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COLLEGE OF HUMANITIES

EFFICIENCY OF HOUSEHOLD ELECTRICITY CONSUMPTION IN GHANA

BY

JACOB OPANTU ABENEY

(10383394)

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DECLARATION

I, Jacob Opantu Abeney do certify that this thesis is a result of research I have undertaken under the guidance of my supervisors toward the award of the Master of Philosophy (MPhil) degree in Economics at the Department of Economics, University of Ghana

…………………………………

JACOB OPANTU ABENEY

(CANDIDATE)

DATE……………………….

………………………………. ……………………………....

PROF. DANIEL K. TWEREFOU **DR. MICHAEL DANQUAH**

(SUPERVISOR) (SUPERVISOR)

DATE: ……………………… **DATE: ………………………**

ABSTRACT

The wave of technological advancement has made electricity an indispensable input in an economy. It reigns at the center of households' basic activities and productivity of industrial and service firms. Its supply in Ghana, like many other African countries has however, not been consistent over the years. This lays demand on policymakers from households and firms to increase the quantity supplied. In response to this, several thermal plants have been installed to augment the limited supply from the hydro sources. Policymakers have also implemented some demand-side measures to encourage efficiency, conservation and energy savings. However, little efforts have been made to estimate empirically how efficient households have been in their use of the limited supply. It is against this backdrop that this study was conducted, to obtain empirically the efficiency of households in their consumption of electricity in Ghana.

The stochastic demand frontier was employed and a mean efficiency of approximately 71% was obtained for households in Ghana. This indicates an immense opportunity for electricity energy savings through efficiency measures. A further locational disaggregated study revealed that the mean efficiency for rural and urban households are approximately 67% and 78% respectively. Though a direct comparison between these two locational areas was not the goal of the study, a significant difference can be noticed.

Among the factors that influence the level of inefficiency, it was obtained that, the years of appliances, the age of household head, dwelling types and house ownership status were significant. However, the educational qualification of the household head was not a significant determinant. Regarding the demand for electricity, the average price, income of households, appliance ownership, household size and ecological zones were found to impact the demand for electricity. Policy recommendations to help realize this opportunity was offered at the end of the study.

DEDICATION

This work is dedicated to my family, my loved ones, my friends, lecturers and colleagues who have always been there for me in my academic pursuit.

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My profound gratitude goes to the Lord God for His Grace that has brought me this far in my academic carrier. I am equally grateful to my supervisors, Professor Daniel K. Twerefou and Dr. Micheal Danquah for their immense support, guidance and contributions that have made this work a success.

I want to show much appreciation to my parents, Mr. Eric Abeney Opantu and Madam Comfort Ntiriwa Akuffo, for their countless sacrifices to ensure that my academic carrier was not terminated. This could not have happened without the support of my able siblings, of whom am also grateful.

Special thanks go to all my friends and colleagues that have been a source of encouragement and motivation to this far.

Finally, I duly accept the responsibility for any errors that may be identified in this work.

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LIST OF ABBREVIATIONS

AAF	Automatic Adjustment Formula
CFL	Compact Fluorescent Light
CO_2	Carbon Dioxide
CRECS	China Residential Electricity Consumption Survey
DEA	Data Envelopment Analysis
DMU	Decision-Making Unit
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
EU	European Union
GAMA	Greater Accra Metropolitan Area
GDP	Gross Domestic Product
GLSS 6	Ghana Living Standard Survey, Round Six
GPRS	Ghana Poverty Reduction Strategy
GRA	Ghana Revenue Authority
GRIDCo	Ghana Grid Company
GSS	Ghana Statistical Service
GTRE	Generalized True Random Effect
GWh	Gigawatt - hour
IPP	Independent Private Producers
ISSER	Institute of Statistical, Social and Economic Research
KTPP	Kpone Thermal Power Plant
KWh	Kilowatt Hour

MOFEP	Ministry of Finance and Economic Planning
MRP	Mines Reserve Plant
MW	Megawatts
NED	Northern Electricity Department
NEDCo	Northern Electricity Distribution Company
OECD	Organization for Economic Co-operation and Development
OEE	Office of Energy Efficiency (Canada)
OLS	Ordinary Least Squares
ONS-UK	Office of National Statistics, United Kingdom
PPF	Production Possibility Frontier
PURC	Public Utilities Regulatory Commission
SE4ALL	Sustainable Energy for All
SFA	Stochastic Frontier Analysis
SLT	Special Load Tariff
TAPCO	Takoradi Power Company
TT1PP	Tema Thermal 1 Power Plant
TICO	Takoradi International Company
TRIPP	Tema Reserve Power Plant
TT2PP-X	Tema Thermal 2 Plant Expansion
VALCO	Volta Aluminum Company
VAT	Value Added Tax
VRA	Volta River Authority
WAPP	West African Power Pool

CHAPTER ONE

INTRODUCTION

1.1 Background to Study

Electricity, the invisible input at the center of almost all life activities, is no longer a luxury for the rich elites that can afford sophisticated appliances but a necessity for even the rural poor that own only a mobile phone. Thondhlana and Kua (2016) asserted that energy is one of the fundamental requirements for both human life and economic development. It is at the center of a household's basic activities and leisure enjoyment, industrial and service firms' productivity and economic growth. Evidence of this is the outcry of citizens over indiscriminate and unannounced power outages and the efforts made by several governments to expand electricity accessibility to all citizens (Taale & Kyeremeh. 2016). Ghana, for instance, had an electricity accessibility of about 82.5% in 2016 (Kumi, 2017), with universal accessibility expected to be achieved by 2020. Though the heavy dependence on electricity can be attributed to several factors, key among them is the ongoing technological advancements that have made electricity an indispensable part of human life.

However, the quality of electricity supply in many countries, especially in Africa, is nothing to boast of. Both the production and transmission sectors are plagued with obsolete infrastructures, heavy dependence on rainwater, debt non-recoverability due to low tariff rates and illegal connections by consumers (Kumi, 2017). Most African countries have suffered from an unreliable supply of electricity over prolonged periods, which has affected the growth of their economies. In Ghana, ISSER (2015) reported that due to power crises in 2014, the country lost on average production worth about US$ 2.1 million per day. This translated to about US$ 680 million or about

2% of GDP. Similarly, the 2013 Ghana Enterprise Survey by the World Bank revealed that the provision of electricity to firms in Ghana is insufficient compared to international standards. This led to approximately 28% rise in the ownership or sharing of generators by firms from 2007 to 2012. In response to this limited supply is the continuous installation of thermal plants to augment the output from hydro sources. However, this decision comes with its own environmental repercussions that nations will like to avoid.

The aim of nations to increase the supply of electricity without compromising the quality of the environment has made end-user energy efficiency an important goal (Comer, 2008). Quaglione et al. (2017) indicated that the attitude of consumers toward energy conservation has become a great concern, influencing many national policies and deliberated in countless interdisciplinary studies. According to Filippini et al. (2014), among the top five European Union (EU) 2020 energy strategies, is an effort to increase energy efficiency. In Ghana, measures like the ban on the importation, production and sale of inefficient appliances point to the same objective (Dramani & Tewari, 2013).

Technically, electricity consumption efficiency can be achieved by reducing the use of outdated and inefficient electrical appliances. However, a good measure of electricity consumption efficiency needs to consider both technical and allocative efficiency. This is because the achievement of high technical efficiency without considering allocative efficiency will blur the expected results. A typical example is the case where one buys an energy saving bulb but leaves it on when not needed and still waste electric power. In such instances, Quaglione et al. (2017) indicated that the energy saving presumed to be obtained by the efficient appliance is partly or wholly offset by the inefficient behavior of the consumer, a phenomenon known as the ‘rebound effect’ in energy economics. Regarding this, Mizutani and Nakamura (2015) pointed out that, total electricity demand can be divided into two sections; an irreducible amount irrespective of price and income levels and a reducible amount resulting from behavioral changes. They indicated that this consumption slack(s) will be a function of the household's measures put in place to ensure electricity savings.

According to Carley (2012), electricity efficiency points to the use of both technology and operational measures that can yield the same or higher electricity services whiles using less electrical power. Whiles the adoption of efficient technology will reduce the technical inefficiency, operational methods adopted by a household goes a long way to influence the allocative efficiency. There is therefore a need to adopt a methodology that captures both technical and allocative efficiencies to ensure that reliable results are obtained.

Anderson (1993) indicated that paying attention to electricity consumption efficiency can lead to less expenditure on electricity, sustained supply of electricity and less greenhouse gas emission. Efficient consumption of energy has therefore been identified as one of the most cost-effective means of reducing carbon dioxide (CO_2) emission, increasing energy supply security, improving industry competitiveness (Ang et al., 2010; Ozturk, 2013; Filippini et al., 2014) and sustainable economic development (Inglesi-Lotz & Pouris, 2012).

This study focuses on households' electricity consumption partly because, both researchers and policymakers admit that, households constitute substantial consumers of energy, which results in both environmental and financial cost (Thondhlana & Kua, 2016). The Energy Information Administration (EIA) (2015), asserted that households in Organization for Economic Co-operation and Development (OECD) countries consume a third of end-user electricity. In Ghana, it is estimated that about half of domestic electricity consumption goes to the residential sector whiles the other half goes to commercial and industrial users (ISSER, 2005). This estimate might be a little biased due to its inability to account for individuals working from home using electricity. For instance, small-scale services like corn milling, hairdressing, tailoring among others may be operated from home using electricity. However, the percentage of household electricity consumption is still high and worth considering. There is therefore the need to examine how efficiently the limited supply is being used among households. Furthermore, knowledge on the factors influencing households' demand for electricity and their inefficiency will help policymakers implement appropriate policies to curtail the rising demand for electricity and consumption inefficiency.

1.2 Problem Statement

The importance of a reliable supply of electricity to Ghanaian homes cannot be undermined. Twerefou (2014), found that households are willing to pay 0.2734 cedis more for a kilowatt-hour to avoid electric power outages. This amount is about one and a half times more than what they were paying at that time. A study by Taale and Kyeremeh (2016) for the Cape Coast Metropolitan Area indicated a willingness to pay of 44% more, relative to the mean monthly bill for improved electricity services. The case is not different in other countries. For instance, Ozbafli and Jenkins (2015) reported that households in North Cyprus are willing to pay 13.8% more to avoid the cost of outages. All these studies reflect the extra amounts households are willing to pay to avoid electric power outages. One way to achieve this is to use what is already produced efficiently.

This is because the electricity sub-sector of Ghana is burdened with the challenge of supply insecurity (Gyamfi et al., 2018). The supply side is challenged with low generation capacity, uncertainty in rainfall, generation inefficiency and transmission losses. The Energy Commission, for instance, recommended in the 2016 Energy Sector Outlook that, the Akosombo Hydropower station should as much as possible not be operated beyond three (3) units until adequate rains are realized during the year to ensure system stability (Energy Commission, 2016).

This influenced the Energy Commission's recommendation for an effort to complete the on-going power generation projects. It also recommended that the decision of bringing in additional power rentals to offset the power supply deficit be hastened (Energy Commission, 2016). The persistent imbalance in the supply and demand for electricity in most African countries is not a news. Evident to this is the creation of the West African Power Pool (WAPP) to enable electricity trade among countries. Ghana, for instance, had an imbalance (shortage) of 25% of peak demand for the period 2014-2015, (Gyamfi et al., 2018).

The demand side, on the other hand, is met with a market of inefficient and high energy consuming electrical appliances, low power-saving knowledge and behavior among consumers and low concern for environmental quality (Gyamfi et al., 2018**).**

Even though the use of efficient appliances that consume less electricity has been encouraged over the years in Ghana, the demand for electricity by households continues to increase. Total residential electricity demand in Ghana was 1996 GWh and 3060 GWh in 2007 and 2013 respectively, a 53.31% increase over the period. Though this fell to 2772 GWh and 2436 GWh in 2014 and 2015 respectively, this cannot necessarily be attributed to a reduction in demand by households since the supply side experienced significant fall in output during those years. Recovery from the supply shock in 2016 saw residential demand rise to 3932 GWh, a 61.41% upsurge from 2015 to 2016. Generally, whiles the annual demand for fuelwood and petroleum product grows at 3% and 5% respectively, the demand for electricity grows between 6%-7% annually (Ghana Sustainable Energy for All Action Plan, 2012)

Thus, the impact of several end-user efficiency measures introduced by policymakers to ensure a reduction in electricity consumption is less felt. Factors like increase in the number of households connected to the grid, purchase of more appliances as income levels rise and so on, can be cited as reasons for the persistent rise in total residential electricity consumption (Dramani & Tewari, 2013).

However, there is still a gap in the literature on an empirical measurement of efficiency in consumption of electricity among Ghanaian households. Kwakwa (2014) noted that irrespective of the existence of some empirical predictions of the demand for electricity in Ghana, less of similar work is done on the intensity of electricity consumption to aid policymaking. This means that policymakers lack accurate information on the efficiency level of electricity consumption to help them in policy formulation. There is, therefore, the need to obtain an empirical measurement of electricity consumption efficiency among Ghanaian households and to examine the factors that significantly influence their demand for electricity and consumption inefficiency.

Research questions that emerge from the above discussion are:

1. What are the determinants of electricity demand among Ghanaian households?
2. Is electricity used efficiently among Ghanaian households?
3. What are the determinants of electricity consumption inefficiency among Ghanaian households?

1.3 Research Objectives

The main objective of the study is to assess the efficiency of electricity usage among Ghanaian households. The specific objectives are to:

a. Analyze the determinants of demand for electricity among Ghanaian households.

b. Ascertain the average efficiency of electricity consumption among Ghanaian households.

c. Determine factors that influence electricity consumption inefficiency among Ghanaian households

1.4 Significance of the Study

This study is significant after several energy-saving measures have been undertaken. The motivation to undertake this study springs from the constant demand on government to increase the supply of electricity due to the recent several power outages and the positive response from policymakers by installing more thermal plants. We, therefore, want to investigate whether households are using the limited supply efficiently and if there exist some opportunities for energy savings via efficiency measures.

This may help policymakers to have an idea of the actual level of efficiency and the factors that affect inefficiency in electricity consumption among households in Ghana. A successful implementation of policy recommendations from this study may help in achieving the second objective of the Sustainable Energy for All (SE4ALL) initiative stated as "doubling the rate of improvement in energy efficiency by 2030" (SE4ALL Action Plan, pg.1). The development of cost-effective solutions that can help in achieving the SE4ALL is one of the objectives of the Sustainable Energy for All Acceleration Framework (SEAAF) adopted by Ghana. Since energy efficiency has been identified as one of the cost-effective means of sustainable energy supply, knowledge from this study may help policymakers identify the existence or otherwise of a cost-effective means of energy sustainability through efficiency measures.

The study also explores the factors that influence the demand for electricity among Ghanaian households. This knowledge is intended to help policymakers to formulate policies targeting the determinants of electricity demand to ensure energy savings. This is because failure to identify and implement such policies will mean electricity supply must increase significantly as Ghana aims to achieve universal accessibility under the National Electrification Scheme project by 2020. This calls for the need of demand-side measures to curb the rate of acceleration in the demand for electricity, and this study seeks to identify the factors influencing this high demand and make policy recommendations that can help reduce it when implemented.

Furthermore, necessary measures to target specific groups like urban and rural households, to ensure electricity consumption efficiency will be explored. This is to ensure that appropriate policies are targeted to each group due to possible differences in factors affecting their demand and inefficiency. Individually, readers will have an idea of the factors influencing their inefficiency in the consumption of electricity. This will help them to make the necessary adjustments to reduce expenditure on electricity.

Finally, the study fills the knowledge gap and can be a reference to which other works can be compared in subsequent years to determine if there have been any changes in the level of efficiency.

1.5 Organization of the Study

This study is organized in six main chapters, the first chapter gives a background to the study in which the problem statement together with the research questions, objectives of the study and significance of the study are outlined. Chapter two provides an overview of the electricity sub-sector of the Ghanaian economy. Chapter Three reviews the literature on the measurement of energy/electricity consumption efficiency using the stochastic frontier analysis. Chapter four details the theoretical framework and methodology used in this study. Chapter five presents analysis and discussion of findings from the research. Chapter six is dedicated to the summary, policy recommendations based on the findings of the study and limitations of the study. Attention is also given to recommendations for future research in the last chapter.

CHAPTER TWO

OVERVIEW OF THE ELECTRICITY SUB-SECTOR AND EFFICIENCY MEASURES IN GHANA

2.1 Introduction

This chapter gives an overview of the electricity sub-sector in Ghana. A brief history of the evolution of electricity production in Ghana is presented in this chapter. The three main phases, namely; production, transmission and distributions, together with the institutional bodies responsible at each phase are discussed. Furthermore, discussions on the trend of electricity supply, demand and net import, as well as challenges facing the sector, are also discussed. A brief description of the roles of various regulatory bodies involved in the sector is presented. Attention is also given to various efficiency measures that have been carried out in Ghana and some successes achieved. The chapter concludes with some challenges encountered in implementing efficiency measures in the nation.

2.2 Background to Electricity Production in Ghana

The electricity sub-sector of Ghana is one of the drivers of socioeconomic growth and development (Asumadu-Sarkodie & Owusu, 2016; Taale & Kyeremeh, 2016). Ghana, like many other countries, generates electricity from diverse sources namely; hydropower, fossil fuel (thermal energy) and renewable sources (solar). Government-sponsored electricity production started in 1914 at Sekondi in the Western Region under the operations of Ghana Railway Administration. Even though expansion of the project to supply electricity to Takoradi took place in 1928, the Ghana Public Works Department already commenced on a limited scale the supply of Direct Current (DC) in Accra in 1922. In 1924, a large Alternating Current (AC) commenced with Koforidua receiving its share in 1925 following the installation of three horizontal single cylinder oil-powered engines. There was also the establishment of a fully operating power station in Kumasi in 1927 following small startups in the preceding year. Work on the extension of electricity supply continued for subsequent years with Winneba, Swedru, Tamale Cape Coast, Oda, Dunkwa-on-Offin, Bolgatanga, Nsawam, and Keta receiving coverage by the end of 1955. A significant investment in the sector occurred in the early 1960s towards the construction of the Akosombo Hydroelectric Dam with mass power generation from the dam occurring in 1965 by the Volta River Authority.

