest that this increase is largely explained by SHEP.

As a robustness check, CEM is used to confirm the results.³¹ The CEM algorithm allows both control and treated communities to be matched according to various community-level characteristics. Two different sets of community-level characteristics

³¹ This chapter used the Stata *cem* library as described by Blackwell et al. (2010) to implement the CEM.

are matched First, communities are matched on average expenditure, average household size, community electrification rate and the logged population. The results are shown in model (5) of Table 4.6 with a matched sample size of 289. Second, they are matched on average expenditure, average household size, community electrification rate, the logged population and district fixed effects. The results with matching are also shown in model (6) of Table 4.6 with a sample size of 204. The smaller sample size in model (6) is a result of the more covariates used in the matching as compared with model (5). The results in both models (5) and (6) support the positive relationship between SHEP and improvements in community electrification rates found earlier in models (1) – (4). Specifically, rural communities on SHEP between the period 2012-2017 improved their community electrification rates by about 11%–12% on average, suggesting that coefficients obtained without matching are slightly overstated.

A further robustness check is conducted by using the number of years a community has been on SHEP as the key independent variable instead of the dummy variable representing implementation of the program. The same models are estimated applying the same matching techniques as in Table 4.6. The full results are shown in Table 4.7. Once again, this chapter found that the effect is positive and statistically significant. Evidence shows that SHEP has improved community electrification rates.

[Table 4.6]

[Table 4.7]

4.5.3 Impact of Rural Electrification Program on Community Welfare

Rural electrification programs can affect household and community welfare through channels such as expenditure and poverty. In this sub-section, the impact of SHEP on community welfare is estimated. Community welfare is measured using two variables: average annual household expenditure in a community and the percentage of poor households in a community. Table 4.8 presents the results for the former. Results in columns (1) – (4) are from panel DID fixed effects regressions; results from column (5) are obtained by employing panel DID weighted fixed effects regression to the matched data using CEM. Across all models, the results suggest that household expenditure is 12%–22% higher on average for communities on SHEP than for those without grid connection. These results remain robust after adding other control variables as well as varying district fixed effects.

Obtained results are consistent with previous studies such (Khandker et al., 2013; Saing, 2018; and Adu et al., 2018). For example, Khandker et al. (2013) finds that rural electrification increased household expenditure by approximately 23% in Vietnam. Saing (2018) also finds that rural electrification increased daily per capita consumption by approximately 17%. The results indicate that SHEP improves welfare. In terms of the control variables, population, which is used as a proxy for community size, is positive and statistically significant, suggesting that rural communities with larger populations tend to benefit more in terms of welfare than communities with smaller populations. This is intuitive because connecting large communities to the grid directly benefits large number of households.

Rural electrification via SHEP generates outcomes through multiple channels. The initial impact is that households in communities with electricity access begin to purchase electrical appliances such as television sets, light bulbs, and business equipment. These initial impacts could also produce various outputs such as increased quality of lighting, access to non-agricultural activities, modernization of agriculture, attraction of infrastructure (such as health facilities, roads and water supply), access to information, and knowledge to enhance education (Adu et al., 2018). In the medium term, these outputs also lead to more hours for studying, extended work time for shops and businesses, and greater access to knowledge and information that has the potential to improve community welfare in the long run.

All of the above suggest that rural electrification eventually leads to poverty reduction. Thus, this sub-section estimates the impact of SHEP on poverty using panel DID fixed effects regressions and panel DID weighted fixed effects regression. The results are shown in Table 4.9. With the exception of model (1), the average treatment effect of rural electrification is negative and statistically significant. Specifically, connecting a community to the grid through SHEP reduces the percentage of poor rural households by 8% – 10% on average. The results show that policy makers can substantially reduce poverty through rural electrification projects such as SHEP.

[Table 4.8]

[Table 4.9]

4.5.4 Distributional Impacts of Rural Electrification Program on Community Welfare

The results presented in Tables 4.8 and 4.9 show that rural electrification through SHEP improves welfare. However, it is still unclear if SHEP has the same benefits for various rural community quantile groups. Therefore, this sub-section employs unconditional DID quantile panel fixed effect regression to assess the heterogeneous impacts of SHEP across groups. Three quantiles – the 25th, 50th and 75th – are created to examine whether communities with a higher average household expenditure and a lower percentage of poor households benefit more from rural electrification. The expectations are that communities with higher average household expenditure will benefit more from rural electrification since they are better able to take advantage of economic opportunities. The results for the average annual household expenditure in a community are presented in Table 4.10.

