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HOUSEHOLD ANALYSIS OF ENERGY POVERTY, INEQUALITIES, AND TRANSITIONS: A CROSS -COUNTRY STUDY OF RWANDA AND MALAWI

By

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July, 2024

DECLARATION

I declare that the PhD thesis with the title "HOUSEHOLD ANALYSIS OF ENERGY POVERTY, INEQUALITIES AND TRANSITIONS: A CROSS-COUNTRY STUDY OF RWANDA AND MALAWI" submitted at the College of Science & Technology is my work.

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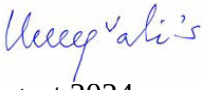
Signed: 

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DEDICATION

To Jehovah El Roi (The God Who Sees Me), the God of Israel who made me a chosen one. To my two children Shalom and Blossom and the other bonus child yet to be born: May PhD holders never cease in their lineages until the second coming of our Lord Jesus Christ of Nazareth!

ABSTRACT

In resource-constrained country settings coupled with growing population such as Rwanda and Malawi, countries which are still ranked as low income and majority are rural dwellers who depend on biomass fuels to meet basic energy need, the opportunity cost of resource collection and its adverse effects remain a big concern from human well-being perspective. In contrast to earlier studies that focused only on energy access, this cross-country study investigates the status of energy poverty, inequalities and transitions amongst Rwandan and Malawian households from micro-economic perspective. The overall goal of the doctoral research study was to assess the status quo for energy poverty, inequalities and transitions at household level. The specific objectives were investigated based on publications and are presented under specific chapters. Firstly, chapter 1 presents general introduction and background information regarding theoretical frameworks. This thesis addressed these specific objectives: (1) To analyse the state of energy poverty and its determinants; (2) To assess how energy insecurity influence the education and health outcomes at household level; (3) To explore fuel choices, transitions and inequalities with special interest on the Sustainable Development Goal number 7. On data sources, the study utilised data from the nationally representative samples, collected under Household Integrated Living Standards surveys from the two countries. In terms of methods, the study employed mixed methods and different analytical techniques in order to address the specific objectives with full details under each chapter. Empirical evidence from this investigation is very timely and critical to shape two countries' public policies that will embrace the notions of energy transition readiness and social inclusion within the developing country contexts.

Key words: Energy poverty, transitions, inequalities, fuel choices, gini, lorenz curves