The production, transmission and distribution of electricity form the three basic stages that electricity passes before it gets to the domestic consumer. These three phases are operated by different institutions in Ghana.

2.2.1 Production

Even though electricity production in Ghana commenced on small scales in early years as explained earlier, bulk production started with the construction of the Akosombo Hydroelectric Dam and the establishment of the Volta River Authority. After independence in 1957, the nation needed the support of electricity to boost its economic activities. With support from Volta Aluminum Company (VALCO), the dam was constructed between 1961- 1965. The Volta River Authority was established in 1961 by the parliament of Ghana through the passage of the Volta River Development Act, (Act 16) of the Republic. The fundamental task of the institution regarding electricity power can be summarized as management of the development of the Volta River Basin. This comprises three main responsibilities, namely; building and management of the dam, the power station and the power transmission network. This was to ensure their production and supply of electricity for industrial, commercial and domestic use.

The VRA basically started operations with the Akosombo Hydroelectric Dam in 1965 and the Kpong Dam downstream of the Akosombo Dam which was established in 1982. However, it has gradually expanded its operations in response to the power crises that plague the nation. The VRA now operates in addition to the two hydro sources; the TAPCO 1 & 2, Takoradi 3, Mines Reserve Plant (MRP), Tema Thermal 1 & 2 plants, Tema Thermal 2 Plant Expansion (TT2PP-X), Kpone Thermal Power Plant (KTPP), all of which are thermal plants that runs on either gas or light crude oil and the VRA Navrongo Solar Plant.

However, following the Volta River Development (Amendment) Act, 2005 (Act 692) and in accordance to the power sector reform of the Government of Ghana, the VRA has been shredded off the transmission of electricity and left to fully concentrate on only production. The same amendment process created the required environment to draw Independent Private Producers (IPP) to the Ghanaian energy market. This is to help increase the available power supplied and create a competitive environment that can improve the efficiency of electricity producers. The number of Independent Private Producers have over the years increased. Some private producers include; Bui Hydro, Ameri Power Plant, Kar Power Plant, Sunnon Asogli Phase 1, Sunnon Asogli Phase 2 stages 1 & 2, Cenit Power Plant, AKSA and BXC solar. However, all these independent producers had to obtain a due license from the Ghana Energy commission before beginning to operate. A summary of various electricity generating sources can be found in Appendix 1.

2.2.2 Transmission

Following the Power Sector Reform in 2005, power transmission became the sole responsibility of the Ghana Grid Company (GRIDCo). The establishment of GRIDCo followed the requirement of the Energy Commission Act, 1997 (Act. 541) and the Amendment Act of Volta River Development, 2005 (Act. 692). They allowed for the formation of the National Interconnected

Transmission System, operated by an autonomous entity. GRIDCo receives power from wholesale suppliers and transmits it to its various bulk customers, namely; ECG, NEDCo and the Mines. In this regard, they are to provide billing and metering services to these bulk customers.

2.2.3 Distribution

Domestic distribution of electricity is mainly shouldered by ECG and NEDCo. ECG started in 1947 as the Electricity Department and transcended to Electricity Division in 1962, and to Electricity Corporation of Ghana in 1967. It functioned as the sole distributor of electricity in the country until the establishment of NEDCo in 1987. NEDCo followed from the Northern Electricity Department (NED), a distribution agency of VRA and was to take-up distribution to the northern sector of the nation, namely Northern, Upper East and West and Brong Ahafo regions. ECG, therefore, concentrates on distribution to the southern sector and occupies the largest share of the market (70%), consisting Greater Accra, Eastern, Ashanti, Central, Western and Volta regions. Supply of electricity to industries in the Free Zone Enclave in Tema is however done by a privately-owned distribution company named, Enclave Power Company.

2.3 Regulatory Bodies

2.3.1 The Ministry of Energy

The Ministry of Energy plays a key role in the regulation of the energy sector. The formulation, monitoring and evaluation of policies, programmes and projects relating to the sector lies on it. It also serves as a representative of the sector to the various government bodies including at parliament. In relation to this is its support to the sector by securing funds from the Ministry of Finance and Economic Planning (MOFEP). It also holds the direct obligation of executing the National Electrification Scheme in various parts of the nation.

2.3.2 The Ghana Energy Commission (EC)

Ghana Energy Commission is a statutory body established under the Energy Commission Act, 1997 (Act 541), to regulate and manage the development and utilization of energy resources in the country. This is to ensure a reliable and efficient supply of energy to enhance the economic well-being of citizens without compromising environmental quality and public safety. As part of its duties, the Commission is required to provide legal supervisory and regulatory frameworks for energy providers in Ghana. It has the authority of granting a license for transmission, distribution and sale of electricity. Notable among its functions is its duty as government's energy policy adviser and the prescription by legislative instruments; standards of performance, technical and operational rules for the supply and sale of electricity. It is required to secure a comprehensive database to aid its decision making for the development and utilization of energy resources.

2.3.3 Public Utilities Regulatory Commission (PURC)

In 1997, the Public Utilities Regulatory Act, (Act 538), allowed for the establishment of PURC as a Multi-Sectorial Regulator. Its core mandate is to control the provision of utility services in the water and electricity sectors. It is to protect the interest of stakeholders by building a credible and sustainable utility regime. It operates autonomously in discharging its duties to ensure fair competition among public utility providers by providing guidelines for charging utility rates. It equally reserves the power to approve rates charged for electricity and water to protect the interest of both consumers and service providers.

2.4 Supply and Demand Trends of Electricity in Ghana

2.4.1 Supply

Production of electricity in Ghana as explained earlier occurs by hydro, thermal and various renewable sources. Though data exists for production from previous years for some of the production sources, this study presents the power generation from various sources from 2007 to 2016.

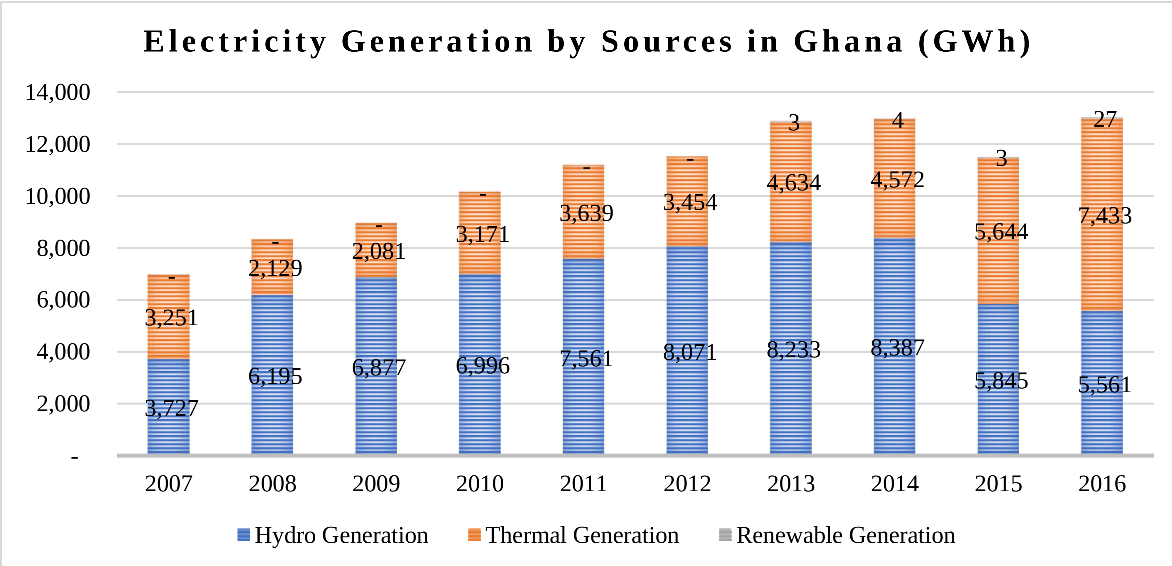

Figure 2. 1. Electricity Generation by Sources in Ghana, 2007-2016 (GWh)

Data source: Energy Commission (2017)

Hydro production is from three sources; Akosombo and Kpong hydropower operated by VRA and the Bui hydropower operated by Bui Power Authority. It must be noted that not all sources have been effective in production over the years (2007-2016). Figure 2.1 shows the total production from the various sources; hydro, thermal, and renewable respectively for the stated years.

Hydro production is the summation of outputs from the three plants. However, Bui started operating only from 2013 with an initial output of 362 GWh. Total hydro production in 2007 was 3,727 GWh, this experienced a persistent increase to 8,387 GWh in 2013, approximately 125% increase over the period. However, subsequent years experienced drastic falls to about 5,845 GWh and 5,561 GWh in 2015 and 2016 respectively. These represent approximately 30.34% and 33.7% respective falls relative to the hydro production in 2014. This is not as expected because those years had the services of Bui producing a portion of hydropower to complement Akosombo and

Kpong. This drastic fall is attributed to the poor inflow of the Akosombo Dam which resulted in relatively very low levels of water in the reservoir. The recommendation from the Ghana Energy Commission indicates that the Akosombo reservoir could support only 3 units of operation at the end of the dry season in July 2016. However, in previous years, the reservoir supported 4 units of operation at the off-peak periods and 5 units of operation during the peak period, with some days having 5 units operated the entire day. With the drastic fall in water levels, the results were not surprising.

Thermal production over the years has not been consistent. It experiences a lot of fluctuations mainly due to variations in the number of existing and operating plants at any point in time. Thus, the introduction of some new plants and the shutdown of some old plants. Thermal output represented in Figure 2.1 is a summation of production from all installed thermal plant (both VRA and private owned plants*)*. Among the installed plants, only Takoradi Power Company (TAPCO) and Takoradi International Company (TICO) operated in all the years under consideration. Though Tema Thermal 1 Power Plant (TI1PP) and Tema Reserve Power Plant (TRIPP) were in operation in the years 2007 and 2008, they were totally shut down for the subsequent years. However, new plants were introduced year on year with the last ones being Trojan and Kpone Thermal Power Plants (KTPP) which were introduced in 2016. The Mines Reserve Plant (MRP) did not produce anything in 2013 but was in operation for the rest of the years. We see the total thermal output of 3,251 GWh in 2007 which was followed by a fall of approximately 36% in 2009. The addition of two thermal plants in 2010 saved the dwindling production. Subsequently, as more plants were added, the sector received a recovery with production rising from 2,081 GWh in 2009 to 7,433 GWh in 2016, an average of 257.2% increase.

Talking about the hydro-thermal production mix, Figure 2.1 indicates that, hydro production was always higher than thermal production from 2007 till 2014. However, the introduction of more thermal plant and the production shock in the hydro output in 2015 and 2016 saw the total thermal output outweighing the hydro output.

Irrespective of the strong advocate for electricity generation from renewable sources, recorded output from renewable source started only in 2013 with a negligible contribution to the total output. As at the end of 2016, generations from hydro and thermal were 42.70% and 57.1% respectively with renewable contributing only 0.2% of total national electricity output.

2.4.2 Demand

The Energy Commission of Ghana categorizes consumers of electricity into four groups; namely residential, non-residential, industrial and street lighting. Residential consumers comprise of the proportion of electricity that goes to households. The industrial consumers are sometimes referred to as Special Load Tariff (SLT). This comprises of consumers that need electricity for industrial work such as VALCO, mining and other production companies.

Non-Residential consumers are basically other commercial facilities whiles street lighting category is meant for total electrical power used for street lighting. Figure 2.2a indicates that Special Load Tariff consumers have always constituted the major electricity consumers in the nation. The second major consumer group is the residential sector.

Residential demand increased steadily from 1996 GWh in 2007 to about 3060 GWh in 2013, however, a fall was observed in 2014 and 2015 due to supply-side shocks resulting from some of the crises earlier discussed. The least consumer category is street lighting that constituted 101 GWh in 2007 and 603 GWh in 2016

However, a sizeable proportion of the power produced is wasted through transmission and distribution losses. Figure 2.2b shows a trend in total electricity produced, consumed and total losses over the period 2007 to 2016.

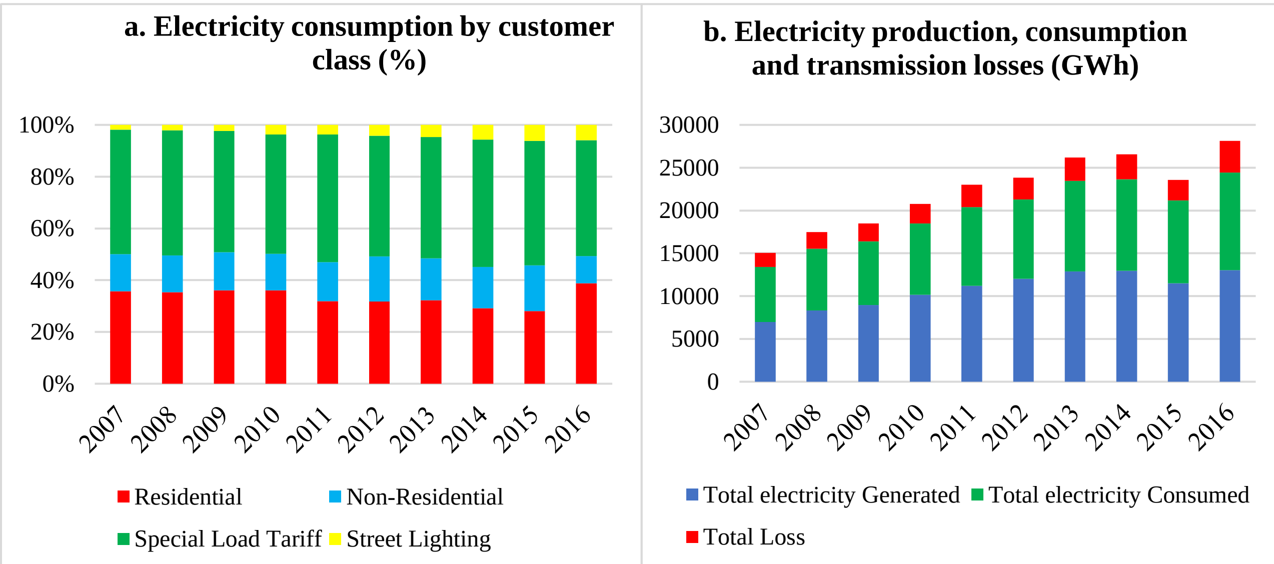

Figure 2. 2 Electricity production, consumption and transmission losses (%)

Data source: Energy Commission 2017.

Total losses here comprise the summation of transmission and distribution losses from ECG and NEDCo. Comparatively, the total losses recorded in a year exceeds the electricity consumption by the Non-Residential sector.

2.4.3 Export and Import of Electricity

Following the signing of the ECOWAS Energy Protocol, Ghana now trades in electricity with neighboring countries namely, Togo, Burkina Faso and Cote D'Ivoire. Figure 2.3 indicates a trend of trade between Ghana and its neighboring countries for the periods 2007 to 2016. The difference between electricity imports and exports is the net import. A positive net import means, the nation imported more electricity from the neighboring countries than it exported in that year. Intuitively, a positive net import leads to a reduction in the foreign reserves of the nation whiles a negative net import does the opposite.

From Figure 2.3, in two instances (2007 and 2016), the nation experienced positive net imports. These were periods that domestic productions were low and the need to import additional power to supplement the limited domestic output.

Figure 2. 3: Export, Import and Net Import of Electricity in Ghana (GWh)

Data Source: Energy Commission (2017)

However, in-between these periods, the nation experienced some negative imports which can be deemed good news. It must, however, be realized that these were equally the periods when most thermal plants were mounted to augment the hydro productions and hence the likelihood of high CO_2 emission. It is evident from the figure that, the highest net import (in negative terms) was obtained in 2010, after which it continued to fall steadily until a positive net import was realized in 2016.

2.5 Challenges Faced by the Electricity Sub – Sector in Ghana

The electricity sub-sector of Ghana has over the years been confronted with several challenges. These challenges include limited diversification in the production process, poor transmission and distributions systems and poor pricing mechanisms.

2.5.1 Limited Diversification in Production

The generation of electricity in Ghana was for a long time mainly dependent on hydro, supplemented with thermal production. Irrespective of the high advocacy for the use of renewable energy of which Ghana has enormous potential, the nation only has a negligible proportion of generation from renewable sources. Hydro production is mostly preferred because it is relatively cheaper compared to thermal and renewable production. However, the certainty of flow to the Akosombo Dam cannot be guaranteed. This makes production very sensitive to changes in rainfall patterns and even more threat due to climate change accompanied by low rainfall. This is evidenced with thermal production exceeding hydro production in 2016.

Though the nation has been trying to augment the reducing hydro generation with thermal generation, this is not easily achieved. Apart from the environmental impact, the supply of gas and liquid fuels to power the thermal plants are met with numerous challenges. Until the establishment of the Atuabo gas processing facility in 2015, the sector mainly depended on the supply of gas from Nigeria via the West African Gas Pipeline (Boadu & Aklorbortu, 2015). The desire of Nigeria to increase their installed power capacity to 15, 000 MW by 2020 together with the usual reason of non-payment of gas bills threatens the consistency of gas supply. Generally, gas supply has over the years suffered inadequacy, planned and unplanned supply interruptions and payment deficits. It is worth mentioning also that the importation of crude to fuel electricity generating plants are highly affected by the fluctuating prices of crudes.

The country has the tendency of scooping much power from wind and solar. However, this has not been adequately tapped. Measurement of wind speed at various parts of the nation ranges from 6m/s to 9m/s (EADTF, 2014)[1]. It is in the scope of this opportunity that the Renewable Energy Act was enacted in 2011. However, there is currently no wind power generating source in existence and the solar production sources are negligible relative to the total energy output of the nation.