The estimation results suggest that the impact of SHEP are heterogeneous: the impact of the program is stronger for quantiles of higher expenditure levels. For instance, the impact of SHEP at the 50th percentile of the welfare distribution is 32%. At the upper quartile, the average treatment effect increases to about 0.42, implying that the impact of SHEP at the 75th percentile of the welfare distribution is 42%. Although the average treatment effect for the bottom 25% of the welfare distribution is not statistically significant, the above results generally show that the welfare impacts increase as a rural community on SHEP moves up the welfare distribution from lower quantile to upper quantile. The results also suggest that welfare impacts of SHEP are not uniform but skewed towards rural communities with higher average household expenditures.

Table 4.11 presents the results for the percentage of poor households in a community. The results show that welfare impact of SHEP cannot be found beyond the 25th percentile. This suggests that rural communities on SHEP with the lowest percentage of poor households benefits more from rural electrification, while such impact is not statistically significant in rural communities with higher percentage of poor households. Communities with lower percentage of poor households are more likely to have more working population than communities with higher percentage of poor households. Thus, the working population would benefit more from rural electrification through the extension of evening working hours and paid work activities. This could explain why rural communities on SHEP with the lowest percentage of poor households benefits more from rural electrification compared to those with the highest percentage of poor households.

[Table 4.10]

[Table 4.11]

4.6 Conclusions

This chapter has examined the role of socio-economic factors in household electrification in Ghana and assessed the welfare impact of one of Ghana's flagship rural electrification programs. Results of analysis based on the GLSS VI and GLSS VII samples showed that at the household level, robust predictors of access to electricity are quite similar. This chapter found that households with higher expenditures, male-headed households, and households with employed heads are more likely to have electricity connections in Ghana. Household expenditure and employment status were found to be the two strongest predictors of household electrification in Ghana. After combining the two household datasets with community data, the results suggested that rural communities with low electrification rates are more likely to be selected for SHEP. Also, the results further suggested that SHEP correlates with actual improvements in electrification rates of rural communities. By constructing a two-period community panel data using the same household datasets, this chapter found that rural electrification through SHEP improves community welfare.

In light of these findings, some policy implications can be derived. First, the results reveal that household expenditure plays a vital role in rural household electrification. As a result, this chapter recommends a shift of policy efforts towards making electricity affordable, especially for low expenditure rural households. This can be achieved by employing sophisticated metering, such as encouraging households to install individual meters that is still uncommon in many parts of Ghana. It makes it easier for poorer households to pay affordable amount for electricity. Another possibility is to encourage installing prepaid meters, allowing households to pay electricity bills in small

increments. Although the Electricity Company of Ghana (ECG) has outlined the processes of obtaining prepaid meters, ECG should promote the program more effectively.³² Second, budget allocations for rural electrification projects should be complemented by introducing some incentives to attract the private sector and non-governmental organizations into funding some of these projects. Although the results suggest that policy makers can achieve substantial reduction in poverty through rural electrification projects such as SHEP, it is important to note that rural electrification is a necessary, but not a sufficient condition. Poorer communities are known to be deprived of some key amenities such as good roads, water supply, health facilities and irrigation projects. The goal of improving welfare and reducing poverty can be fully achieved if rural electrification projects are complemented with these other investment projects.

³² <https://meqasa.com/blog/electricity-prepaid-meter-acquisition-process-in-ghana/>

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List of Tables and Figures

Table 4.1: List of variables and definitions

Variables	Definition
<i>Household</i>	
Gender of household head	Dummy (male=1, female=0)
Age of household head	Continuous
Log annual household expenditure ³³	Continuous
Household size	Continuous
Electricity	Dummy (yes=1, no=0)
Employment status	Dummy (Employed=1, otherwise=0)
<i>Community</i>	
SHEP	Dummy (community received SHEP between 2012-2016=1, otherwise=0)
Years on SHEP	Years communities have been on SHEP
Electrification rate	Continuous (average HH electrification rate in the community)
Average HH size in a community	Continuous
Average annual HH expenditure	Continuous
Population	Continuous (number of people in the community)
Poverty	Continuous (percentage of poor rural households in a community)

³³ Household electricity expenditure is deducted from the total annual household expenditure.