LIST OF SYMBOLS AND ABBREVIATIONS

CI = Confidence Interval

EAs: Enumeration Areas

EDI: Energy Development Index

EICV: Enquête Integrals les Conditions de Vie des Ménages

EU: European Union

EUCL: Energy Utility Corporation Limited

GDP: Gross Domestic Product

GNI: Gross National Income

HDI: Human Development Index

HEPIn: Household Energy Poverty Index for n^{th} household

ICT: Information Communication Technology

IEA: International Energy Agency

LIHC: Low Income High Cost

LPG: Liquified Petroleum Gas

MEPI: Multidimensional Energy Poverty Index

MGDs: Malawi Growth and Development Strategy

MIS: Minimum Income Standard

MTF: Multi-Tier Framework

MW: Mega watts

NISR: National Institute of Statistics of Rwanda

NSO: National Statistics Office

OR: Odds Ratio

PCA: Principal Component Analysis

PSUs: Primary Sampling Units

SDGs: Sustainable Development Goals

SE4ALL: Sustainable Energy for All

SEDI: Sustainable Energy Development Index

UNAGECC: UN Advisory Group on Energy and Climate Change

UNDP: United Nations Development Programme

USA: United States of America

WHO: World Health Organization

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Rwanda and Malawi envision to become middle-income countries within the Sub-Saharan region as reflected by their national development strategy papers. For instance, apart from Vision 2020 and Vision 2050 development plans, 2017-2024 Rwandan National Strategy for Transformation (NST) synchronize the Sustainable Development Goals (SDGs) with three national priorities captured by three pillars namely: Social transformation, economic transformation and transformational governance [1]. On the other hand, Malawi's development has evolved from its Vision 2020 that was launched in 1998 with the goal of becoming a middle-income country. This followed the attainment of a mature democracy, sustainable environment, self-reliance that fosters equal participation by all groups, as well as a strong base of social services that is hinged on both religious and cultural values. The country implemented this vision in form of five-year development plans namely, The 2002-2005 Malawi Poverty Reduction Strategy , the Malawi Growth and Development Strategy (MGDS) I- 2006 to 2011, MGDS II- 2012 to 2016, and the MGDS III- 2017 to 2022 that has five pillars: (i) Energy, Industry, and Tourism Development, (ii) Agriculture and Climate Change Management , (iii) Education and Skills Development,(iv) Transport and Information and Communication Technology, and (iv) Health and Population Management [2], [3]. Furthermore, Malawi has developed and is implementing a new Malawi 2063 development strategy paper, replacing the Vision 2020 to spearhead the national development agenda that resonates with the global development agenda. For example, the country has stipulated clear targets on use of the renewable energy sources (77% in 2018 to 100% in 2063) in order to mitigate the carbon emissions challenge [4].

As such, these governments have developed various policy measures to ensure that they meet different targets on development goals by the year 2030, under the umbrella of UN's SDGs. Of special focus in this study are SDG 1 which focuses on eliminating poverty in all its forms everywhere, and SDG 7 which focuses on promoting use of modern energy sources for all and also making sure these fuels are cheap, dependable and sustainable. [5], [6] discussed in detail how this goal is linked to the rest of the SDGs. She argued that this goal remains the central point to accomplish all the remaining SDGs. Furthermore, of interest in this study is also SDG 10 which calls for reducing inequalities within and among countries by implementing national

policies that encourage equal opportunities and reduce inequalities to uplift people from all forms of poverty including energy poverty. Global statistics show that the share of persons that use modern clean fuels for cooking and other technologies rose from 66 percent in 2019 to 69 percent in 2020 [7]. Despite the world's progress, the Sub-Saharan African region still lags behind due to a compendium of reasons such as low consumption levels, failure in power system development, investment in new generation capacity, and poor maintenance of existing electrical power infrastructure amidst a growing population [8], [9]. For instance, around 2.4 billion people had no access to clean cooking fuels in 2020 but the access deficit was more pronounced in Africa's Sub-Saharan Region (SAA) than the rest of the world whereby there are now approximately 923 million people in the region that lacks access to clean cooking modern energy services which has doubled between 1990 and 2020 [7].

1.1.1 Rwandan research context

Rwanda targets to achieve universal electricity access through grid connections and also off-grid solutions. For instance, the Rwanda electricity distribution master plan shows the targets of at least 52% to come from the national grid and 48% to come from off-grid solutions by year 2024. The country's energy sector continues to rely on natural resources that include hydro, solar and methane gas with biomass resources taking a dominant share of approximately 85 % of the national energy consumption [10]. Rwanda power sector faces the big challenge of high production cost to generate electricity which translates into high electricity tariffs compared to its neighbouring countries. For instance, [10] reported a mean value of US$0.24 per kilowatt-hour which is on a higher side comparing to its neighbours like Kenya (US$0.15) and Uganda (US$0.17). Hence, Rwanda's electricity price is expensive. For example, in the year 2016, [11] found that the price was on the higher side in relative terms with the rest of the countries within the Eastern Africa Community (US$ 0.22 / kWh versus a range of US$0.12 and US$0.18 / kWh). Rwanda is considered as a "large gap" country by Sustainable Energy for All (SE4ALL), based on the statistics that the country provides 62 % of electricity to urban areas whilst the rural areas get only 8% [12]. So far, the country had 216 MW of installed electricity capacity in 2018 [10]. Its population was projected to reach 11.3 million in 2015 and is likely to be 16.3 million by 2032 whilst its economy grew at a steady average rate of 7.9 percent between 2001 and 2016 leading to a rise in per capita GDP from 211 USD to 729 USD [13]. By 2018 Rwanda was

ranked 157th out 188 countries in terms of Human Development using the Human Development Index [14].