2.5.2 Poor Transmission and Distribution Systems

The next challenge that the electricity sector of Ghana is facing is the huge volumes of power that is wasted in the transmission and distribution process. Irrespective of the cost incurred in power generation, a sizeable proportion of it goes wasted mainly due to the use of obsolete equipment in the transmission and distribution processes. In 2016, transmission losses from the total of 13,022 GWh generated were 607 GWh while the joint distribution losses from ECG and NEDCo amounted to 1,365 GWh (Energy Commission, 2017). This indicates a sufficient room for improvement through investment in efficient equipment to reduce these huge losses

Key to commercial losses is the non-payment of bills by electricity consumers. This makes it difficult for service providers to mobilize enough revenue for the development of the sector. Some users are also involved in illegal activities where the power they consume is not accounted for. This calls for the need to fasten the nationwide decision on installing prepaid meters to all users.

[1] Energy Access Data Task Force

With this approach, consumers will have to pay before they use power and the service providers can reduce their commercial losses drastically.

2.5.3 Poor Pricing Mechanism

Equilibrium production of any commodity requires that the marginal revenue be equal to the marginal cost in a competitive market. However, the pricing system for electricity does not follow this theory due to the substantial control of government regulatory bodies in the sector. The pricing mechanism makes it difficult for service providers to recover the cost of production. The prices paid by customers are far below the cost of production because of government subsidy. This partly led to the creation of the PURC as part of the Energy Sector Reform, with the hope that it will curtail the problem. PURC introduced the Automatic Adjustment Formula (AAF) to ensure sustaining the real value of tariffs via adjustments based on variations in key variables like fuel prices, exchange rates, inflations and generation mix. However, the problem seems not to be eradicated since tariffs still lag far behind production cost, with substantial quantity lost through distribution inefficiency. Coupled with these problems is the irregularities in the payment of subsidies by the government to these service providers, and poor debt servicing behavior of most public institutions (Kumi, 2017). This makes the sector less attractive for private investors due to the non-recoverability of production cost.

The introduction of the life-line tariff is to help low-income consumers (Ghana Poverty Reduction Strategy [GPRS]. 2003; Kumi, 2017). This was part of the Government of Ghana's Poverty Reduction Strategy (GPRS). However, the structure of the tariff system in the nation makes everyone to enjoy this benefit. This means even residential consumers that can afford to pay always benefit from high subside for the first 50 kWh that they consume. There is the need to improve the mechanism as much as possible to target the poor residential consumers that must benefit from it.

2.6 Efficiency Measures in Ghana

The prominent level of technology gap and reliance on outdated inefficient gadgets in most African countries has made Africa identified as having a great deal of opportunity to improve energy efficiency. Ghana has been recognized as one of the leading African countries in undertaking efficiency measures to control the increasing demand for energy and its adverse environmental challenges (Gyamfi et al., 2018). This has become necessary because most African countries usually concentrate on supply-side measures such as increasing production and transmission capacities in response to various power crises rather than considering demand-side alternatives.

Some efficiency measures that Ghana has undertaken over the years include standards and labeling, the mass rollout of inefficient technology, legislation, awareness, and promotions.

A research by the Copenhagen Centre on Energy Efficiency (2015) on the topic "*Accelerating Energy Efficiency: Initiative and Opportunities –Africa*", indicated that the various measures taken by African countries can be categorized as policy and regulations, funded interventions and voluntary initiatives. In Ghana, various measures undertaken can mainly be grouped into policy and regulations and encouragement of voluntary initiatives.

2.6.1 Policy and Regulation Measures

This is to provide a framework upon which other efficiency policies are built. In the capacity of the Ghana Energy Commission, it prepared the Strategic Energy Plan and developed legislation for electricity supply and efficiency standard of appliances.

Ghana has over the years introduced legislative instruments for energy efficiency and were subsequently updated as the years go by. The aim of the policy is to reduce the demand for energy through efficiency standards and labeling on household refrigerating gadgets. According to the provisions of the law for energy efficiency and standards, (LI1815), appliance producers that export to the Ghanaian market and retailers involved in such businesses are required to display a label indicating the efficiency rating of the appliance before permitted onto the market. This seeks to prohibit the manufacturing, importations, and sale of various inefficient gadgets like Incandescent Filament Lamps, used air conditioners and refrigerators. This means such appliances are required to meet the minimum efficiency performance and standards approved by the implementing body. For instance, an acceptable air condition on the Ghanaian market should meet the required Energy Efficiency Ratio (EER). Thus, it must yield at least 2.8 watts of cooling per watt of electricity input whiles an efficient lamb is to provide a minimum efficacy of 33 lumens per watt. This has been implemented by using the efficiency star rating approach ranging from one star to five stars. The efficiency level of an appliance is deemed higher with the increase in the stars, with a zero-star meaning the appliance is not efficient and consumers are advised to desist from patronizing such appliances.

In addition to this is the performance and efficiency standards for Compact Fluorescent Lamps (CFL), introduced by the Energy Foundation, Energy Commission and the Standard Board of Ghana in 2003. This is to complement the removal of import duties and VAT on such products to ensure their affordability on the Ghanaian market. It was further backed by the procurement and free distribution of six million CFLs to households to help manage peak electricity demand as a demand-side antidote to the power crises the nation faced due to low rainfalls. This measure is reported to have reduced peak load by 124 MW

2.6.2 Voluntary Actions

Voluntary actions of people in the promotion of energy efficiency can be categorized as those measures that don’t have any regulatory backing. The essence of undertaking these measures may be because of the direct benefits that they will obtain in the form of paying lower bills or based on moral conscience (just because they want to do the right thing). For example, though there is a regulation restraining people to the use of Compact Fluorescent Lamps, there is no regulation telling people the number of hours to use it, or to put it off when not in use. The decision of an individual to be conscious of his/her power consumption and put various appliances off when not in use is a voluntary decision motivated by either financial gains or moral conscience (Copenhagen Centre on Energy Efficiency, 2015)

However, policymakers can help individuals develop these habits via the provision of requisite information. Policymakers have therefore over the years being educating the public on various efficiency measures available and why they should participate. There is the need to also publish achieved successes from the program to motivate stakeholders participating in it and to encourage others who are not already participating. For instance, the report from the Copenhagen Centre on Energy Efficiency research indicated that the various initiatives have led to a drastic fall in CO_2 emission of about 112, 320 tons per annum and an average saving of about Ghc 31.00 of households' income in 25 districts nationwide. In the process of dismantling and scrapping refrigerating appliances that were voluntarily turned in by users and those that were confiscated, it was realized that about 1,500 Kg of Chlorofluorocarbon (CFC) was recovered. These are motivating results that can encourage households to partake in the efficiency measures when made known to them.

2.7 Challenges of Energy Efficiency Programs in Ghana

The implementation of these initiatives has not come without challenges. Poor cooperation among key stakeholders of the program due to the emergency nature of the program can be cited as a barrier (Copenhagen Centre on Energy Efficiency, 2015). In Ghana, though most policies originate from the Energy Commission in collaboration with the Ministry of Energy, their enforcement is by the Ghana Standards Authority. In the course of implementing the program, more attention was placed on satisfying the power requirement with negligible concerns for the environment. There was also inadequate training to aid the implementation team in carrying out their required duties (Copenhagen Centre on Energy Efficiency, 2015)

Another challenge facing the success of the program reported by the Copenhagen Centre on Energy Efficiency (2015) is the low level of electricity tariff. Because of the high subsidies that people enjoy, there is less motivation to undertake energy-saving measures. Some view the habit of energy saving as the trajectory of the poor who cannot pay electricity bills.

The soaring prices of efficient gadgets also serve as a challenge facing the programs. In general, the prices of efficient appliances are higher than that of inefficient appliances. However, most citizens have low levels of income and limited access to credit which can limit their affordability of efficient appliances. There are fewer attempts of domestic production of these efficient appliances to help moderate the prices except for the production of CFLs. This has caused many dealers in appliances to find illegal ways of still importing and trading inefficient appliances. The ineffective implementation of legislations and bulging level of corruption creates porosity at the various ports and does not deter people to desist from illegal trading activities.

2.8 Summary

The chapter has presented a brief history of the production of electricity in Ghana. The key phases which are production, transmission and distribution were also discussed. The chapter further discussed discrepancies in production and consumption of electricity as well as trade in electricity between Ghana and its neighboring countries. Regarding efficiency, discussions on some efficiency measures implemented in Ghana and their respective challenges were presented.

CHAPTER THREE

LITERATURE REVIEW

3.1 Introduction

In this chapter, reviews of various related works are presented. The chapter begins by introducing the evolution of empirical energy economics and efficiency measurement. Subsequently, the two key approaches to the measurement of efficiency were discussed, followed by some key concepts in energy economics. It concludes with empirical findings by different authors in their study of energy/electricity demand and efficiency in different countries. These empirical findings are grouped into four main themes namely, the determinants of household demand for electricity, measurement of electricity consumption efficiency, determinants of electricity consumption efficiency and barriers to reducing electricity consumption and efficiency improvement.

3.2 Evolution of Empirical Energy Economics and Efficiency Measurement

The study of energy using empirical econometrics started with the work of Houthakker (1965). The initial focus was on obtaining price and income elasticity of energy demand. This led to several other economists/researchers modeling the demand for electricity in line with classical demand theory which pre-supposes the demand for a commodity to be determined by its price, the price of other related commodities and consumers' income. Even though these three key factors cut across the literature, there are other identified factors like demographic features (Filippini & Pachauri, 2004; Adom et al., 2012), capital stock (Narayan & Smyth, 2005); appliance prices (Diabi, 1998) and real GDP per capita (Adom et al., 2012), that also have remarkable impact on the demand for electricity. However, this classical economic theory assumes away inefficiency where the first and second order optimizing conditions are satisfied. This variable (inefficiency), however, exists and the need to account for it.

In literature, discussions on energy efficiency started with Hartman (1979), who wrote briefly on the importance of energy consumption efficiency. However, there was no effort made to undertake econometric measurement of this efficiency. In production theory, efficiency was for a time used interchangeably with productivity. Cooper et al. (2000), for instance, described both efficiency and productivity as the ratio of output to input. In such instances, output to input ratios of various production processes can merely be compared to determine which production process or producer is more efficient.

The application of rigorous methodical approach to the measurement of efficiency in production commenced with the work of Koopmans (1951) and Debreu (1951) and was also empirically applied in Farrell (1957). Koopmans (1951) indicated that technical efficiency in production is the level of production where the producer is unable to increase one output without a reduction in another output or an increase in input with the existing technology. In such instances, an increase in output of a product is only possible by moving inputs from the production of other outputs or increasing the inputs employed.

In his '*coefficient of resource utilization'*, Debreu (1951), became the first to illustrate the measurement of productive efficiency using a 'radial' approach. The radial approach of efficiency measurement requires that all inputs will be reduced proportionately for efficiency improvement. In his application of the concept of efficiency measurement, Farrell (1957) extended the original model by Koopmans (1951) and Debreu (1951) to include allocative efficiency. This assumes that producers can choose the right combinations of input and output given their prevailing prices. This implies that overall efficiency will be equal to both technical and allocative efficiency. He further suggested that critical analysis of technical efficiency should be done in terms of deviation from an idealized frontier/isoquant. Following this, formal econometric analysis of frontier models was introduced by Aigner and Chu (1968) in their reformulation of the Cobb-Douglas production function. Their estimation was however based on linear or quadratic programming techniques by solving a deterministic optimization problem. However, since this approach sacrifices the analysis of random shocks, it does not provide an accurate measure of efficiency (Murillo-Zamorano, 2004). According to Murillo-Zamorano and Vega-Cervera (2001), recent estimation of efficiency in the literature is monopolized by two main methods, namely parametric and non-parametric

3.2.1 Parametric Approach to Efficiency Measurement

Parametric approaches to the measurement of efficiency require the specification of a functional form for the model. The approach can further be subdivided into deterministic and stochastic models (Murillo-Zamorano & Vega-Cervera, 2001). Specification of frontier functions in which deviations of observations from the theoretical optimal is solely attributed to inefficiency is termed deterministic frontier (Greene, 2008). In such frontier functions, the stochastic components are totally contained in the inefficiency term. This is estimated as the difference between the potential output defined by the frontier that envelopes all the observations and the observed production level. However, the deterministic nature of this estimation technique does not permit the separation of random errors from inefficiency. Simultaneously, the Stochastic Frontier Analysis (SFA) was introduced by Agner et al. (1977) and Meeusen and Broeck (1977). This is a methodology that incorporates both a random shock and an inefficiency term. This is because deviations from the frontier might not entirely be under the control of a firm being studied. For deterministic frontiers, shocks like climate changes, the breakdown of machinery and so on might be interpreted as inefficiency. Furthermore, any error in measurement, as well as model misspecification, will equally be interpreted as inefficiency since the approach does not make provision for any statistical noise. These limitations are however overcome by the SFA technique of efficiency measurement.

3.2.2 Non-Parametric Approach to Efficiency Measurement.

A non-parametric method to the measurement of efficiency embodies the technique for analyzing production and cost data without parametrizing the technology (Greene, 2008) or imposing a functional form to define the efficient frontier (Lin & Du, 2014; Murillo-Zamorano & Vega-Cervera, 2001). Examples of non-parametric models include the Data Envelopment Analysis (DEA) and the Free Disposal Hull (FDH). For instance, the estimation of DEA frontier follows a linear programming technique initiated by Charnes and Cooper (1961) and popularized in the Data Envelopment Analysis (DEA) in the late 1970s. The DEA aids in evaluating the performance of comparable organizations/firms that convert inputs into an output (Mardani et al., 2017). It therefore permits every Decision-Making Unit (DMU) to freely choose combinations of inputs and outputs that will maximize its relative efficiency. With the aid of the DEA, the relative efficiency of each DMU can be computed, depending on the linear relation between inputs and outputs to determine how efficiently it is producing a given level of output. (Mardani et al., 2017). DEA is therefore based on an assessment of observed producers by comparing them to each other through the construction of a quasi-convex hull around the data points in the input space. The wrapping of the hull indicates which among the sample is closer to the frontier (or farthest from it). Technical efficiency requires producing on the frontier and hence the closer a DMU is to the frontier, the more efficient it is deemed to be.

The non-parametrizing of this technique makes it computationally convenient to use, however, it comes at a cost. This is because it does not consider the presence of statistical noise in the form of outliers or measurement errors. This makes the model very sensitive to outliers with every deviation from the frontier attributed to inefficiency (Danquah & Quattara, 2014). However, recent attempts to overcome these challenges have introduced the bootstrapping method to minimize the deficiency. In the study of energy economics, many researchers (Wei et al., 2007; Zhou & Ang, 2008; Wu et al., 2012; Zhao et al., 2014; Cui et al., 2014) have employed the DEA approach in their analysis.

In conclusion, the above discussion offers us an understanding of how efficiency is measured and will aid our understanding of applying the concept in measuring electricity consumption efficiency.

3.3 The Concept of Energy Efficiency and Energy Conservation

Theoretically, the two terms; “energy efficiency” and “energy conservation” are mostly used interchangeably in policy discussions. However, there exist some differences between them (Herring, 1996). Energy efficiency, which was initially proxied to be the changes in energy intensity, measured the variation in the ratio of energy service to a unit of energy input (Ang et al., 2010; OEE, 2009). In more recent times, it mainly concentrates on new systems that can encourage energy saving without restricting people’s lifestyle (Prete et al., 2017). Thus, the ability to obtain the best of every unit of energy input to ensure that the quantity of energy required to produce the same energy service is reduced (Herring, 2000; Rudin, 2000; Ozturk, 2013). Technically, Wu (2012) explained it as a specific reduction in energy use due to technological progress and improvement in energy management. Al-Shemmeri and Naylor (2017) therefore concluded that energy efficiency is using technology to decrease energy losses and to eradicate energy wastage.

Energy conservation, on the other hand, deals with the reduction in energy consumption via changes in quality of energy service (Herring, 2000). Gillingham et al. (2009), typically described energy conservation as a decrease in the total quantity of energy used. This may or may not be related to improvement in energy efficiency, contingent on how energy services change. This means the quality of services that the individual enjoys may be affected under energy conservation but not affected under energy efficiency. Al-Shemmeri and Naylor (2017) indicated that energy conservation is the change in wasteful behavior to cut down energy demand. Thus, energy conservation mainly depends on consumer behaviors, regulations and changes in lifestyle (Herring, 2000). This is because, energy conservation involves less energy to achieve lesser energy services via behavioral changes and sometimes efficiency means (Ozturk, 2013). An example of energy conservation without energy efficiency may be living in a less bright room with the aim of not wanting to use much energy. However, the idea behind demand side management is to increase the market proportion of efficient use of electricity without depressing the level of services provided (Rudin, 2000).

Furthermore, Newton and Cantarello (2014) offered a distinction between the technical definition and economists' definition of energy efficiency. They indicated that technical definition focuses on the reduction in energy consumption for a given level of energy service, through the purchase of efficient technologies (appliances). However, economists' definition of energy efficiency focuses on "all kinds of technological, behavioral and economic changes that reduce the amount of energy consumed per unit of energy service" (p. 189). In this regard, it is possible for economists to consider energy efficiency as constituting both technical and allocative efficiencies without depressing the utility of consumers.

To save energy, there has mostly been a contrast in the desired approaches from policymakers and residential electricity consumers. Whiles policymakers usually prefer energy savings via both technical and allocative efficiencies, consumers, on the other hand prefer energy saving through only technical efficiency. Thus, policymakers prefer consumers to change their consumption attitudes and also use labeled and standardized products. However, consumers hardly change their consumption attitudes and participation in energy management, but easily give in for more efficient gadgets (Herring, 2000). This results in the energy rebound effect where the objectives of policies are hardly achieved.