Table 4.2: Descriptive Statistics

Variable	Obs.	Mean	SD	Max	Min
<i>Household</i>					
Male head (GLSS VI)	2235	0.76	0.43	1	0
Male head (GLSS VII)	3807	0.70	0.46	1	0
Age of household head (GLSS VI)	2235	47.44	16.43	98	15
Age of household head (GLSS VII)	3807	47.02	16.27	99	17
Annual HH expenditure (GLSS VI)	2235	6506.84	6298.64	146345.4	31.2
Annual HH expenditure (GLSS VII)	3807	8196.56	7251.99	111002.9	86.25
Household size (GLSS VI)	2235	4.74	2.97	29	1
Household size (GLSS VII)	3807	4.50	3.05	28	1
Employment status (GLSS VI)	2235	0.84	0.33	1	0
Employment status (GLSS VII)	3807	0.79	0.41	1	0
<i>Community</i>					
SHEP	415	0.35	0.44	1	0
Electrification rate (GLSS VI)	415	42.34	40.48	100	0
Electrification rate (GLSS VII)	415	61.09	37.23	100	0
Average household size	415	4.73	1.39	10.93	1.8
Average annual HH expenditure	415	6722.042	3703.458	38735.92	1460.838
Population	415	1387.819	1381.629	4990	29
Years on SHEP	144	5.17	2.37	6	1
Poverty (GLSS VI)	415	90.04	14.20	100	14.29
Poverty (GLSS VII)	415	37.64	32.57	100	0

Note: SD. denotes standard deviation, Obs. represents number of observations, and Min. and Max. are minimum and maximum.

Table 4.3: Regression results (dependent variable: dummy for whether or not a rural household has access to grid electricity in an electrified community) using GLSS VI

Variables	(1)	(2)	(3)	(4)
	Logit	Linear	Logit	Linear
Age of HH head	0.95 (0.153)	0.28 (0.035)	0.08 (0.046)	0.01 (0.050)
Expenditure (log)	23.62*** (0.084)	11.30*** (0.091)	20.01*** (0.033)	9.18*** (0.005)
Household size	-0.20 (0.018)	-0.40 (0.020)	-0.14 (0.012)	-0.23 (0.120)
Male head	0.62* (0.002)	0.59** (0.004)	0.41** (0.003)	0.34* (0.002)
Employment status	14.26*** (0.013)	8.33** (0.014)	15.24*** (0.021)	7.34** (0.013)
Observations	2235	2235	2235	2235
District FE	No	No	Yes	Yes
Community FE	No	No	Yes	Yes
Clustered SE	No	Yes	No	Yes
R-squared		0.304		0.392

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

Note: Logistic regressions are estimated with conditional fixed effects at the community level; robust standard errors are clustered by community and reported in parentheses. Marginal effects are multiplied by 100 to convert to percentage points.

Table 4.4: Regression results (dependent variable: dummy for whether or not a rural household has access to grid electricity in an electrified community) using GLSS VII

Variables	(1)	(2)	(3)	(4)
	Logit	Linear	Logit	Linear
Age of HH head	1.30 (0.301)	0.30 (0.040)	0.09 (0.020)	0.02 (0.030)
Expenditure (log)	26.80*** (0.043)	12.40*** (0.005)	26.50*** (0.031)	10.90*** (0.004)
Household size	-0.87 (0.076)	-0.69* (0.002)	-0.19 (0.015)	-0.30 (0.02)
Male head	1.60** (0.006)	1.30** (0.004)	1.10*** (0.007)	0.50** (0.001)
Employment status	14.70** (0.019)	9.70*** (0.028)	20.80*** (0.013)	11.50*** (0.031)
Observations	3807	3807	3807	3807
District FE	No	No	Yes	Yes
Community FE	No	No	Yes	Yes
Clustered SE	No	Yes	No	Yes
R-squared		0.163		0.281

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

Note: Logistic regressions are estimated with conditional fixed effects at the community level; robust standard errors are clustered by community and reported in parentheses. Marginal effects are multiplied by 100 to convert to percentage points.

Table 4.5: Regression results (dependent variable: dummy for whether or not a rural community implemented SHEP between 2013-2016)

Variables	(1)	(2)	(3)	(4)
	Logit	Linear	Logit	Linear
Electrification rate (0-100)	-1.02*** (0.003)	-1.62*** (0.002)	-0.23*** (0.001)	-0.28*** (0.0004)
Average expenditure (log)			0.22 (0.037)	0.05 (0.037)
Average household size			-0.05 (0.015)	-0.05 (0.014)
Population (log)			-4.35** (0.022)	-4.55* (0.024)
Observations	415	415	415	415
District FE	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes
R-squared		0.455		0.381

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

Note: Robust standard errors are clustered by district and reported in parentheses. Marginal effects are multiplied by 100 to convert to percentage points.

Table 4.6: Regression results (dependent variable: difference in community electrification rates between 2016/2017 and 2012/2013 samples)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
					CEM1	CEM2
SHEP	17.42** (4.867)	16.33*** (5.196)	15.51*** (4.305)	14.61*** (4.468)	11.23*** (5.096)	12.30** (4.107)
Average expenditure (log)			9.95*** (3.394)	7.76*** (3.748)		
Average household size			-3.63 (4.498)	-2.99 (4.806)		
Population (log)			19.17*** (2.330)	18.89*** (2.344)		
Observations	415	415	415	415	289	204
District FE	No	Yes	No	Yes	No	No
Clustered SE	Yes	Yes	Yes	Yes	No	No
R-squared	0.023	0.035	0.179	0.191	0.015	0.017
Overall imbalance					0.793 (0.839)	0.849 (0.942)

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

Note: Robust standard errors are clustered by district and reported in parentheses. In model (5), the control and treatment groups are matched on logged average expenditure, average household size, electrification rate and logged population. In model (6), however, the control and treatment groups are matched on logged average expenditure, average household size, electrification rate, logged population and district fixed effects.

Table 4.7: Robustness results (dependent variable: difference in community electrification rates between 2016/2017 and 2012/2013 samples)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
					CEM1	CEM2
Years on SHEP	4.81*** (1.577)	4.50*** (1.491)	4.44*** (1.377)	4.17*** (1.327)	3.06*** (1.472)	3.25** (1.250)
Average expenditure (log)			12.71*** (3.783)	10.346*** (3.395)		
Average household size			-4.96 (5.802)	-3.77 (5.507)		
Population (log)			18.88** (2.345)	18.62*** (2.360)		
Observations	415	415	415	415	289	204
District FE	No	Yes	No	Yes	No	No
Clustered SE	Yes	Yes	Yes	Yes	No	No
R-squared	0.023	0.036	0.177	0.189	0.037	0.022
Overall imbalance					0.794 (0.839)	0.849 (0.942)

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

Note: Robust standard errors are clustered by district and reported in parentheses. In model (5), the control and treatment groups are matched on logged average expenditure, average household size and logged population. In model (6), however, the control and treatment groups are matched on logged average expenditure, average household size, electrification rate, logged population and district fixed effects.

Table 4.8: Impact of SHEP on community welfare (measured by average household expenditure in a community in log)

Variables	(1)	(2)	(3)	(4)	(5)
	DID-FE	DID-FE	DID-FE	DID-FE	CEM-DID-FE
Treat	-0.032 (0.080)	0.021 (0.106)	0.027 (0.107)	-0.116* (0.069)	0.055 (0.054)
Post	0.178*** (0.065)	0.265*** (0.062)	0.273*** (0.063)	0.162*** (0.058)	0.059 (0.076)
Treat × Post	0.124* (0.072)	0.221** (0.017)	0.116* (0.069)	0.202* (0.026)	0.168*** (0.0451)
Average household size			0.012 (0.017)	0.016 (0.085)	
Population (log)			0.230** (0.108)	0.202*** (0.005)	
Observations	830	830	830	830	784
District FE	No	Yes	No	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes
R-squared	0.530	0.520	0.450	0.456	0.322

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

Note: Robust standard errors are clustered by district and reported in parentheses. In model (5), the control and treatment groups are matched on average household size and population. CEM-DID-FE is a weighted fixed-effects model with the pre-estimated CEM weights constant within the panel.

Table 4.9: Impact of SHEP on poverty (measured as the percentage of poor households in a community [0-100])

Variables	(1)	(2)	(3)	(4)	(5)
	DID-FE	DID-FE	DID-FE	DID-FE	CEM-DID-FE
Treat	1.645 (1.060)	1.674 (1.091)	1.632 (1.089)	-0.903*** (0.348)	1.074*** (0.348)
Post	-1.126*** (0.06)	-1.017 (0.631)	-1.152 (0.880)	-0.808*** (0.176)	-1.601 (1.942)
Treat × Post	-8.726 (5.502)	-10.125* (5.671)	-8.156** (4.822)	-9.732** (4.182)	-8.302*** (2.245)
Average household size			-4.261*** (1.087)	-4.043 (4.390)	
Population (log)			5.752*** (1.606)	5.270*** (1.715)	
Observations	830	830	830	830	784
District FE	No	Yes	No	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes
R-squared	0.321	0.557	0.566	0.531	0.452

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

Note: Robust standard errors are clustered by district and reported in parentheses. In model (5), the control and treatment groups are matched on average household size and population. CEM-FE is a weighted fixed-effects model with the pre-estimated CEM weights constant within the panel.