Yue et al. (2013) and Kaplowitz et al. (2012) indicated that attempts to promote only energy efficient technology (technical efficiency) won't be enough to resolve the issues of high energy consumption and environmental quality deterioration through emissions from energy consumption. This is because, irrespective of the numerous policies that have been introduced to attain a cost-effective reduction in energy consumption, energy savings due to behavioral changes are far from achieving their prospective (Gynther et al., 2012; ODYSSEE-MURE, 2013). Gram-Hanssen et al. (2004) therefore indicated that household electricity consumption could substantially be lowered if more attention is paid to unnecessary use, followed by changes in everyday human behavior. Reduction of energy consumption in a household can be achieved via both adoptions of technical measures and changes in human behaviors (Oikonomou et al., 2009; Aini et al., 2013). The demand frontier adopted in this study measures both technical and allocative inefficiencies that are affected by both technology and behavior of households toward energy management. This enables us to consider these factors in the study. This is hinged on the indication by Broadstock et al. (2016) that behavioral factors contribute greatly to household energy consumption efficiency. Thus, in this study, the results account for both technical and allocative efficiencies.

3.5 The Concept of Energy Rebound Effect

The need for considering the measurement of both technical and allocative efficiencies become very important when analyzing the issue of the rebound effect. This is because advocates for energy efficiency acknowledge that, part of the energy savings from technical efficiency improvement is offset by an increase in energy consumption, a terminology referred to as the 'take back' or 'rebound' effect in the literature (Herring, 2000). The rebound effect may be described as situations where the demand for energy services rise due to a reduction in the marginal cost of these services, induced by technical efficiency. It therefore measures the percentage of estimated decrease in energy consumption that is 'lost' due to the combination of market and consumer responses (Gillingham et al., 2016). This means the reduction in energy consumption can be obtained with or without technical efficiency, whiles it is also likely to experience rising consumption of energy alongside an improvement in technical efficiency.

The presumed effectiveness of most efficiency policies is commonly met with criticisms because they ignore or underestimate the rebound effect (Gillingham et al., 2009). For instance, Filippini et al. (2014) indicated that the rebound effect is cited as one of the reasons that may lead to failure of the EU member states in achieving the 20% savings of energy consumption by 2020. In his paper, Herring (2000) argued that the notion of improving energy efficiency to reduce the emission of greenhouse gas is flawed since it rather reduces the implicit cost of energy and encourages more usage. Thus, the study of the rebound effect is important when aiming at reducing emissions, since its effect together with technological advancement determines the total reduction in energy consumption. Yu and Guo (2016), for instance, indicated that the ineffectiveness of appliance labeling on energy savings among rural households in China can be attributed to the rebound effect which cancels out energy saving potentials from technical efficiency. This is consistent with the findings of Ouyang et al. (2010), who asserted that efforts and technologies on energy efficiency have yet not been able to curb the accelerating energy consumption by Chinese households after identifying a 30% rebound effect among households in China.

3.6 Empirical Review

This section presents the review of findings from various researchers in the field of energy economics, namely; the determinants of energy/electricity demand, the measurement of electricity consumption efficiency, determinants of electricity consumption efficiency and barriers to reducing electricity consumption and efficiency improvement. The first three themes are mainly influenced by the objectives of the study whiles the last one looks at some potential hindrances to the achievement of electricity consumption efficiency.

3.6.1 Determinants of Electricity Consumption

There are several studies pointing to diverse factors influencing household electricity consumption. In Pakistan, a cross-sectional analysis by Zaman et al. (2012) revealed that electricity consumption is positively related to levels of household income. A positive correlation between electricity consumption and income was also reported by Yohanis et al. (2008) among the 27 dwellings they studied in Northern Ireland. In Singapore, Loi and Le (2018) reported that the influence of income on electricity consumption is relatively negligible whiles Esmaeilimoakher et al. (2016) reported a considerable influence of disposable income on household electricity consumption among households in Perth, Western Australia. The results from Adom (2011) and Mensah et al. (2016) also affirmed the significant impact of income on the consumption of electricity in Ghana.

Among Irish households, Leahy and Lyons (2010) established approximately a 19% higher consumption of electricity per week by a two-person household, compared to a one-person household. Similarly, Zhou and Teng (2013) reported an 8% rise in electricity consumption by a unit increase in the number of people in the house among Chinese households. The findings of Yohanis et al. (2008) pointed out that in Northern Ireland, the top position of electricity consumption is occupied by households with over four members. These findings are supported by the report of the UK Office of National Statistics (2013), which indicated that domestic energy consumption is higher for households with higher occupancy rates. However, the results by Filippini and Hunt (2012) indicated that among US households, as family size increases, there is the tendency to use less energy per person, which depicts a sort of economies of scale in residential energy consumption. This finding is very informing since as people in the house increases, there is no tendency to increase the number of household appliances like refrigerators, television sets, air conditioners and so on. This means that the addition of a person to a household may have a negligible marginal change in energy consumption.

Regarding the number of rooms, a positive relationship was found between the quantity of electricity consumed and the number of rooms in Dutch homes by Bedir et al. (2013). The study by Leahy and Lyons (2010) affirmed that houses with more than five rooms consume more electricity than houses with one or two rooms. This also indicates a positive relationship between electricity consumption and the number of rooms among Irish households. A similar report was presented by Tiwari (2000) among households in India that a unit increase in the number of rooms leads to an 11% rise in electricity consumption. Conversely, the findings of Brounen et al. (2012) reported a negative relationship between the number of rooms and quantity of electricity consumed among Dutch homes, with Wiesmann et al. (2011) recording no significant relationship from their studies on households in Portugal.

With the view that electricity has a derived demand, the relationship between the ownership of electrical appliances and electricity consumption has been subjected to extensive studies, with most studies recording a positive relationship (Nielsen., 1993; Leahy & Lyons.,2010; Zhou & Teng., 2013; Singh et al., 2018). Leahy and Lyons (2010) further indicated that modeling energy use without the inclusion of appliances will lead to a biased result and an incorrect inference. Among Indian urban households, Singh et al. (2018) reported that an increase in the ownership of main household appliances like air conditioners and refrigerators contribute significantly to electricity consumption. The responsiveness of electricity consumption to a percentage increase in appliance ownership was revealed to be 0.35% among Danish homes by Nielsen (1993). Zhou and Teng (2013) reported that ownership of computers and refrigerators among Chinese homes respectively lead to about 10% and 22.2% increase in electricity consumption compared to similar households without them. Television was reported to cause electricity consumption to increase by approximately 1301 kWh per annum among Norwegian homes by Larsen and Nesbakken (2004).

The impact of changes in electricity prices on the quantity consumed has also been studied by numerous researchers. Singh et al. (2018) reported a price elasticity of -0.72 among Indian urban households. For the economy of Jordan, Al-Bajjali and Shamayleh (2018) also indicated a negative relationship between electricity consumption and its price. In the USA, Filippini and Hunt (2012) reported that the demand for energy is price inelastic which is supported by the findings of Loi and Leg (2018), that the price responsiveness of electricity demand among households in Singapore is low.

Carvalho (2016) studied electricity consumption efficiency among 28 transition economies and 5 Western European OECD countries over the period 1994-2007. His results after employing the Bayesian Generalized True Random Effect (GTRE) stochastic frontier model indicated that urbanization rate had a strong influence on electricity consumption, thus, there seem to be fuel switches as people move to urban areas. In Ghana, urbanization is one of the factors influencing the consumption of electricity as reported by both Adom (2011) and Mensah et al. (2016). For instance, according to Mensah et al. (2016), urbanization had the highest influence on the consumption of electricity. This was attributed to the higher accessibility to electricity among the urban folks compared to the rural dwellers.

3.6.2 Measurement of Electricity Consumption Efficiency

Empirical literature examining energy saving potential has been on the increase in recent years. In their studies, Yu and Guo (2016), employed the stochastic frontier approach on rural households in China. They used the China Residential Electricity Consumption Survey (CRECS) to estimate the potential for electricity savings. Results from their studies indicated that, on average, Chinese rural households are efficient in electricity savings with an average efficiency of 93%. The employment of the stochastic frontier Approach was to enable them to decompose residential energy consumption into minimum requirement based on household characteristics and excess consumption. This enabled them to estimate the consumption slack which could be avoided.

Filippini and Hunt (2012), pioneers of the energy demand frontier, followed their previous methodology (2011) to study a panel data for 48 American states over the period of 1995 – 2007 and estimated a US residential energy demand frontier. The estimated average efficiency was from 85% to 95%. They equally indicated that the use of energy intensity as a measure of energy efficiency is not appropriate.

Among the European Union member states, Filippini et al. (2014) followed the energy demand frontier proposed by Filippini and Hunt (2011) to estimate the level of energy efficiency for 27 EU member states for the period 1996-2009 and indicated an average efficiency of 83%. This indicates an existing potential for the household sector of EU states to save energy via a reduction in levels of inefficiency. The appropriateness of the methodology used is its ability to control for the difference in socio-economic and environmental factors among member states relative to measurements using energy intensity. Conclusions from the study indicated that significant differences arise when member states are ranked based on intensity and efficiency measurements and hence not a good approach to proxy energy efficiency by variations in energy intensity.

According to a study by Carvalho (2016) on electricity consumption efficiency among 28 transition economies and 5 Western European OECD countries, mean efficiency of approximately 56% was identified among the sample with a sign of convergence. The sign of convergence indicates that, after controlling for technological variance and other heterogeneity in the data, there seem to be similar levels of efficiency among the groups, implying that, the difference in their mean efficiency scores can be attributed to technology and equipment rather than their usage behavior. In such cases, most country groups seemed to be converging at an average level of approximately 60% efficiency (Carvalho., 2016). He further indicated that in transition economies, there exist larger persistent inefficiency compared to transient inefficiency.

Among households in Portugal, Weyman-Jones et al. (2015) reported a mean electricity efficiency of 96.9%. They further indicated that regions with higher consumptions were not necessarily the least efficient. However, the model they used was relatively simple with only a few explanatory variables as indicated by Boogen (2017). Boogen (2017) therefore employed the sub-vector input distance frontier function on two waves of Swiss households' data with the aim of obtaining the potential for energy savings. In his estimation, he obtained an average inefficiency of electricity usage between 20%-25%. However, estimation of the technical efficiency alone as he did in his work may not be exhaustive enough to aid in realizing the full impact of any efficiency policy undertaking. This is because the estimation does not cater for allocative inefficiency and the potential existence of a rebound effect. In such instances, the full forecasted energy savings that policymakers might be expecting may not be realized.

The energy demand frontier by Filippini and Hunt (2011) was employed by Broadstock et al. (2016) on about 7000 households in China to estimate the efficiency of electricity consumption. They however extended the original model to a meta-frontier context to control for structural heterogeneity arising from locational differences (city, towns and villages). According to their analysis, the meta-frontier was defined by city households that constitute the wealthiest of the group but at the same time the most inefficient in the use of electricity. The definition of the meta-frontier by city households indicates that they have the potential to obtain the highest efficiency, but the opposite was the case. They therefore called for a refinement of the hypothesized household energy ladder, based on their adopted definition that the wealthiest households are to have the most efficient gadgets and can obtain the highest level of efficiency. They brought out the fact that caution must be taking not to straightaway compare households from villages, towns and cities due to structural heterogeneities. Hence the need to first compare the efficiency of a household to other households in the same locality, before the comparison is made with respect to households in other localities via the meta-frontier. Their research found that the average efficiency of Chinese household in the consumption of electricity was 63% and a clear opportunity for improving it via various efficiency measures. The result from this research does not deviate from the findings of Lin and Du (2014), who employed a latent class stochastic frontier approach on the Chinese energy economy for the periods 1997 – 2010 and recorded a mean efficiency of 63.2%. Similar research conducted by Murata et al. (2008), forecasted that China holds the potential of obtaining a 28% reduction in electricity consumption through improvement of end-user appliance efficiencies by 2020.

In Ghana, empirical estimates of the efficiency level of electricity consumption and its determinants were not found. This limitation serves as the drive for this study to fill the gap in the literature. However, an overview of the efficiency status of three household appliances by Gyamfi et al. (2018), indicated that Ghana is among the countries in the ECOWAS sub-region that have implemented energy efficiency measures for electrical appliances. It was also detailed that the first efficiency measure for air conditioners and Compact Fluorescent Lights (CFLs) was introduced in 2005 with some successes achieved.

3.6.3 Determinants of Electricity Consumption Efficiency

Researchers have found the impact of several factors on electricity consumption efficiency among households. For instance, among Swiss households, Boogen (2017) reported that a reduction in appliance standby can contribute to improving the technical efficiency of household electricity consumption. In China, Yu and Guo (2016) pointed out that, the level of efficiency is affected by numerous factors that influence the potential to save energy in the household. They indicated information feedback and social demographic factors to be the main factors influencing the energy saving behavior of households rather than the presumed efficiency labeling and average electricity prices.

In their study, Broadstock et al. (2016) indicated that behavioral factors contribute greatly to the efficiency level of household energy consumption. In their findings, they reported that attaining higher education by a household head and power failure sometimes lead to a low energy consumption whiles efficiency levels are improved by using other energy sources in the house. Among the European Union, Filippini et al. (2014) indicated that financial incentives and energy performance standards played a significant role in energy efficiency whiles information measures did not have any significant impact. This, however contradicts the findings of Yu and Guo (2016) who reported that in China, information feedback does have considerable influence on energy savings whiles efficiency labeling do not. This calls for the need of such studies to be conducted on country basis because differences among countries will mean varied factors affect their efficiency decisions. In Denmark, Baldini et al. (2018) pointed age, the number of inhabitants, housing type and the behavior of end-users as factors that strongly influence the choice of efficient appliances which will ultimately impact consumption efficiency.

The impact of education on the adoption of efficient technology and efficiency measures which ultimately affect the efficiency of household electricity consumption have also been studied (Ürge-Vorsatz & Hauff, 2001; Poortinga et al., 2004; Prete et al., 2017). For instance, Prete et al. (2017) indicated a positive relationship between the intention to adopt efficiency measures and higher levels of education among Southern Italian households. In their research, Poortinga et al. (2004) also reported that the adoption of efficient measures and technologies is influenced by the level of education.

According to Mahapatra and Guastavsson (2008), the adoption of efficient technologies is negatively related to age. Similarly, Prete et al. (2017) indicated that among Southern Italian homes, the aged are less likely to adopt efficient appliances, whiles Sardianou (2007) also reported a similar inverse relationship between age and efficiency measures adopted in a household.

3.6.4 Barriers to Reducing Electricity Consumption and Efficiency Improvement

Irrespective of the numerous benefits associated with electricity consumption efficiency and conservation, their patronage among residential consumers seemed to be hindered by several factors. Levine and Kendall (2016), argued that the structure for power transaction does not reward efficiency. The seller who is a profit maximizer optimizes his/her profit by selling more power and no incentive to encourage energy efficiency. Private generators of power also benefit from being able to sell all that they produce at relatively higher market clearing prices. The promotion of efficiency, however, has the tendency of reducing both demand and market clearing prices. Intrinsically, there is less incentive on the part of power sellers to encourage energy savings.

On the part of policymakers, the first solution that comes to mind amid power crises has been to invest in more power generation plants, buy more power from neighboring countries or increase transmission capability, rather than encourage end-user efficiency. Most attention to solving power crises has thus focused on the supply side with limited attention to the demand side measures.

Another key hindrance to the patronage of energy conservation and efficiency measures has been information barriers (Gillingham et al., 2009). Consumers usually lack sufficient knowledge of the difference between the present cost of an efficient appliance and the subsequent operating cost of a less efficient appliance that provides the same services (Howarth & Sanstad, 1995). They therefore fail to take into consideration the future operating cost of the appliance when buying (Dresner & Ekins, 2006; Gillingham et al., 2009). In the present-day appliance markets, flooded with less efficient gadgets, there is a great level of information asymmetry leading to adverse selection (Dresner & Ekins, 2006).

The sellers of appliances turn out to have more information and knowledge about the efficiency of the appliance than buyers. In some instances where sellers are willing to reveal to buyers the true efficiency level of an appliance because consumers cannot observe the efficiency levels of appliances, compounded with distrust for appliance sellers, they turn not to buy the idea (Dresner & Ekins, 2006). This calls for the need to embark on more education to the public on identifying efficient appliances and the benefits that accrue in the form of less operating cost when they are patronized.

One key factor that can also influence the energy saving attitude of households is information about their power consumption. Thongersen and Gronhoj (2010) asserted that research has indicated the effective impact of timely and convenient feedback on households' electricity consumption that contains the requisite information in reducing electricity consumption. It has thus been shown that the ability to provide households with information on their actual electricity consumption can be an effective way of conserving energy without necessarily having to buy efficient appliances (Ueno et al., 2006a, 2006b).

For instance, Chen et al. (2017) found that energy conservation intentions were positively predicted by bill consciousness among low-income households in the United States. In China, Yu and Guo (2016), found that information feedback played a key role in influencing energy-saving behavior among rural households as compared to the presumed efficiency labeling and average electricity prices. Among European low-income households, Podgornik et al. (2013) reported that the use of smart meters alongside customized and adaptive consumption feedbacks are effective in reducing electricity consumption.

Research has also indicated that, even though households usually have information concerning their energy consumption on their bill, they don't usually have the same on appliances. They usually hold erroneous ideas concerning the power consumption of appliances. Thus, they usually turn to relate the power consumption of an appliance to its size. This means, households usually turn to believe that, bigger appliances consume more energy whiles the smaller ones do the opposite (Steg, 2008). This means, more attention is paid to controlling the energy consumption of bigger appliances compared to smaller appliances. However, smaller household appliances like microwaves, irons and kettles turn to consume more electricity compared to some large television sets. This calls for an extensive education for appliance users on some key high-power consuming household appliances.

3.7 Summary

The chapter has presented the evolution of empirical energy economics and the various approaches to measuring efficiency. Some concepts in energy economics were also explained, and the chapter concluded with empirical findings from various researchers grouped under four main themes.

CHAPTER FOUR

THEORETICAL FRAMEWORK AND METHODOLOGY

4.1 Introduction

This Chapter explains the theoretical framework on which this study is grounded. It further spells out a general theoretical model for stochastic demand frontier, an empirical model for a stochastic frontier function and an inefficiency model. The section continuous to specify a specific stochastic demand frontier and an inefficiency model for this study. Finally, description of the variables and the source of data used in this study are presented.

4.2 Theoretical Framework

4.2.1 Theory of Production Applied in Energy Economics

The estimation of an energy demand frontier follows from the microeconomic theory of Production Possibility Frontier (PPF). Efficiency requires that production happens on the PPF. Following this concept, energy and resource economists adopted the idea in their field. The underlying question that guided their research was; how energy, as an input, is being used efficiently to produce energy services? This is to enable the employment of both DEA and SFA in their analysis (Boyd & Pang, 2000; Hu & Wang, 2006). In this regard, energy has a derived demand, thus, it is needed to be used in the production of energy services either in the house or at work. The application of the stochastic frontier approach in the study of energy economics has gained much popularity. This is because of the inherent ability of the methodology to estimate the inefficiency term independent of the random noises.

Researchers initially employed the radial measurement of technical and allocative efficiency introduced by Farrell (1957). In the application of the radial approach in energy economics, energy and capital (capacities of electrical appliances) will have to be reduced proportionately for improvement in efficiency.

As a follow up to the radial measurement by Farrell (1957) was a non-radial approach introduced by Kopp (1981). The non-radial approach aids in the measurement of input specific efficiency, holding other inputs constant. Thus, in energy economics, the non-radial approach helps to estimate the efficiency of energy holding capital inputs constant. Applications of non-radial measurement of energy efficiency were carried out using input requirement functions (Boyd, 2008; Khayyat & Heshmati, 2013) and sub-vector input distance functions (Zhou et al., 2012; Lin & Du, 2013; Boogen, 2017). However, most of these approaches only measure the technical inefficiency of energy consumption without paying attention to its allocative inefficiency.

4.2.2 The Energy Demand Frontier

Filippini and Hunt (2011), introduced the energy demand frontier to be able to capture both technical and allocative inefficiencies when using the non-radial approach. The concept of energy demand frontier has ever since been used extensively in the literature. In their work, Filippini and Hunt (2011, 2012) and Filippini and Zhang (2016), indicated that the frontier defines the minimum energy a household is expected to consume given its capital stock and other household characteristics. Any deviation from this (consuming above) is a measure of inefficiency.

Figure 4.1 provides the illustration of an electricity demand frontier adopted from Broadstock et al. (2016). From the figure, the demand for electricity is depicted to be increasing in terms of electricity price, household income and other factors that affect the demand for electricity. The demand frontier, {Q = f (P, Y, Z)}, gives the minimum electricity required (MER) by a household dependent on its characteristics. For instance, a household that consumes at point **A** is efficient because it is exactly on the defined frontier. However, it is possible that the same household may be consuming at point **A***, with the excess consumption being a measure of inefficiency. Households that consume at point **B** are efficient, irrespective of it been higher than **A.** The difference can be explained by differences in household characteristic. At point **C**, a household deviates from the demand frontier and is not efficient. The dotted line can be viewed as an acceptable minimum electricity requirement for life sustenance.

Electricity consumption

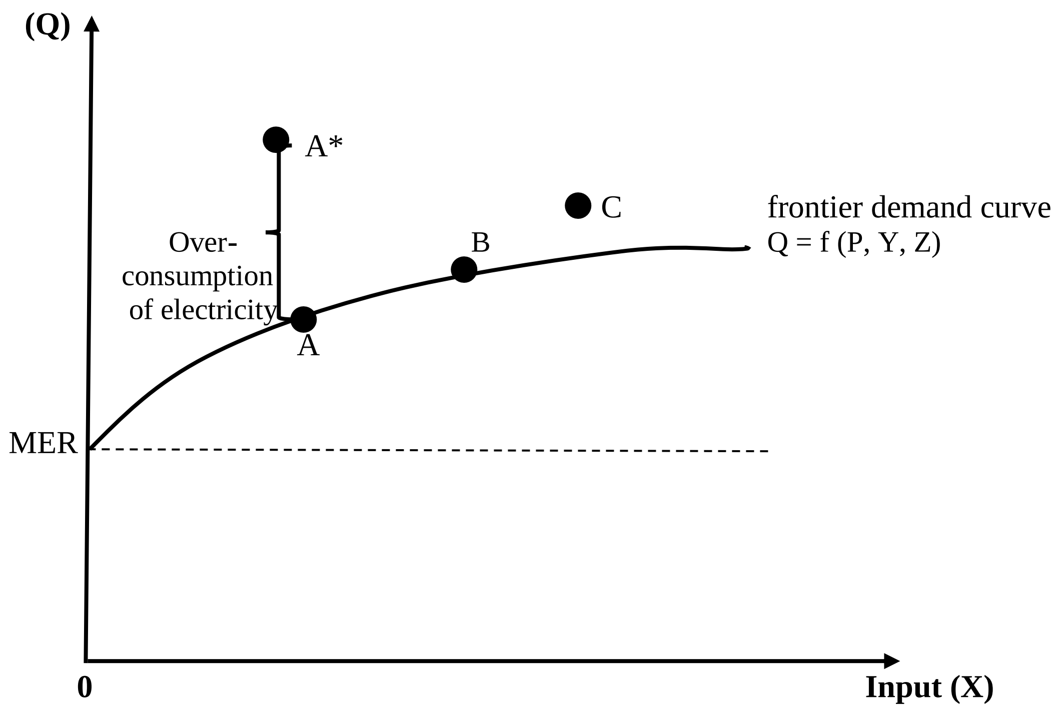

Figure 4. 1 An Illustration of MER and Energy Demand Frontier

A stochastic frontier analysis aids in the measurement of the difference between the actual electricity consumption and the required minimum consumption defined by the demand frontier (Filippini & Hunt, 2011, 2012).

The application of energy demand frontier has over the years been employed mostly using panel data (Filippini & Hunt. 2011, 2012; Filippini et al., 2014; Orea, et al., 2015) and time series data (Weyman-Jones et al., 2015; Alberini & Filippini, 2015). Its application on micro (disaggregate/cross-sectional) data was not found in the literature until recently when Weyman-Jones et al. (2015) and Broadstock et al. (2016) used a disaggregated/cross-sectional data to estimate the efficiency of Portuguese and Chinese households respectively in their consumption of electricity.

4.3 Empirical Model for Stochastic Frontier

An idealized frontier function that springs from fundamental output maximization or cost minimization process depicts the optimum output attainable with a set of inputs or the least possible cost of producing a given output, given input prices. Deviations from this frontier provide an approximate measure of inefficiency. The generalized function can be written as;

$Y_i = f(\mathrm{X}_i;\beta) + \varepsilon_i$ ……………………….4.1

Where

$\varepsilon_i = v_i - u_i$ for a stochastic production function and

$\varepsilon_i = v_i + u_i$ for a stochastic cost function.

From equation (4.1), Y_i is defined as outputs produced using input set X_i with the vector of coefficient parameters to be estimated given as β. In a cost function, Y_i will be the cost of production with X_i representing a combination of output and input prices. The error term constitutes a statistical noise (v_i) that is normally distributed and a one-sided positive inefficiency component (u_i). The symmetric component of the composed error term is assumed to have a zero mean and a constant variance $[\mathrm{N} \sim (0, \sigma_v^2)]$ while the u_i is independently distributed as $[\mathrm{N}^+ \sim (0, \sigma_u^2)]$. Furthermore, v_i and u_i are independently distributed of each other and of the regressors (Danquah et al., 2013).

Traditional estimation of a stochastic frontier model follows a two-stage procedure as proposed by Aigner et al. (1977). In this approach, the inefficiency value is obtained at the first stage and a vector of potential determinants of inefficiency is regressed on the inefficiency values obtained from the first stage, in the second stage regression (Danquah & Quattara, 2015). However, Deprins and Simar (1989) questioned the statistical validity of this two-stage approach. This is because the first stage assumes an independently and identically distributed inefficiencies which are contradicted by the second stage (Kumbhakar et al., 1991; Danquah & Quattara, 2015). In response to this, Battese and Coelli (1995), proposed a single-stage efficiency effect model generalized as;

$$Y_i = f(\mathrm{X}_i;\beta)\exp\{v_i - u_i(\mathrm{z}_i\,\delta_i)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.2)}$$

Where z_i and δ_i are potential determinants of inefficiency and their parameter estimates respectively.

The estimation of the stochastic frontier is carried out under a maximum likelihood estimation approach. The log-likelihood function for the normal-half normal stochastic frontier model can be specified as;

$$\ln L(\alpha,\beta,\sigma,\lambda) = -N\ln\sigma - \delta + \sum_{i=1}^{N}\left\{\ln\Phi\left[\frac{-\varepsilon_i\lambda}{\sigma}\right] - \frac{1}{2}\left[\frac{\varepsilon_i}{\sigma}\right]^2\right\}$$

Where $\Phi(-\varepsilon_i\lambda/\sigma)$ is the standard normal cumulative density function, $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$, $\varepsilon_i = v_i - u_i$ and δ is a constant. (Greene, 2008)

4.4 Inefficiency Effect Model

In empirical studies, the inefficiency component is assumed to take on various distributions like half-normal (Aigner et al., 1977), exponential (Meeusen & Broek, 1977), truncated normal distribution (Stevenson, 1980) and a normal-gamma density distribution (Greene, 1980). Battese and Coelli (1995) indicated that the variables in z_i (from equation 4.2) assumes a linear relationship with the inefficiency term and can be specified as;

$$u_i = \delta_i z_i + w_i \text{ .... (4.3)}$$

Where u_i represents inefficiency. The vector of explanatory variables for inefficiency and their estimated coefficients are represented by z_i and δ_i respectively. According to Danquah and Quattara (2015), w_i represents a truncated normally distributed and a random variable such that the point of truncation is $\delta_i z_i$, and has a zero mean and variance σ_u^2.

The challenge of disentangling the inefficiency component from the symmetrically distributed noise was resolved by the proposal by Jondrow et al. (1982). They indicated that, within a normal-half normal stochastic frontier model as specified by Aigner et al. (1977), the inefficiency component can be obtained as a conditional estimate given the total error term. This can be depicted as;

$$\hat{u} = E[\mathrm{u}_i \mid \varepsilon_i] = \frac{\sigma\lambda}{(1+\lambda^2)}\left[\frac{\phi(\varepsilon_i\lambda/\sigma)}{\Phi(-\varepsilon_i\lambda/\sigma)} - \frac{\varepsilon_i\lambda}{\sigma}\right]$$

Where $\phi(\varepsilon_i\lambda/\sigma)$ is the density of the standard normal distribution, $\Phi(-\varepsilon_i\lambda/\sigma)$ is the cumulative density function, $\lambda = \frac{\sigma_u}{\sigma_v}$, $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$ and $\varepsilon_i = v_i - u_i$.

Technical efficiency of each Decision-Making Unit (DMU) can then be obtained from the conditionally predicted inefficiency as $TE_i = \exp(-\hat{u}_i)$, where $0 \le TE_i \le 1$.

An estimation approach for inefficiency attained by parameterization of the variances was also provided by Battese & Corra (1977) as;

$$\sigma^2 = \sigma_v^2 + \sigma_u^2; \qquad \gamma = \frac{\sigma_u^2}{\sigma^2} = \frac{\sigma_u^2}{(\sigma_v^2 + \sigma_u^2)}; \qquad \lambda = \frac{\sigma_u^2}{\sigma_v^2}$$

The total variance from the model (σ^2) is the summation of the variances from the statistical noise (σ_v^2) and inefficiency (σ_u^2). The degree of variability due to inefficiency is measured by γ. This implies that, if $\gamma = 0$, then the variation from the frontier is solely due to random disturbances. However, a $\gamma = 1$ will imply that all variations from the frontier are due to inefficiency. A joint explanation of the variation by both statistical noise and inefficiency requires that $0 < \gamma < 1$. The ratio of the variance of the inefficiency term to the variance of the random noise is depicted by lambda (λ)

4.5 Stochastic Demand Frontier Model for this Study

This study employs the stochastic energy demand frontier by Filippini and Hunt (2011) and partly draws on the modified version by Broadstock et al. (2016) for cross-sectional data analysis.

Given a generalized demand function $Q_i = f(Y_i, P_i, X_i) + \varepsilon_i$ ……………..... (4.4)

where Q is the quantity of energy demanded expressed as a function of a household's inputs; income (Y_i), energy price (P_i) and other household determinants of energy consumption (X_i). Filippini and Hunt (2012), indicated that for an input demand function, the deviation of actual input from the cost-minimizing input denotes both technical and allocative inefficiencies. Even though the graphical view and the concept of the demand frontier are drawn from the Production Possibility Frontier (PPF), its estimation follows like the estimation of a cost frontier. This is because, the aim is to fit a frontier that defines the possible minimum energy a household is required to consume, just like a firm seeks to fit a frontier that defines the possible minimum cost of production.

Given the demand function in equation (4.4), the two functional forms that dominate the literature on efficiency measurements are the Cobb Douglas and the translog. A Cobb Douglas functional form is adopted in this study, consistent with many empirical studies using energy demand frontier (Filippini & Hunt, 2011, 2012; Filippini et al., 2014; Weyman-Jones, 2015; Broadstock et al., 2016). This functional form is flexible without the imposition of strict restrictions on the input parameters and provides an easy interpretation of the coefficients estimated (Ahwireng, 2014). The logarithmic form of equation (4.4) can be presented as;

$$q_i = \alpha_0 + \beta_1 p_i + \beta_3 y_i + \eta x_i + \varepsilon_i \text{ ……………………… (4.5)}$$

Where $q_i = ln\left(Q_i\right)$, $p_i = ln\left(P_i\right)$, $y_i = ln\left(Y_i\right)$, and $x_i = ln\left(X_i\right)$

The set of variables in X_i comprises a series of household characteristics and control variables such as house size, ownership of various appliances etc. Furthermore, these variables (X_i) can contain continuous variables, dummy variables and categorical variables. Regarding this, the dummy variables and categorical variables are not affected by the natural log.

In the estimation of equation (4.4), Filippini and Hunt (2011, 2012) extended the energy demand function to include a variable that will cater for the level of inefficiency, resulting in a stochastic demand frontier which can be denoted as;

$$q_i = \alpha_0 + \beta_1 p_i + \beta_3 y_i + \eta x_i + v_i + \mu_i \text{. ………………… (4.6)}$$

Where the term μ_i reflects the level of inefficiency and is half-normally distributed as $\mu_i \sim N^+(0, \sigma_u^2)$. The symmetric disturbance term (v_i) assumes its normal distribution

$v_i \sim N(0, \sigma_v^2)$ (zero mean and constant variance) and the estimation of equation (4.6) follows a maximum likelihood technique.

4.6 Inefficiency Effect Model for this Study

This study follows the efficiency effect stochastic frontier estimation technique (single-stage) proposed by Battese and Coelli (1995). This requires the introduction of determinants of inefficiency in the estimation process. This can be represented similarly as;

$$q_i = \alpha_0 + \beta_1 p_i + \beta_3 y_i + \eta x_i + v_i + \mu_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6),$$

where;

$$\mu_i \sim N^+ \left\{ \mathrm{f}(\mathrm{z}_i), \sigma_u^2 \right\} \quad \ldots\ldots\ldots\ldots\ldots (4.7)$$

From equation (4.7), $\mathrm{f}(\mathrm{z}_i)$ contains variables that explain the inefficiency of household electricity consumption such as the age of appliances, household head educational qualification and so on.

The prediction of household electricity consumption inefficiency follows the conditional inefficiency estimation technique proposed by Jondrow et al. (1982) as;

$$\hat{u} = E[\mathrm{u}_i \mid u_i + v_i] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

The level of efficiency can then be expressed as;

$$EF_i = \frac{E_i^F}{E_i} = \exp(-\hat{u}_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.10)$$

Where the observed level of electricity consumed by the household is given by E_i and E_i^F is the possible minimum energy consumption with respect to the electricity demand frontier. From the above estimation process, an efficiency value of one indicates a 100% efficiency whiles anything less than one indicates some level of inefficiency in the consumption of electricity.

4.7 Description of Variables and Source of Data.

This section describes the variables used in the estimation process. It begins by explaining the dependent variable which is the quantity of electricity consumed and proceeds with the explanation of the variables in the demand frontier. The next sub-section describes the variables for the inefficiency model and concludes with a brief description of the data source.

4.7.1 Description of Variables for the Demand Frontier

Electricity Consumption

Electricity consumption measures the monthly electricity consumed by a household in kilowatt – hours. The Ghana Living Standard Survey, Round Six (GLSS 6) data, however, did not record the quantity of electricity consumed by households. The data rather provided the annual monetary cost of electricity to households, and how frequently they paid their electricity bills. Average monthly expenditure on electricity was computed and various tariff rates for the various consumption tiers for households were applied to it to obtain the monthly electricity consumption. The tariff rates and fixed distributional cost for the period over which the data were collected were obtained from the Ghana Energy Commission (Energy Commission, 2017) and presented in Appendix 2.

Average Price

The treatment of electricity prices in the literature follows two approaches. Weyman-Jones et al. (2015) and Broadstock et al. (2016) indicated that, in a cross-sectional data, all consumers face the same marginal price of electricity (tariffs) as determined by regulatory bodies. In this regard, estimation of price effects in a regression model cannot be easily obtained. However, Ito (2014), indicated that households tend to be responsive to average prices due to inexplicable price setting and information barriers. This study therefore follows Filippini and Pachauri (2004) and Yu and Guo (2016), and the price effect is captured by using the average prices. This is computed as the total expenditure on electricity (cost) divided by the quantity of electricity consumed in kilowatt – hours and expected to have an inverse relationship with the quantity consumed. Thus, when the price of electricity increases, people may substitute other energy sources for it causing demand to fall. Secondly, an increase in the price of electricity will inversely impact the real income of consumers causing them to buy less.