Table 4.10: Distributional impact of SHEP on community welfare (measured by average household expenditure in a community in log)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	25th	25th	50th	50th	75th	75th
Treat	-0.051 (0.069)	-0.029*** (0.007)	-0.051** (0.020)	-0.022 (0.069)	-0.030 (0.060)	-0.036 (0.027)
Post	0.036*** (0.005)	0.084*** (0.022)	0.014*** (0.004)	0.027*** (0.005)	0.070*** (0.022)	0.049*** (0.016)
Treat × Post	0.273 (0.452)	0.251 (0.336)	0.320*** (0.045)	0.305** (0.081)	0.424*** (0.054)	0.396*** (0.075)
Average household size		-0.022 (0.171)		-0.102 (0.125)		-0.032 (0.080)
Population (log)		0.131*** (0.016)		0.194** (0.093)		0.165*** (0.039)
Observations	830	830	830	830	830	830
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.400	0.327	0.411	0.330	0.315	0.167

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

Note: Robust standard errors are clustered by district and reported in parentheses.

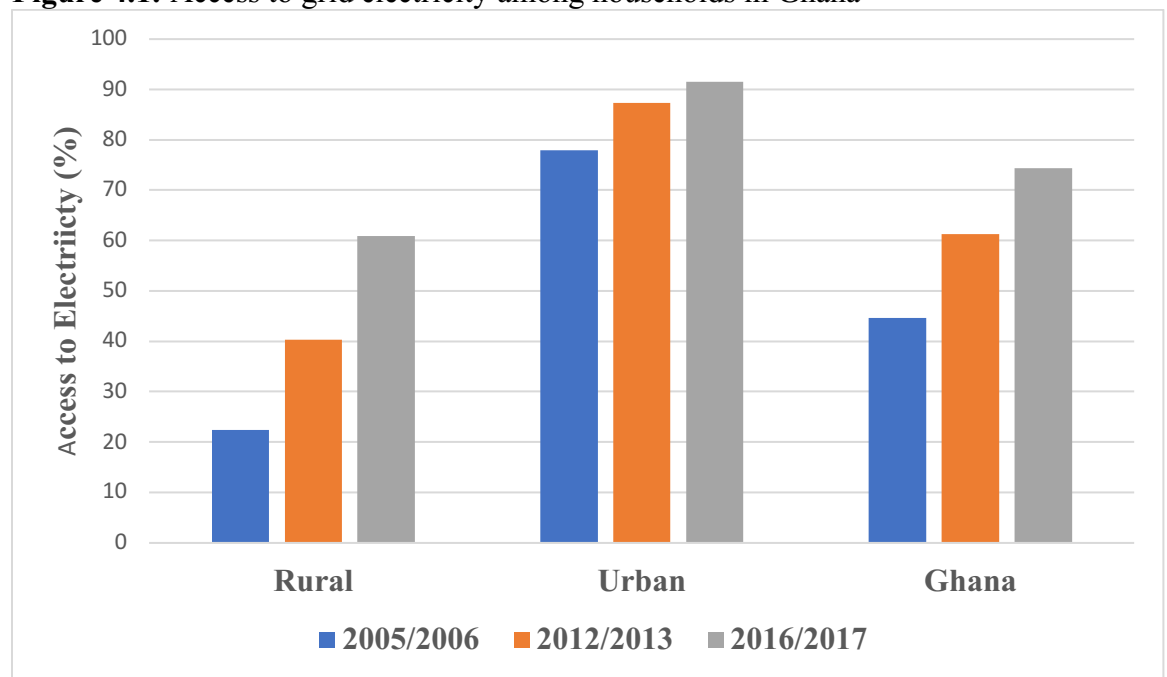
Table 4.11: Distributional impact of SHEP on poverty (measured as the percentage of poor households in a community [0-100])