Income

The impact of households' income on energy consumption has been extensively studied in the literature. This study follows the approach by Eakins (2016) and Broadstock et al. (2016), where the household expenditure is used as a substitute for household income. This is because household expenditures are mostly reported with accuracy compared to levels of income. A monthly income was obtained from the annual income of the household. Higher income levels are expected to be associated with more electricity consumption and vice versa. This is motivated by the findings of other researchers (Zaman et al., 2012; Weyman-Jones., 2015). Furthermore, the Office for National Statistics-United Kingdom (ONS-UK) (2013) indicated that higher incomes may be associated with more appliances that lead to higher electricity consumption

Household size

The fundamental assumption is that the larger a house is, the more energy they should consume. In the measurement of household size, most studies in the literature use the area of the house measured in meter squares or the number of people in the house (Twerefou, 2014; Ozbafli & Jenkins, 2015; Taaale & Kyeremeh, 2016; Yu & Guo, 2016; Boogen, 2017). This study, however, deviates from these studies and uses the number of rooms as a measure of household size. The impact of the number of rooms on electricity consumed has also been studied extensively (Tiwari, 2000; Leahy & Lyons, 2010; Brounen et al., 2012; Bedir et al. 2013). This is because, in most cases, it turns out that in rural communities in Ghana that have abundant land, a household may be having a very large compound that does not have any meaningful relationship with the demand for electricity. However, in cities that have scarce land, a small meter square of land could be associated with numerous rooms that significantly affect the demand for electricity. We, therefore, expect a positive relationship between this variable and the quantity of electricity consumed.

Appliance Ownership

This measures the ownership of electrical appliances by a household. This study uses eight household appliances namely air condition, fan, refrigerator, television, freezer, kettle, desktop and washing machine. A household that owns a particular functioning appliance is assigned a dummy value of one, while a household that does not own that appliance or owns the appliance but not functioning is assigned a dummy value of zero. This gives us eight dummy variables representing appliance ownership. It is expected that the ownership of an appliance will increase the consumption of electricity and hence a positive relationship.

Ecological Zone

Ecological zone is included in the demand function as a categorical variable labelled as (0 = Coastal zones; 1 = forest zone; 2 = savannah zone and 3 = GAMA[2]). This is motivated by the assumption that both weather conditions and access to energy fuels at the various ecological zones affect the choice of an energy fuel and hence levels of electricity consumption. The Coastal zones

[2] Greater Accra Metropolitan Area

serve as the basis of comparison and any other ecological zone can have either a positive or negative sign relative to the base.

4.7.2 Description of Determinants of Efficiency

Included as determinants of efficiency are; household head educational qualification, the age of household head, house ownership status, dwelling type and average years of appliances owned.

Education

This variable represents the educational level of household heads. This assumes that most electricity related expenditures and choices are catered for by the household head and hence his/her educational level will have a significant impact on efficiency. Thus, if he/she is more educated, he/she will be able to make choices between efficient and inefficient appliances as postulated by Broadstock et al. (2016). Similarly, higher education is expected to raise concerns for environmental quality and ways to remedy excessive emission. Regarding this, their choice of appliances may be affected by their concerns for the environment. Education is categorized as No Formal Education, Basic Education (kindergarten, primary, JHS and middle school), Secondary Education, and Post-Secondary Education (vocational, nursing, technical, teacher training, post-secondary diploma, Bachelor’s degree and post-graduate education). No Education serves as the basis of comparison and any other educational level can assume a positive or negative sign relative to the base.

Household Head Age

This is a continuous variable for the age of the household head of which the sign cannot be determined *a priori* the estimation.

House ownership

Included as an explanation for inefficiency is house ownership status, this measures whether the house is owned by a member of the family, rented or the individual is just perching/squatting[3]. This is a categorical variable labelled as (0 = owning; 1 = Renting; 2 = Perching). Renting and Perching are compared to owning and they can assume either a positive or negative sign relative to this base.

Dwelling type

Another categorical variable that is included as an efficiency variable is the dwelling type. This measures whether the house is a compound house or a private apartment (separate houses, semi-detached houses, flat apartments and huts on different compounds). It is labelled as; (0 = Compound house 1 = Private house; 2 = other houses). Private houses and other house types are compared to compound houses and the sign cannot be determined *a priori* the estimation.

Years of Appliances

Years of appliances measure the average years of appliances owned by the household. This assumes that, as the years of the appliance increases, it becomes less efficient. A limitation to this will be the high 'second hand[4]' appliance market prevalent in the nation. Even though some households might have reported holding an appliance for only a short while, the appliance might

[3] People living in abandoned buildings that they neither own or have rented.
[4] Appliances that are being offered for sale but are not new.

have changed several hands already, however, the value used in this study is the average years of all appliances owned by the household and assumed to be an appropriate proxy for this study.

4.7.3 Data Source

All the variables for this study are from the sixth round of the Ghana Living Standard Survey (GLSS 6). This is a secondary data sourced from the Ghana Statistical Service (GSS). The data is chosen for this study because it reports sufficient information on both appliance ownership, household electricity cost, socio-economic and demographic factors that are required for this study. The data has a large sample size (16,772 households) to aid a better analysis, robust results and effective policy recommendation. This study focuses only on households that have access to electricity and pay their electricity bills monthly. In the data, 9,501 households provided information on the duration within which they pay their electricity bills. Out of this, approximately 79% reported that they do their payment monthly. However, some values reported were extremely low that we lost them after the fixed electricity distribution service charges have been deducted from them. This caused us to have a sample size of 5,688 households that are used in this study.

4.8 Summary

This chapter has presented the theoretical and empirical framework used in this study. Further attention was paid to the source of data and the specific variables used. Brief descriptions and justifications for the choice of variables were also presented.

CHAPTER FIVE

EMPIRICAL RESULTS AND ANALYSIS

5.1 Introduction

This chapter begins by presenting an analysis of the variables used in the estimation process. Summaries, as well as cross tabulation results to explain the relationship between the variables, are also presented. The chapter continues by presenting an OLS regression results as a guide in the choice of appropriate variables for the frontier function estimated by Maximum Likelihood procedure. Diagnostic results confirming the choice of stochastic frontier function and maximum likelihood technique over OLS regression were further presented before the discussion of results from the stochastic demand frontier. The factors influencing the demand for electricity among households were discussed, followed by the average efficiency for households in the nation. The next section discusses the variables that affect inefficiency, and the chapter concludes with similar discussions peculiar to rural and urban households.

5.2 Descriptive Analysis of Data

Electricity Consumption

This study uses 5,688 households that have access to electricity and reported paying their electricity bills monthly. From the summary statistics (Table 5.1), the minimum and maximum monthly electricity consumption were approximately 1.547 kWh and 2501.96 kWh with an average of 100.6744 kWh. However, it is mostly the case that some households have either too low or too high monthly electricity consumption as evident in the data. This can be attributed to households that use electricity for small-scale businesses like corn milling, hairdressing and so on in the house. Other households that might have been away from home for a period would record too low consumption. Broadstock et al. (2016), for instance, handled this outlier issue by excluding

Table 5. 1 Summary Statistics of Variables

Variable	Average	Standard Deviation	Minimum	Maximum
Dependent Variable (Output variable)				
Electricity consumption	100.6744	125.6683	1.5474	2501.964
Variables for Demand Frontier (Input Variables)				
Income	840.8698	728.4859	30.8863	12493.44
Price	0.1729	0.0857	0.1281	1.1633
Location	0.6671	0.4713	0	1
House size	2.0557	1.522	1	16
Appliance Ownership:				
Air condition	0.0149	0.1211	0	1
Fan	0.6588	0.4742	0	1
Refrigerator	0.4434	0.4968	0	1
Television	0.7546	0.4303	0	1
Freezer	0.0842	0.2777	0	1
Kettle	0.0915	0.2883	0	1
Washing machine	0.0117	0.1075	0	1
Desktop computer	0.0765	0.2658	0	1
Ecological zones:				
Coastal zone	0.15683	0.3637	0	1
Forest zone	0.4656	0.4988	0	1
Savannah zone	0.2275	0.4193	0	1
GAMA	0.1500	0.3571	0	1
Variables for Inefficiency				
Household head age	44.2983	15.1881	15	99
Appliance years	3.6259	2.773	0	35
***Household Head Edu*.**				
No formal education	0.0092	0.0956	0	1
Basic Education	0.6440	0.4789	0	1
Secondary Education	0.1495	0.3566	0	1
Tertiary Education	0.1974	0.3980	0	1
Dwelling type:				
Compound house	0.7096	0.4540	0	1

Variable	Average	Standard Deviation	Minimum	Maximum
Private house	0.2750	0.4466	0	1
Others	0.0154	0.1231	0	1
House Ownership				
Owning	0.4036	0.4907	0	1
Renting	0.5923	0.4914	0	1
Perching	0.0041	0.0640	0	1

Source: Author's analysis from GLSS 6

all households that were part of the transitory migrant's population in China and constrained reasonable residential electricity consumption between 10 kWh and 1000 kWh. However, this study follows the approach by Yu and Guo (2016), and electricity consumption is winsorized at 5% level to reduce the weight of outlier values using Stata module Winsor.

Socio-Economic Factors

From Table 5.1, the average monthly household income for the sample was approximately Ghc 840.86 with a standard deviation of 728.49. Among the respondents, 0.92% of household heads have had no formal education. The majority (64.4%) of household heads have had some basic education, with secondary education scoring 14.95%. Tertiary education recorded a value of 19.74%. The age of household heads averaged 44.3 years with a standard deviation of 15.18 years

Locational Factors

The descriptive statistics further indicated that, approximately, 46.6% of households are in the forest zones with the coastal zone hosting 15.7%. Furthermore, 22.8% of the households were reported to stay at the savannah zones with the remaining 15% in the Greater Accra Metropolitan Area. The average household size measured by the number of rooms was obtained to be 2.056 with the minimum and maximum values of one and sixteen respectively. Rural-Urban distribution revealed that 66.71% of respondents reside in urban areas.

Appliance Ownership

In Table 5.1, 65.88% of households owned fans with only 1.49% owning air conditions. Regarding refrigerators, 44.34% of households were in possession of functioning refrigerators whiles only 8.42% reported to own freezers. The data revealed that 75.46% of households had functioning televisions with 9.2% and 1.2% in possession of electric kettles and washing machines respectively.

Furthermore, 48.27% of households owning air conditions were from the Greater Accra region with only 0.8% from Brong Ahafo. Even though the Greater Accra region scored the highest percentages in ownership of almost all assets, it lagged in Desktop computers with the Ashanti region taking the lead with 22.87%.

Additionally, dwellers of GAMA secured the highest place among the ecological zones in ownership of air condition. However, respondents of the forest zones remain the leaders in ownership of the remaining appliances (Figure 5.2b). It was also obtained that; urban households have the highest possession of all appliances (Figure 5.2a).

Regarding the years for appliances, a mean of 3.63 years with a standard deviation of 2.77 years was obtained.

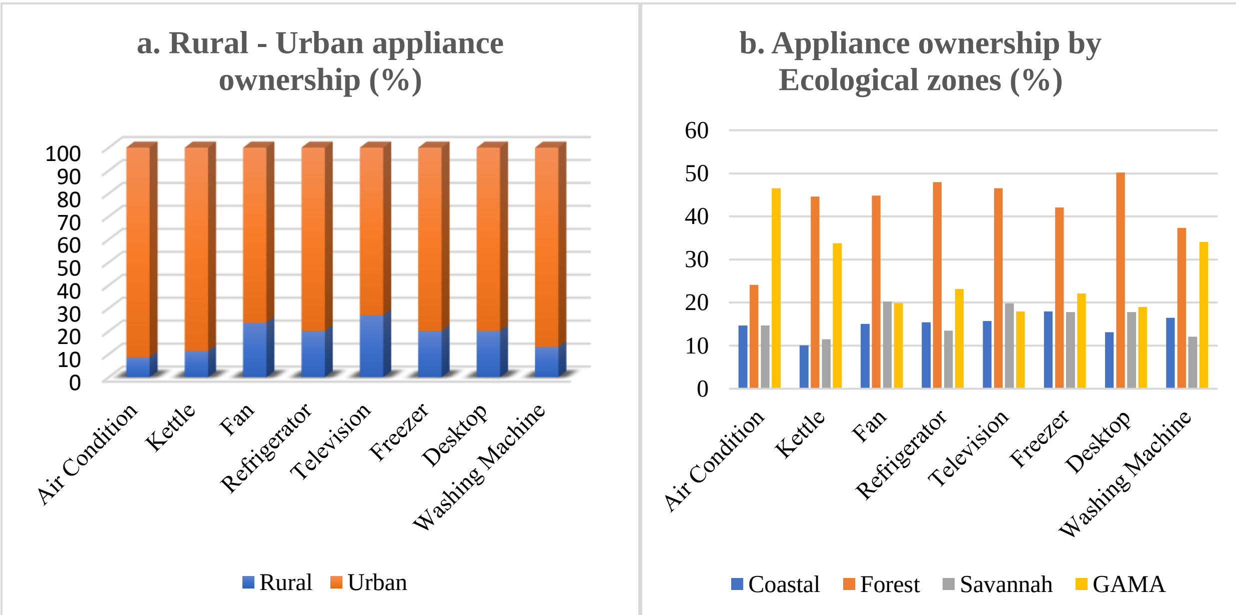

Figure 5. 1 Distribution of Appliance Ownership by Location and Ecological Zones (%)

Source: Author's analysis from GLSS 6

Average Price

The average price of electricity stood at approximately 0.173 Ghana Cedis per kilowatt-hour. This average tariff is similar to that reported by Adjei-Mantey (2013), as GHs 0.1818 per kWh for the Accra – Tema Metropolitan Area.

House ownership and dwelling type

It was further discovered that 40.36% of houses were inhabited by their owners whiles 59.23% of households are living in rented apartments. Some 0.41% of individuals reported to be perching or squatting. Similarly, 70.96% of households were reported to reside in compound houses whiles 27.5% were lodging in private houses. Other accommodation types hosted only 1.54% of the respondents.

5.3 Ordinary Least Squares Results

Estimation of the energy demand frontier begins with the OLS technique. This aids in the choice of appropriate variables that explains the demand for electricity.

Table 5. 2 Ordinary Least Squares Results

Variable	Coefficient	Standard Error
Income	0.1038***	0.0079
Price	-0.8032***	0.0163
Location	0.0639***	0.0104
House size	0.0396***	0.0033
***Ecological zone**:*		
Forest zone	-0.0370***	0.0128
Savannah zone	-0.0722***	0.0147
GAMA	0.0610***	0.0164
(Reference: Coastal Zone)		
Appliance Ownership:		
Air condition	0.1355***	0.0380
Fan	0.0387***	0.0113
Refrigerator	0.1209***	0.0106
Television	0.0192	0.0122
Freezer	0.0823***	0.0166
Kettle	0.0476***	0.0163
Desktop computers	0.0342**	0.0169
Washing machines	0.0846**	0.0422
Constant	1.0747***	0.0539
R^2	**0.8076**	
F (18, 5669)	**1811.86*** **	
N	**5688**	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*
Source: Author's computation from GLSS 6

Further diagnostics tests required for the modeling of a stochastic frontier were also conducted. The results from the OLS estimation is presented in Table 5.2. The high adjusted R^2 (0.8076) indicates an appreciable joint explanation of the demand for electricity by the selected variables. Thus, approximately 80.7% of the variation in the demand for electricity is jointly explained by the selected independent variables. As a requirement for modeling a stochastic frontier function, the error term of the OLS estimation must be both heteroskedastic and skewed. This was confirmed by the Breusch-Pagan and Cameron & Trivedi's test for heteroskedasticity and skewness respectively and the results are displayed in Appendix 3a and 3b respectively. A further Variance Inflation Factor (VIF) test for the presence of multicollinearity in the explanatory variables reported the opposite.

The sign of most of the variables does not deviate from what was expected a *priori*. In conformity to economic theory, the average price has an inverse relationship with demand whiles income satisfied a significant positive elasticity. Ownership of any of the appliances indicated an increase in the consumption of electricity as expected, likewise the number of rooms in the house.

Because OLS estimation technique does not in itself model inefficiency unless a two-stage Modified or Corrected OLS is run or implemented, less attention is paid to the explanation of its results. Moreover, the likelihood ratio test favored the stochastic frontier approach over the OLS technique as explained in the next sub-section (Diagnostic Test Results) and represented in Appendix 4

5.4 Diagnostic Test Results

The presence or absence of inefficiency in a stochastic frontier model can be determined by the value of lambda (λ). The model reduces to a simple OLS if λ equals zero and vice versa.

Waldman (1982), affirmed that in a normal – half normal stochastic production/cost function, the value of λ provides a useful self-diagnostic for the model specification.

In Table 5.3, the presence of inefficiency in the consumption of electricity among households is indicated by the non-zero value of lambda (λ), which is approximately 1.87. The results indicate that the standard deviations of the two error components are 0.256 and 0.4782 for the idiosyncratic and inefficiency component respectively with a joint variance of approximately 0.294.

The test of the null hypothesis of no inefficiency ($H_0 : \sigma_u = 0$) against the alternative for the presence of inefficiency ($H_a : \sigma_u > 0$) was also rejected. This affirms the choice of stochastic modeling to be estimated by a Maximum Likelihood over an OLS modeling. Further details on the results of the diagnostics are presented in Appendix 4

5.5 Discussion of Results from Stochastic Demand Function

The results in Table 5.3 indicate that the responsiveness of changes in income to the demand for electricity is approximately 0.112. This positive responsiveness can be attributed to the ownership of more appliances by households as their income rises. The figure in Appendix 5, shows the distribution of appliance ownership by various income quantiles. It is obvious, as expected that, households that fall in the fourth quantile owned the highest number of all appliances, and it follows in that order from the third down to the first. This indicates that higher income households buy more appliances and tend to consume more electricity. However, the smaller magnitude (0.112) indicates that the income elasticity is inelastic. This means that a percentage rise in income causes a less than proportionate rise in demand for electricity since it mostly works indirectly through the procurement of new electrical appliances. In Singapore, Loi and Le (2018), also reported that the influence of income on electricity consumption is relatively negligible.

Table 5. 3 Results of Stochastic Demand Frontier Function

Variable	Coefficient	Standard Error
Income elasticity	0.1117***	0.0097
Price elasticity	-0.7378***	0.0237969
Location	0.0839***	0.0126
House size	0.0249***	0.0044
Ecological zone:		
Forest zone	-0.0342**	0.0147
Savannah zone	-0.0495***	0.0182
GAMA	0.0531***	0.0182
Appliances:		
Air condition	0.0909**	0.0411
Fan	0.0454***	0.0133
Refrigerator	0.1020***	0.0114
Television	0.0339**	0.0174
Freezer	0.0671***	0.0182
Kettle	0.0423**	0.0172
Desktop	0.0231	0.0178
Washing machine	0.0521	0.0464
Constant	0.8051***	0.0726
N	5688	
Log Likelihood Value	**-2698.35**	-
σ_v	0.2560	.0082
σ_u	0.4782	.0147
$\sigma^2 = \sigma_v^2 + \sigma_u^2$	0.2942	.0106
λ	1.868	.0222
Mean Efficiency	**0.7099**	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*
Source: Author's computation from GLSS 6

This finding is supported by the ONS-UK (2013) report, which indicated that higher incomes may be associated with more appliances that will lead to higher electricity consumption. The result also supports the findings of Zaman et al. (2012) that there exists a positive relationship between electricity consumption and income. In Portugal, Weyman-Jones et al. (2015) equally affirmed a strong positive relationship between electricity consumption and income. The significantly positive impact of income on the consumption of electricity found by Adom (2011) and Mensah et al. (2016) at the national level in Ghana is also confirmed at the household level in this study. This indicates that, in Ghana, the findings by Urban and Ščasný (2012), that, as people's income increases, they are more likely to invest in smart home appliances, leading to less electricity consumption is not fully supported. This in any way does not nullify the assumption that higher income homes will be associated with more efficient and smart appliances. However, the increase in the ownership of appliances as income increases and hence more electricity consumption may tend to offset the electricity savings from efficient appliances.

This indicates that, as the marginal cost of operating electrical appliances decrease, due to the expected cost savings from efficient appliances, households tend to consume more electricity due to the increase in the purchase of appliances. Thus, the increase in income, accompanied by reducing marginal cost leads to less attention to electricity savings and conservation. For instance, studies by Thogersen and Gronhoj (2010), Martinsson et al. (2011), Sahin & Koksal, (2014), reported a negative relationship between income and energy conservation.

The price elasticity of electricity consumption stands at -0.7378, inversely related to demand. This inverse relationship does not deviate from economic theory. Similarly, among Indian urban households, Singh et al. (2018) found the price elasticity to be -0.72. A significant negative relationship was also reported by Al-Bajjali and Shamayleh (2018) for the economy of Jordan. Studies by Filippini and Hunt (2012), also indicated that, in the USA, demand for energy is price inelastic which the results from this study supports (elasticity value of -0.7378). Similarly, Loi and

Le (2018), indicated that in Singapore, the responsiveness of households to electricity price changes is low with the potential of price elasticity decreasing as income rises. This can be attributed to the fact that, due to the recent technological advancements, most homes have become 'technology homes.' Most household activities are dependent on electrical appliances, making households less responsive to changes in electricity prices. Perhaps, this has made electricity almost a necessity among households. For instance, in China, Yu and Guo (2016) indicated that the ineffectiveness of price policies in achieving energy conservation is because energy is almost a necessity since it is used in satisfying basic needs like lighting and cooking in homes.

The ownership of various appliances exhibited a positive relationship with the demand for electricity. This does not deviate from other empirical findings (Nielsen 1993; Leahy & Lyons, 2010; Zhou & Teng, 2013; Singh et al., 2018). Among the appliances, refrigerators tend to have the highest magnitude of 10.2%. This can be attributed to the fact that refrigerators are major electricity consuming appliance in their capacity just like air conditioners and freezers. However, just like freezers and unlike air conditioners, they operate a full day. Even though freezers equally operate entire day in most homes, approximately only 8.42% of the respondents reported owning a functioning freezer, compared to 75.46% for refrigerators. Desktop computers and washing machines tend not to have significant coefficients. This means there is no significant difference in the consumption of electricity between households that own these assets and households that do not own them. In the case of desktop computers, this can be attributed to their negligible power usage compared to other appliances.

Ecologically, respondents in the forest zones and savannah zones turn to respectively consume 3.42% and 4.95% less electricity compared to the coastal dwellers. Even though this can be attributed to the easy access to wood fuel that the forest zone households mostly use for heat generation compared to those in the coastal areas as reflected by the data. Thus, approximately 72.13% of households in the forest zones use wood as their main fuel for cooking compared to 65.87% in the coastal zones. There is, however, no evidence that more coastal dwellers use electricity for cooking compared to the forest folks. In terms of ownership of electrical appliances, less percentage of the coastal citizens own all the appliances compared to the forest zone citizens (Figure 5.2b). This calls for the need for thorough research to investigate the key determinants of energy consumption among the Coastal folks. The leading ownership of almost all electrical appliances by residents of GAMA can be cited as a reason for its higher electricity consumption compared to the coastal dwellers.

The results further indicate that the addition of one more room to a house raises the demand for electricity by approximately 2.488%. This positive relationship is consistent with what was expected and supports the results of other researchers (Tiwari, 2000; Leahy & Lyons, 2010; Bedir et al. 2013). However, the magnitude found for Ghana tends to be smaller compared to the results of Tiwari (2000) who reported an 11% rise in electricity consumption resulting from a unit increase in rooms among households in India.

Finally, it was obtained that, the demand for electricity is approximately 8.4% higher among urban households compared to rural households. The higher proportion of appliance ownership among urban households (Figure 5.2b) can be cited as the prime reason for this result. Secondly, Carvalho (2016), reported that there seem to be fuel switches as people move from rural areas to an urban area. Thus, as people move from rural areas, they tend to use more electricity for household activities compared to other energy fuels. In Ghana, the positive relationship between urbanization and electricity consumption found by Adom (2011) and Mensah et al. (2016) is also supported by the results of this study.

5.6 Mean Efficiency

The mean efficiency presented in Table 5.3 is approximately 70.99% for Ghanaian households. This indicates an immense potential for electricity energy saving via efficiency measures. The inefficiency level of approximately 29% does not deviate from the estimated 30% wastage at the end-user as indicated by the Ministry of Energy (2010). This efficiency value (70.99%) also compares well to the values found by other researchers in different countries. Yu and Guo (2016) and Weyman-Jones et al. (2015), found higher efficiencies of 93% and 96.9% respectively. Among the 27 EU member states studied by Filippini and Hunt (2011), an average value of 83% was obtained. However, others like Broadstock et al. (2016), found a lower value of 63% for the Chinese economy. These indicate that the value obtained for Ghana is reliable.

5.7 Determinants of Electricity Consumption Efficiency

The results of the relationship between the inefficiency component and its determinants as obtained from the efficiency effect frontier model are presented in Table 5.4. It must be noted that the dependent variable is inefficiency and hence a negative coefficient indicates improvement in efficiency.

One of the most studied efficiency related variables is education. The basic expectation is that an increase in the levels of education will have an inverse relationship with inefficiency. In this study, level of education tends to have a negative relationship with inefficiency but insignificant. This means there are no significant differences in electricity consumption efficiency between the educated and the non-educated.

Related studies have found both direct and indirect relationship between education and demand for electricity. Ürge-Vorsatz and Hauff (2001) and Poortinga et al. (2004), indicated that the educational level of people positively influences their adoption of efficient measures and technologies. Like this, Prete et al. (2017), affirmed that there exists a positive relationship between the level of education and intention to adopt energy efficiency measures in Southern Italian households.

Table 5. 4 Results of Inefficiency Equation

Variable	Coefficient	Standard Error
Household Head Qualification		
Basic education	-0.2959	0.2871
Secondary education	-0.2197	0.2931
Tertiary education	-0.0217	0.2901
(Reference: No Education)		
Household Head age	0.0041*	0.0023
Years of appliance	0.0263**	0.0103
House Ownership		
Renting	-0.2134***	0.0597
Perching	-0.9782	0.6299
(Reference: Owning the House)		
Dwelling type		
Private House	0.4025***	0.0609
Other Houses	0.3620*	0.2119
(Reference: Compound Houses)		
Constant	-1.6368***	0.3151
N	5688	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*
Source: Author's computation from GLSS 6

Similarly, Kavousian et al. (2015) reported a positive relationship between higher levels of education (advanced degree) and the levels of household electricity consumption efficiency. Yu and Gua (2016), however, indicated that the relationship between education and energy consumption is ambiguous. This is because, though it can work directly through the adoption of efficiency measures to reduce electricity demand, it does work indirectly through higher incomes associated with higher education to increase electricity consumption.

Another most studied efficiency related variable is age. The results indicate a significant positive relationship between age and inefficiency. Even though the coefficient appears to be negligible in magnitude (0.00406), it gives an appreciable relationship between the two variables.

This relationship supports the report by Mahapatra and Guastavsson (2008), that, the aged are less likely to adopt energy efficient technologies. From Prete et al. (2017), elderly people in Southern Italy are less likely to adopt efficient technologies. Among Greece households, Sardianou (2007), reported an inverse relationship between age and number of energy saving measures undertaking.

This means that as people age, they turn to reduce their adoption of energy saving measures. The positive but weak relationship found by Hori et al. (2013) between age and efficiency can be attributed to concerns for electricity bills since incomes decline during retirement.

The impact of the years of appliances on efficiency is less studied in the literature. In this study, an increase in years of appliances is associated with higher levels of inefficiency. This is not different from what was expected *a priori* the study. The implication of this relationship is that significant electricity can be saved via efficiency if attention is paid to the 'used market' for appliances. The influx of second-hand appliances on the market has the tendency of retarding efficiency results expected by policymakers when enacting efficiency policies. Related to this is that, most of the aged appliances are less efficient ones purchased years before the enforcement of efficiency measures (energy stars)[5]. Even though the government has over the years tried to reduce

[5] This is a one-star to five-star energy efficiency rating affixed on electrical appliances to indicate their level of efficiency. Higher number of stars indicates higher efficiency.

the owning of less efficient appliances by letting people submit them for more efficient ones, the data indicates that, approximately, 68.4% of households are owning appliances aged over nine years on average. These old appliances are negatively affecting efficiency. For instance, among Indian urban households, Singh et al. (2018) indicated that all other things being equal, electricity consumption by air conditioners could be reduced by 15% if air conditioners used for over seven years are replaced with new and efficient ones.

Regarding house ownership, it appears that tenants tend to be more efficient in their consumption of electricity compared to households that own their apartment. This finding, however, deviates from the findings of Kavousian et al. (2015), who reported that ownership of a residence in Ireland, averagely is associated with more efficiency. They attributed this to the possibly increased number of retrofits and other energy efficient measures enacted by such households. In Denmark, Baldini et al. (2018), reported that dwellers of apartments that are mostly rented out have a lower likelihood of choosing energy efficient appliances because tenants are less sensitive to energy efficiency investments because of the short duration of their stay.

However, in Ghana, this is not reflected in the results. Even though tenancy can be related to lower levels of income which will affect demand negatively, the successive complains from some landlords when tenants fail to switch off electrical gadgets like electric bulbs, when not in use can indirectly inculcate the habit of energy saving among tenants. This will mean that people tend to be responsive when there is a kind of supervision on them.

However, more to this is the cost burden on tenants to pay diverse bills which further reduces their real income and hence tend to be more conservative. Individuals in their own apartments and landlords, however, do not bear housing cost.

Concerning dwelling types, households in private apartments are less efficient compared to those in compound houses. This again can be attributed to the self-monitoring behavior among households dwelling in compound houses. It is mostly the case that, dwellers of such houses share the same electricity rating meter and the bills are distributed among themselves at the end of the month. This leads to a self-monitoring attitude among them, which eventually improves their conservation and efficiency. Secondly, there is a spillover effect due to shared facilities like electric bulbs.

This indicates the enormous contribution that individuals can make towards efficiency and energy savings. By constantly reminding ourselves of the need to conserve energy, we can achieve remarkable success. Kavousian et al. (2015), reported that in Ireland, not being able to encourage other residents to save energy was negatively correlated with efficiency scores. Energy savings and conservation should not be viewed as a trajectory of the poor who cannot afford to pay their electricity bills but an effective means of protecting our environment.

5.8 Results from Rural and Urban Analysis

As a follow up to the demand frontier and efficiency distribution for Ghana, we further estimate frontier and efficiency effect functions differently for rural and urban households. This will help us to know the factors that significantly influence the demand for electricity among dwellers of these individual locations to aid policy implementation. This will also help us to know the level of efficiency that exists in the two separate locations and how the selected variables impact it. The ideal notion of deriving the efficiency for each location by averaging their already predicted efficiencies is refuted. This is because, in the overall estimation, frontier estimates only one variance for the inefficiency term which is not unique to any location. The average efficiency value obtained for each location will be with reference to the group-specific frontier. Thus, the aim is not to compare the efficiency level between rural and urban dwellers due to possible structural heterogeneities, but for instance, if we study an average urban household, how efficient is it compared to another urban dweller that defines the demand frontier (best practice). This is in adherence to the caution by Broadstock et al. (2016), not to directly compare households from separate locations in measuring their electricity consumption efficiency.

5.8.1 Results from Rural and Urban Stochastic Demand Frontiers

The results from the demand frontier for each location is represented in Table 5.5. A closer look at the results in Table 5.5 indicates that the income elasticity of electricity demand is higher (0.1292) among urban households compared to rural households (0.0641)

This result is not surprising since the income levels of urban dwellers are mostly higher than that of rural dwellers. This means they tend to spend more on electricity via the purchase of new appliances as their incomes increase compared to rural dwellers.

However, rural households tend to be more responsive (a little above unit elasticity) to price changes compared to urban households. This could be attributed to several factors. Firstly, income levels among rural folks are relatively low compared to the urban dwellers, it may be that this causes them to be very sensitive to price changes since it has much impact on their real income.

Secondly, rural dwellers usually resort to cheap fuels like kerosene and wood fuels to undertake basic activities like cooking and lighting in the house. This makes them very responsive to electricity price changes. Urban households, on the other hand mostly prefer to use Liquefied petroleum gas (LPG) and electricity for their daily activities. This makes them less responsive to electricity price changes. They are mainly ‘technology homes’ of which electricity has almost become a necessity.

Table 5. 5 Stochastic Demand Frontier Results for Rural and Urban Locations

	Rural Households		Urban Households	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Income Elast.	0.0641***	0.0169	0.1292***	0.0116
Price Elast.	-1.0014***	0.0421	-0.4331***	0.0461
House size	0.0065	0.0067	0.0324***	0.0056
Ecolog. zone:				
Forest zone	-0.0174	0.0240	-0.0231	0.0181
Savannah zone	.00082	0.0291	-0.0590**	0.0227
GAMA	-	-	0.06375**	0.0202
(Coastal Zone)				
Appliances:				
Air condition	0.3315**	0.1479	0.0868**	0.0427
Fan	0.0263	0.0120	0.0516**	0.0170
Refrigerator	0.0612**	0.0195	0.1056***	0.0138
Television	0.0223	0.0268	0.0311	0.0219
Freezer	0.0484	0.0345	0.0842***	0.0207
Kettle	0.0407	0.0454	0.0316*	0.0186
Desktop comp.	0.0351	0.0372	0.0194	0.0199
Washing mach.	0.2461*	0.1394	0.0157	0.0492
Constant	0.6429***	0.1189	1.404***	0.1368
LLV	**-646.41**		**-1956.10**	
N	**1520**		**4168**	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*
NB: The references for categorical variables are put in parenthesis
LLV = Log Likelihood Value
N = Number of Observations
Source: Author's computation from GLSS 6

It is also evident that most appliances are not significant determinants of demand for electricity among rural households, but they are, among urban households. This is because most of the appliances are concentrated in the urban areas with some rural dwellers totally not having most of the appliances.

5.8.2 Rural and Urban Inefficiency Results

This sub-section presents the results from the relationship between inefficiency and its determinants for rural and urban households in Table 5.6.

From Table 5.6, a mean efficiency of 67% and 78.5% were obtained for rural and urban households respectively. The significant variables leading to inefficiency are not far different from the previous discussion.

Table 5. 6 Results from Inefficiency Equation for Rural and Urban Households

	Rural Households		**Urban Households**	
Variable	**Coefficient**	**Standard Error**	**Coefficient**	**Standard Error**
Education				
Basic Edu.	0.4183	0.6100	-0.4919	0.4519
Secondary Edu.	0.6163	0.6204	-0.5394	0.4909
Tertiary Edu.	0.6026	0.6174	-0.1569	0.4350
(No Education)				
H. Head Age	0.0042	0.0035	0.0059	0.0039
Year of App.	0.0337**	0.0167	0.0242	0.0174
H. Ownership				
Renting	-0.1546*	0.0915	-0.3508***	0.1098
Perching	0.6202	0.8776	-6.504	15.2618
(Owning House)				
Dwelling type				
Private House	0.3204***	0.0925	0.5886***	0.1871
Other Houses	0.7103	0.4468	0.4277	0.3554
(Compound H.)				
Constant	-1.900***	0.6446	-2.2291***	0.6029
N	**1520**		**4168**	
Mean Eff.	**0.6700**		**0.7848**	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*
NB: The references for categorical variables are put in parenthesis
N = Number of observations
Source: Author's computation from GLSS 6

However, a notable difference is in relation to the significance of the impact of years of appliances on inefficiency. The results indicate that the years of appliances does not lead to a significant increase in inefficiency among urban households, however, it has a significant impact on rural households' electricity consumption efficiency. This means the higher patronization of used appliances by rural households is having a significant impact on their efficiency in the consumption of electricity.

This could be because of limited income to patronize new and efficient appliances. An improvement in their income can help improve their efficiency. Furthermore, limited information on the benefits of replacing inefficient appliances will be a factor.