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	25th	25th	50th	50th	75th	75th
Treat	1.103*** (0.365)	1.077*** (0.350)	-1.304 (0.981)	1.074*** (0.348)	-1.442 (1.028)	-1.473 (1.028)
Post	-1.254** (0.553)	-1.416** (0.564)	-1.075 (0.704)	-1.242 (0.811)	-1.232 (0.812)	-1.106 (0.815)
Treat × Post	-9.721*** (2.997)	-9.366*** (3.123)	-7.072 (8.735)	-7.208 (8.857)	-5.681 (7.664)	-5.724 (7.521)
Average household size		-2.925 (2.009)		-2.373 (2.017)		-2.907 (1.903)
Population (log)		6.311*** (2.481)		3.630** (1.044)		7.204*** (2.734)
Observations	830	830	830	830	830	830
District FE	Yes	Yes	Yes	Yes	Yes	Yes
Clustered SE	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.400	0.415	0.480	0.431	0.425	0.448

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

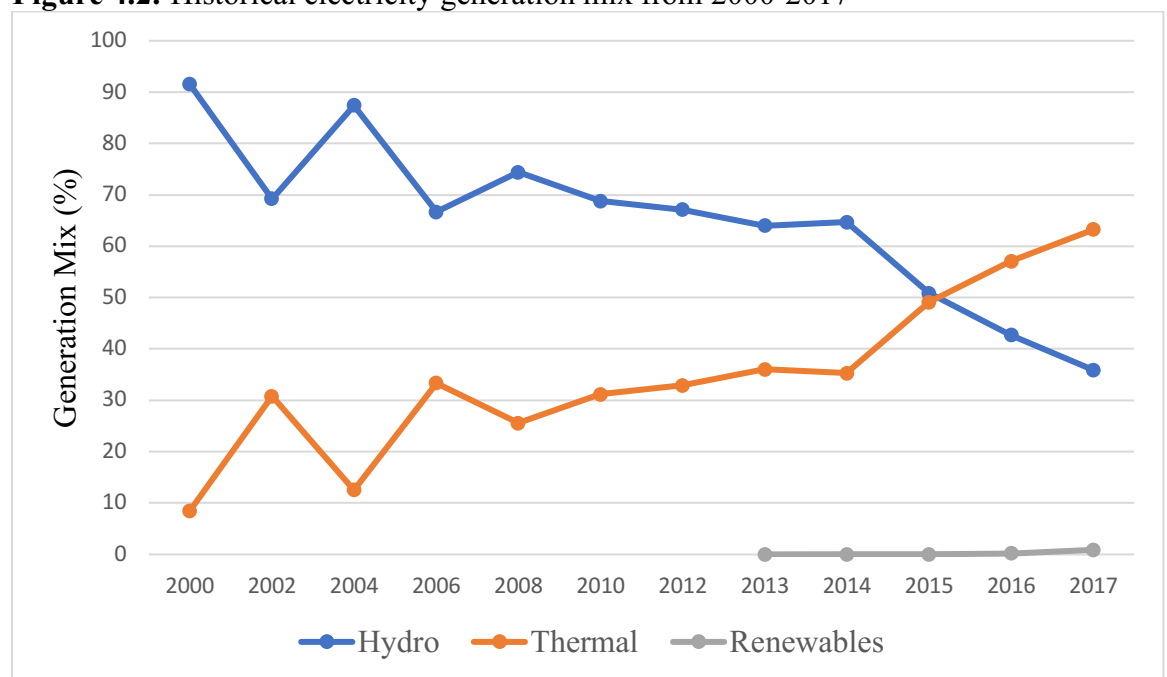
Note: Robust standard errors are clustered by district and reported in parentheses. In reg. (5), the control and treatment groups are matched on average household size and population.

Figure 4.1: Access to grid electricity among households in Ghana



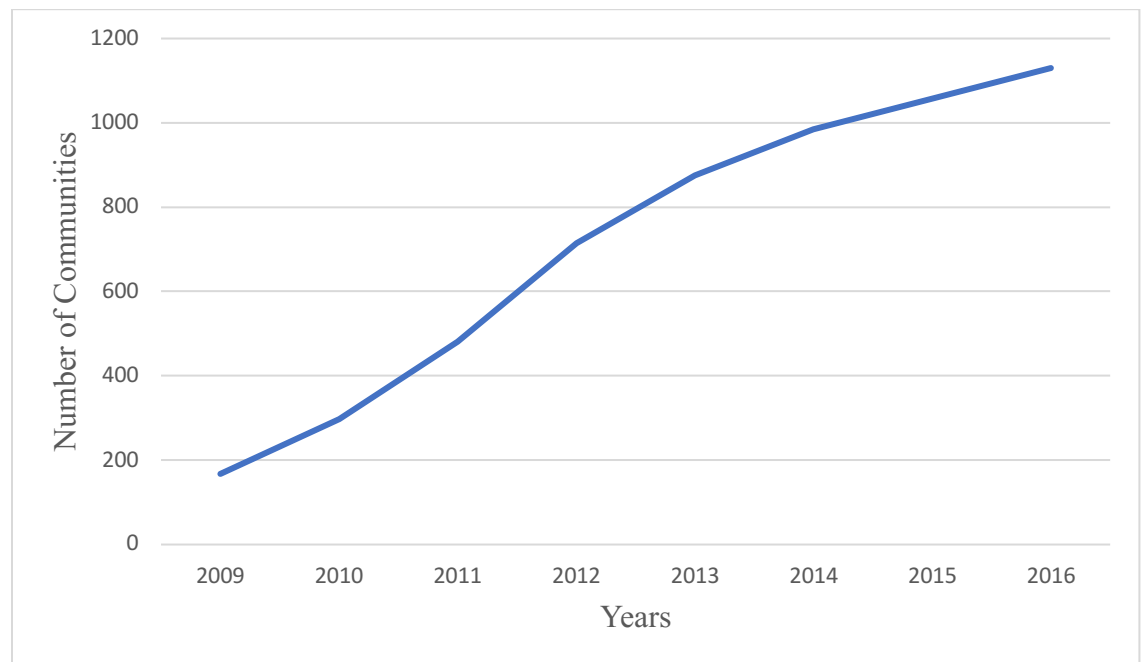
Source: Author's computations using GLSS V, GLSS VI and GLSS VII datasets.

Figure 4.2: Historical electricity generation mix from 2000-2017



Sources: Energy Commission of Ghana, 2017; Energy Commission of Ghana, 2018.

Figure 4.3: Number of communities under SHEP (2009-2016)



Source: Ministry of Energy Database (2017).

Appendix

Table A4.1: Correlation matrix using GLSS VI (2012/2013)

	Household size	Expenditure (log)	Age of HH head	Employment status	Male head
Household size	1.0000				
Expenditure (log)	0.3627	1.0000			
Age of HH head	0.0981	-0.0415	1.0000		
Employment status	0.0177	0.0060	0.0261	1.0000	
Male head	0.2202	0.1410	-0.1491	0.0403	1.000

Table A4.2: Correlation matrix using GLSS VII (2016/2017)

	Household size	Expenditure (log)	Age of HH head	Employment status	Male head
Household size	1.0000				
Expenditure (log)	0.3205	1.0000			
Age of HH head	0.0865	-0.0878	1.0000		
Employment status	0.0573	0.2533	0.2287	1.0000	
Male head	0.2071	0.1013	-0.1337	0.1313	1.000

Table A4.3: Correlation matrix (Community variables)