5.9 Summary

The chapter has presented summaries and cross-tabulations of the variables used in this study. Discussion of regression results from both OLS and stochastic demand frontiers were also presented in the chapter. The chapter further presented a discussion of the average efficiency of electricity consumption and its determinants for households in Ghana. Finally, a disaggregated estimation of demand frontiers for rural and urban areas were carried out with the results discussed.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter concludes the study by providing a summary of the key findings. It further presents some policy recommendations, limitations of the study and recommendations for future research

6.2 Summary and Conclusions

Ghana has over the years been plagued with incidences of electric power outages. This causes citizens to subsequently demand an increase in the supply of electricity by policymakers. In response to this, past governments have increased the installation of thermal plants to augment the limited supply from the Akosombo Dam. This inadequate supply can partly be attributed to the increase in connections to the national grid and numerous supply-side shocks like inadequate rainfall. The installation of these power plants, however, come with their own challenges. In some instances, the required gas or crude oil to power them are limited in supply, not forgetting of their adverse impact on environmental quality. Even though the nation has a promising opportunity to scope much power from renewable energy sources like solar and wind, it is less tapped. This makes the supply side to be less diversified, and more volatile to changes in rainfall patterns and crude oil prices.

Aside from the supply side responses carried out by policymakers in Ghana, there have also been considerable demand-side measures put in place. The nation has implemented the efficiency labeling policy, replacement of incandescent bulbs with Compact Fluorescent Light (CFL) bulbs and several other legislative measures to discourage the production, importation and sale of inefficient appliances on the domestic market. Energy efficiency measures have been discussed internationally and identified as a cost-effective means of ensuring energy security and reducing carbon dioxide emissions. Thus, if what is produced is used efficiently, resources could be channeled from further production to other sectors of the economy, and there will be environmental benefits too.

Irrespective of the numerous efficiency-related measures undertaking in Ghana, little attempt has been made to estimate empirically the level of efficiency in the consumption of electricity among households. Against this backdrop sprung the motivation to investigate empirically how efficient Ghanaian households have been in their consumption of electricity. The study aimed at identifying the factors that influence the demand for electricity among households and their average efficiency. Furthermore, it sorted to identify the determinants of inefficiency among households in their consumption of electricity. This study is deemed important as the nation hopes to achieve nationwide coverage of electricity accessibility by 2020. With the expansion of access to electricity, the demand is expected to be high and intuitively, more investment will be required in production. However, if inefficiency issues are dealt with, there can be considerable electricity savings.

The second chapter of this study presented a brief overview of the electricity sub-sector in Ghana. It was obtained that, from the years 2007 to 2014, electricity generation from hydro sources outweighed supply from thermal sources. However, due to supply-side shocks such as inadequate rainfall, coupled with the subsequent increase in the installation of thermal plants, total generation from thermal sources was more than total generation from hydro sources in the years 2015 and 2016. The total generation from renewable sources constitutes a negligible proportion of total electricity produced in the nation. Trade in electricity has contributed significantly to the foreign reserve of the nation due to the negative imports experienced between 2008 and 2015. The two end periods (2007 and 2016), however, presented the nation with positive imports. Though production is carried out by VRA and IPP, the transmission is by GRIDCo, whiles mass distribution to households rely on ECG and NEDCo. Regulation of the electricity sector is shouldered by three main bodies; the Ministry of Energy, the Ghana Energy Commission (EC) and the Public Utilities Regulatory Commission (PURC).

The study proceeded by reviewing several kinds of literature in energy economics and efficiency measurement. A brief introduction to the evolution of empirical studies of energy economics was followed by the two main approaches to efficiency measurement. It was obtained that, initial studies of energy economics followed the trend of classical economics, with little attention to efficiency measurement. However, following the measurement of efficiency in production, energy and resource economist started a methodical study of efficiency in their field. Both the DEA under non-parametric approach and SFA under parametric approaches to the measurement of efficiency have been extensively employed in the field. Both approaches, however, have their peculiar strengths and weaknesses. The challenge and complexity of modeling and imposing a structural restriction when using the SFA method is complemented by its intrinsic ability to separate the idiosyncratic error term from the inefficiency term. The DEA approach, however, treats all deviations as a measure of inefficiency. Explanations of key terms like energy efficiency, energy conservation and the energy rebound effect, were further dealt with. Regarding empirical findings, several studies were reviewed, and the results were grouped under four main themes: determinants of demand for electricity, measurement of electricity consumption efficiency, determinants of electricity consumption efficiency and barriers to reducing electricity consumption and efficiency improvement.

The theoretical framework and methodology used in this study follow from the microeconomics theory of production. In a stochastic demand frontier, the household is assumed to have a required electricity consumption, as determined by the frontier. This is based on factors like income, appliance ownership and other demographic factors. Frontier fits the boundary based on the best practice among the group. Deviations from this best practice give a measure of inefficiency and the SFA introduced by Aigner et al. (1977), helps to measure this deviation. This study adopted the energy demand frontier by Filippini and Hunt (2011) and drew partly on the modified version by Broadstock et al. (2016). Estimation of the stochastic demand frontier follows a Maximum Likelihood approach rather than OLS estimation technique. However, to aid in the choice of appropriate variables, an OLS estimation was conducted, but less attention was paid to explaining its results.

Prediction of inefficiency from the stochastic demand frontier followed the conditional inefficiency estimation approach by Jondrow et al. (1982) and a half normal distribution assumed. Among the two main functional forms mostly used in efficiency analysis, the Cobb Douglas functional form was used in conformity with many kinds of literature in the field. It is also flexible and easy to interpret its results. Furthermore, rather than conducting a two-stage estimation, this study followed the single stage approach by Battese and Coelli (1995). The study used a secondary data from the Ghana Statistical Service (GSS); the sixth round of the Ghana Living Standard Survey (GLSS 6). Attention was however paid to households that reported to have access to electricity and pays their electricity bills monthly.

Analysis of the data revealed that among the appliances, 65.88% of households owned a fan with the least appliance owned being washing machines (1.2%). Most households (59.23%), reside in rented apartments with house ownership constituting 40.36%.

Diagnostic test carried out favored the Maximum likelihood estimation of a stochastic demand frontier against OLS estimation technique.

In satisfying the first objective of the study, the results indicated significant negative price and positive income elasticities of -0.738 and 0.112 respectively. It was further obtained that ownership of all the appliances studied positively affect the demand for electricity, except desktops and washing machines which had insignificant coefficients. Increase in the number of rooms in a house appeared to have a positive relationship with the demand for electricity, with urban households consuming more electricity than rural households in Ghana.

Regarding the second objective, it was empirically realized that the average efficiency of electricity consumption among Ghanaian households is approximately 71%. This indicates an immense potential to save energy via efficiency measures. A disaggregated frontier estimation, individually for rural and urban households revealed an average efficiency of approximately 67% and 78% for rural and urban households respectively.

Finally, in satisfying the third objective of the study, the analysis revealed that an increase in years of household appliances has a significant impact on the level of inefficiency. It was also obtained that the level of household head education does not have a significant impact on inefficiency. Thus, there is no significant difference in electricity consumption efficiency between the educated and the non-educated in Ghana. However, the age of household head, dwelling type and house ownership status have a considerable influence on inefficiency.

6.3 Policy Recommendations

Following the findings of this study, we have realized an enormous opportunity for energy saving through efficiency means, therefore, we make the following policy recommendations to help realize this opportunity.

Firstly, it appears that there is still a sizable proportion of households owning relatively old appliances that are significantly reducing their efficiency in the consumption of electricity. We therefore recommend to policymakers to ensure that, they get rid of the vast 'used appliance' (second hand) market in the nation. Sellers in this market should be educated on the negative impact their activities are having on the economy. Necessary task forces should be deployed to ensure that this market is discouraged in the country. However, this must be done after putting in place measures like education of buyers to discouraged them from patronizing from this market.

They should provide sufficient incentives to households to turn in their old appliances for new ones. For example, sharing with households financial savings from owning efficient appliances can motivate them to obtain efficient appliances. Furthermore, bringing these appliances closer to them will serve as an incentive.

There is also the need to invest more in educating the public on the need for patronizing efficient appliances. They should be made to understand that, the lifetime cost of operating an inefficient appliance is way higher than operating and efficient one. They should, therefore, consider the lifetime cost of operating the appliance rather than only considering the purchasing price. Some achieved successes from these measures can be shared to encourage consumers. Furthermore, the development of simple web-pages and mobile apps that help individuals to calculate the life-cycle cost of operating an appliance could influence their appliance purchase process which may significantly impact efficiency as suggested by Blasch, et al. (2017). A substantial investment in educating citizens on the meaning of the efficiency stars on appliances and the need to consider them at the time of purchases will also yield considerable results.

Inferring from the fact that, we obtained a higher price elasticity for rural households compared to urban households, we recommend that electricity price discrimination should be considered. The rural dwellers that are more responsive to price changes should be made to pay lower tariffs to reduce their dependence on environmentally harmful fuels. These people are poor and are to benefit from the 'lifeline' initiative introduced as part of the Government of Ghana's Poverty Reduction Strategy (GPRS). This can also help electricity producers to recoup their cost to an extent since the less responsive urban households who consume a greater proportion of electricity will be paying a higher tariff. A similar policy for energy price discrimination was offered by Inglesi-Lotz and Puris (2012) when they found out that blanket pricing structure in the energy sector was likely to affect the industrial structure and foreign direct investment in South Africa.

Attention should also be paid to the development of rural markets to ensure that they can easily have access to efficient appliances at subsidized prices. This will motivate them to discard the patronize and use of old inefficient appliances. This must equally be supported with intense education for the rural folks since the literacy rate among them is usually lower, compared to urban dwellers.

6.4 Limitations of the Study

Limitations of this study mainly come from the limited variables provided by the data. This is because there are other key factors that can equally affect the demand and efficiency of electricity consumption which are not included in this study. For example, with the mass installation of prepaid electricity rating meters in the country for the past few years, readers of this study will be curious to know the impact of this policy on efficiency. However, such information on meter types was missing from the dataset. Furthermore, information on the recent efficiency star policies introduced in the nation is worth studying to identify their contribution to electricity saving in the nation. However, we were again restrained by data. Finally, we admit that the use of sufficiently collected panel data will yield better results for a well-informing policy. This is because a panel data analysis will help to identify both transient and persistent sources of inefficiency to enable policymakers to address it well.

6.5 Recommendations for Future Studies

Following from the findings of this study and its limitations, we recommend that funds should be made available for the collection of sufficient data for a thorough study of the topic. We also recommend that the study should not be limited to only household consumers but should be extended to the industrial and service sectors of the economy. This is because an empirical estimate of their efficiencies will be of much help to policymakers in their decision making. Furthermore, we recommend studies of this nature to be conducted periodically. This will help assess any changes in the efficiency levels over time.

6.6 Summary

To this end, the set objectives of this study have been achieved with the help of a stochastic demand frontier and a secondary data from the Ghana Statistical Service. It can be concluded that there exists some appreciable opportunity to save electricity energy through efficiency measures. Sufficient policy recommendations, limitations and recommendations for future research have also been provided in this concluding chapter.

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APPENDIX

Appendix 1. Electricity Generation by Sources in Ghana (2007 – 2016)

Plant/Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Hydro Generation :										
Akosombo	3,104	5,254	5,842	5,961	6,495	6,950	6,727	6,509	4,156	3,854
Kpong	623	941	1,035	1,035	1,066	1,121	1,144	1,148	819	763
Bui	-	-	-	-	-	-	362	730	870	944
Sub-Total	***3,727***	***6,195***	***6,877***	***6,996***	***7,561***	***8,071***	***8,233***	***8,387***	***5,845***	***5,561***
Thermal Generation:										
Takoradi Power Company (TAPCO)	1,521	874	453	1,234	1,137	1,061	1,783	890	1,784	1,204
Takoradi International Company (TICO)	1,417	1,063	1,040	1,160	657	1,168	1,032	712	1,336	1,926
Tema Thermal 1 Power Plant (TT1PP	-	-	570	591	559	622	475	697	541	178
Tema Reserve Power Plant (TRPP)	162	85	-	-	-	-	-	-	-	-
Emergency Reserve Power Plant (ERPP)	80	45	-	-	-	-	-	-	-	-
Kumasi Reserve Power Plant (KRPP)	33	16	-	-	-	-	-	-	-	-
Mines Reserve Plant (MRP)	38	46	18	20	12	20	-	195	170	3
Tema Thermal 2 Power Plant (TT2PP)	-	-	-	28	50	141	94	223	216	25
Sunon Asogli Power (Ghana) Ltd (SAPP)	-	-	-	138	1,224	348	694	1,255	1,185	377
CENIT Energy Ltd (CEL)	-	-	-	-	-	94	454	513	317	413
Takoradi T3	-	-	-	-	-	-	102	87	31	-
Karpowership	-	-	-	-	-	-	-	-	64	1,822
Ameri Plant	-	-	-	-	-	-	-	-	-	1,233
Trojan*	-	-	-	-	-	-	-	-	-	54
Kpone Thermal Power Plant (KTPP	-	-	-	-	-	-	-	-	-	198
Sub-Total	***3,251***	***2,129***	***2,081***	***3,171***	***3,639***	***3,454***	***4,634***	***4,572***	***5,644***	***7,433***
Renewables										
Safisana Biogas*	-	-	-	-	-	-	-	-	-	0
VRA Solar*	-	-	-	-	-	-	3	4	3	3
BXC Solar*	-	-	-	-	-	-	-	-	-	24
Sub-Total	-	-	-	-	-	-	***3***	***4***	***3***	***27***
Total Generation	**6,978**	**8,324**	**8,958**	**10,167**	**11,200**	**11,525**	**12,870**	**12,963**	**11,492**	**13,021**

Source: Ghana Energy Commission, 2017

Appendix 2 Tariff Rates by Tiers for Residential Consumers in Ghana (Dec 2011-Sept 2013)

Tariff Category	***Tariff rates***
0 – 50 (Exclusive)	9.5
51 – 300 (GHp/kWh)	17.6
3001 – 600 (GHp/kWh)	22.8
600+ (GHp/kWh)	25.3
Service Charge (GHp/month)	***165.3***

Source: Ghana Energy Commission, 2016

Appendix 3a. Breusch-Pagan Test for Heteroskedasticity

Hypothesis	χ^2	**Prob>** χ^2	**Decision**
H_0: Constant Variance *H_a: Heteroskedasticity*	311.43	0.0000	Reject H_0

Appendix 3b. Cameron & Trivedi's Decomposition of IM – test

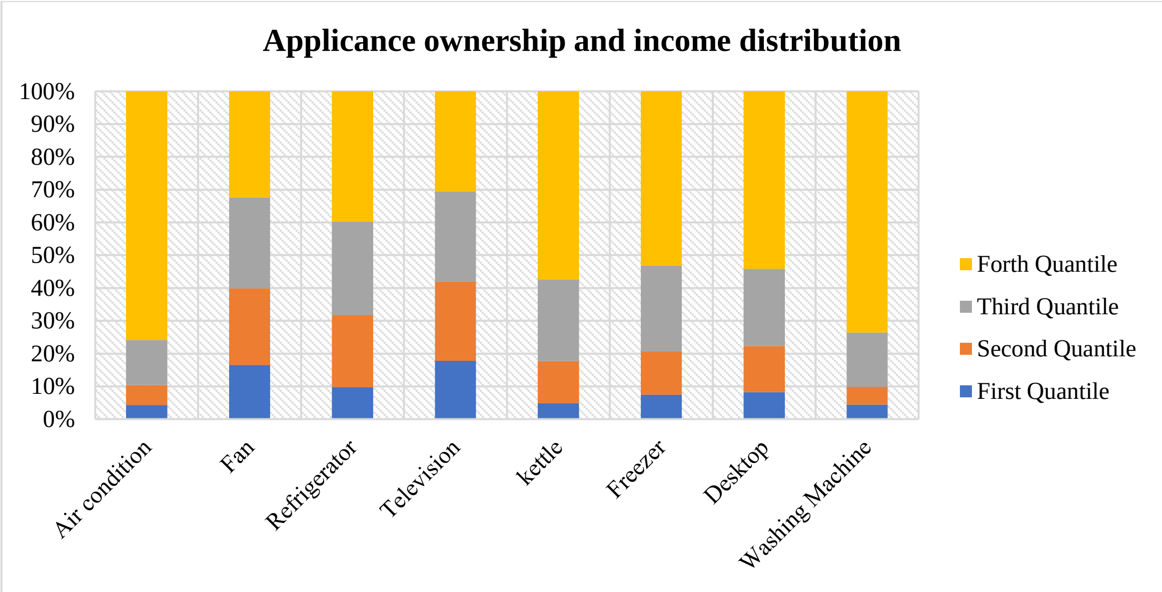
Source	χ^2	**Degree of freedom**	**P value**
Heteroskedasticity	922.29	167	0.0000
Skewness	430.78	18	0.0000
Kurtosis	0.01	1	0.9178
Total	**1353.08**		**0.0000**

Appendix 4. Diagnostic Statistics for Stochastic Frontier

Variable	**Coefficient**	**Standard Error**	**[95% Conf. Interval]**	
$\ln \sigma_v^2$	-2.725	0.0644***	-2.8513	-2.5989
$\ln \sigma_u^2$	-1.4760	0.0614***	-1.5958	-1.3553
σ_v	0.2560	0.0082***	0.2404	0.2727
σ_u	0.4782	0.0147***	0.4503	0.5078
$\sigma^2 = \sigma_v^2 + \sigma_u^2$	0.2942	0.0106***	0.2734	0.3150
λ	1.8678	0.0222***	1.8243	1.911
		Loglikelihood Test		
Null Hypothesis	χ^2	**Prob>** χ^2	**Decision**	
$H_0 : \sigma_u = 0$	**1.5e+02**	**0.0000**	**Reject H_0**	

*Significance levels of 10%, 5% and 1% are represented as *, ** and *** respectively*

Appendix 5. Income Distributions and Appliance Ownership (%)



Source: Author's computation from GLSS 6