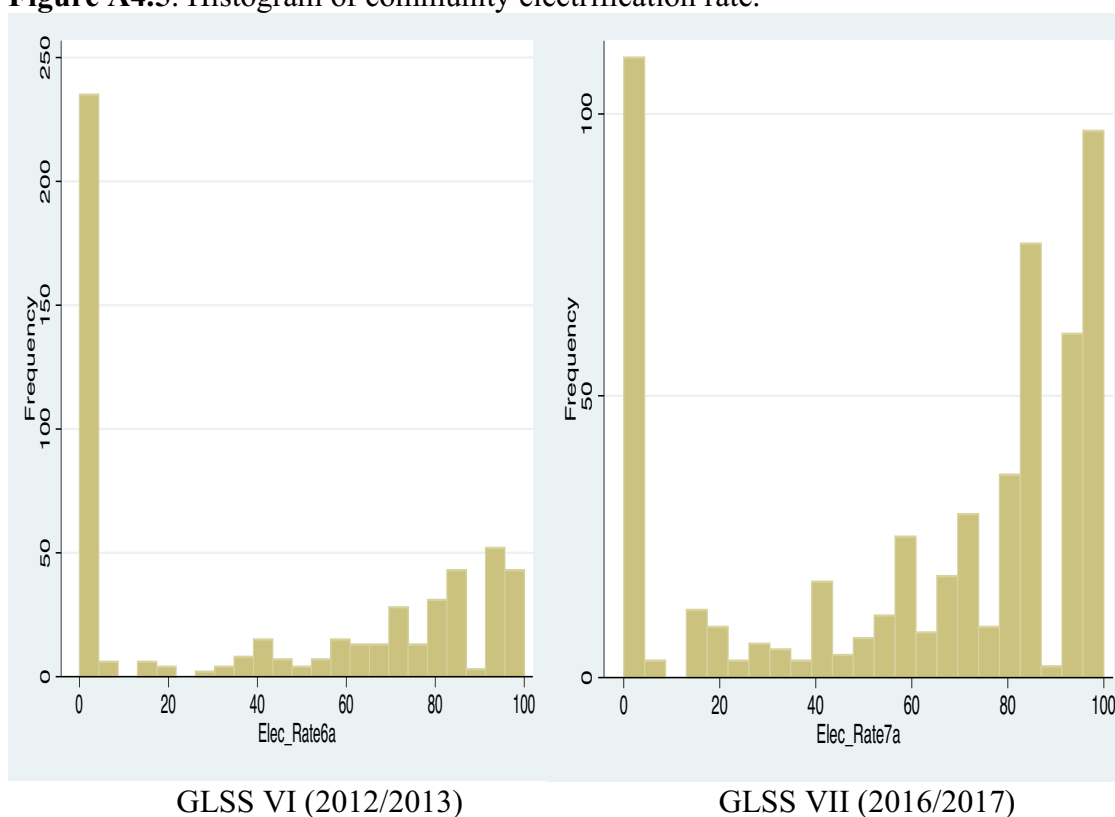
	SHEP	Average expenditure (log)	Population (log)	Average household size
SHEP	1.0000			
Average expenditure (log)	0.0881	1.0000		
Population (log)	-0.0200	0.1340	1.0000	
Average household size	-0.1474	0.0862	-0.1392	1.0000
Poverty		-0.4766	-0.1701	0.2936

Table A4.4: Number of matched and unmatched observations

	Control	Treated
<i>Algorithm 1</i>		
All	271	144
Matched	185	104
Unmatched	86	40
<i>Algorithm 2</i>		
All	271	144
Matched	104	100
Unmatched	167	44
<i>Algorithm 3</i>		
All	830	288
Matched	539	245
Unmatched	291	43

Note: In *Algorithm 1*, the control and treatment groups are matched on logged average expenditure, average household size, electrification rate, and logged population whiles in *Algorithm 2*, the control and treatment groups are matched on logged average expenditure, average household size, electrification rate, logged population, and district fixed effects. In *Algorithm 3*, the control and treatment groups are matched on average household size and population.

Figure A4.5: Histogram of community electrification rate.



Chapter 5

Concluding Remarks

This thesis has compiled three essays that addresses key energy and sustainable development issues concerning energy poverty, energy expenditure, and energy access in Ghana. Recommendations were derived from the results. This chapter highlights three recommendations that deserve further attention.

First, Ghana should immediately intensify steps to address the high dependency on traditional cooking fuels if the country hopes to meet goal seven of the SDG. More importantly, strategies to reduce energy poverty should be incorporated into income poverty reduction strategies to improve not only the accessibility but also the affordability of modern energy.

Second, increasing awareness through public education of the negative effects of using traditional cooking fuels is key to reducing the dependency on traditional cooking fuels and increasing the uptake of modern cooking fuels.

Lastly, household income and household expenditure are the underlying factors that separate households with electricity and those without; households using traditional cooking fuels and those using modern cooking fuels; households spending on modern cooking fuels and those not having the means to spend. Intensification of poverty reduction programs is essential if households are to consume an adequate amount of modern energy to maintain a decent standard of living at a reasonable cost.

There are several topics that should be addressed in future works. Given the findings and recommendations from Chapter 2, how energy poverty contributes to overall

income poverty in Ghana should be investigated further. As Table 2.8 suggests a link between energy poverty and household income as shown in Table 2.8, it would be informative to examine whether households who are energy poor can be classified as income poor. Whereas energy poverty is measured using MEPI, income poverty could be measured using the Multidimensional Poverty Index (MPI). Furthermore, Chapter 4 of this thesis could not explore into details of the possible channels through which rural electrification via SHEP could affect expenditure and poverty. Future works should identify the potential pathways through which electricity access affects welfare of rural households.