However, wood fuel (20 % of annual consumption of wood fuels) still dominates other sources for domestic activities, including in Kigali City [15]. In terms of urbanisation drive, Kigali City continues to thrive with its resident population projected to reach about 3.8 million by 2050 [16]. Such an urbanisation drive validates the need to put in place electricity or general modern energy infrastructures in place to support the economic, social and environmental performances of city life. Modern cities like Kigali cannot function properly with having fundamental conduits that come with modern basic energy service infrastructures.

In terms of topography, Rwanda is characterised by a high altitude and is also mountainous, and these affects economic activities of the majority of people who depend on agricultural activities. In addition, the country is prone to frequent natural disasters and shocks in form of earthquakes, floods and also landslides that have negative implications on the environment and the economy as a whole [1].

1.1.2 Malawian research context

Malawi can also be regarded as one of the least electrified low-income countries having 11 % national grid electricity connection and can be considered as a large-gap country, taking into consideration that 42% of the urban population have access to grid electricity whilst only 4% rural populace have access to national grid [17], [18]. Meanwhile, the country has a huge demand for electricity (> 1000 MW) for business and household consumers which is not matching with the supply for generating the electricity (approximately 361 MW) [17]. This makes Malawi to be one of countries in the Southern Africa that has high energy deficit [19]. Worse still the country mainly depends on hydroelectricity (372 MW) from the overall capacity of 532 MW at national level [2]. Unfortunately, systems of hydropower are susceptible and vulnerable to climate changes such that since December 2017, it has experienced continuous blackouts and up now even in 2021 Cyclone Ana worsened the situation [20], [21] .

As of 2018, Malawi had a total population of 17,563,749 million out of which 84 percent lived in the rural areas [22]. The country is currently facing the urbanisation challenge and has an urbanisation growth rate of 3.5 % on yearly basis. The urbanisation and migration processes

might bring changes in the lifestyles and also consumptions behavior that may affect household fuel choices [23], [24].

An overview of the economic situation in the country shows that, 70 percent of the Malawi population was living in monetary poverty (below the US$ 1.9 daily basis) [25]. In addition, Malawi as a nation suffers from Inequality problem (i.e., Gini coefficient of 0.6 in 2015) in various sectors [26]. Furthermore, the country continues to register a declining economic growth rate on yearly basis (i.e., an average of 4.1 % of real Gross Domestic Product) [4]. Furthermore, in terms of promoting human capital, in 2018 Malawi took 171st position out of 188 countries based on Human Development report [27].

1.2 Statement of the Problem

Poor access to modern energy services affects, not only basic social services delivery, but also has negative implications on the economy, health and environment especially in the Global South. Particular emphasis is placed on the Sub-Saharan Africa (SSA) where majority still depends on solid fuels to meet their household energy needs. For instance, in terms of clean cooking, 80 % of the population cooks with solid fuels such as wood, charcoal and coal in comparison to 58% of population in China and 71% of population in India [28]. These recent statistics call for more coordinated efforts and holistic approach by states and non-state actors to achieve a faster energy transition in the household sector more than ever before especially in the post-Covid-19 era [29]. On the other hand, the Sustainable Development Goal number 7 emphasises the need to achieve universal access to affordable, reliable and modern energy services by 2030 and this goal presents inter-linkages with other 16 SDGs. Of key interest in this study are interlinkages with Goal 1 that calls for the end of poverty in all its forms everywhere, including energy poverty; Goal 10 that aims at reducing inequality within and among countries; Goal 3 that aims at good health and well-being; Goal 4 that emphasizes on quality education; and Goal 11 which stresses the importance of making cities and human settlements inclusive, safe, resilient and sustainable.

To this end, renewable technologies such as solar offer a wide range of the socio-economic benefits that reduce environmental pollution and opportunity costs translating into better long-term development outcomes for women and children [30]. However, these technologies are not provided free of charge as they attract a significant amount of startup capital costs that are incurred when doing installations and also procurements of gas cylinders in case of liquefied petroleum gas. Therefore, successful uptake of clean energy technologies such as solar and LPG

is attributed to consumer demand and energy choices largely from the household sector, notwithstanding, the efforts to put in place some clear energy policies, strategies and programs. Household decisions on energy usage and options for fuel sources are complex since they are tied to a wide array of factors including economical, technical, social and cultural aspects which may come in different forms according to a given study context [31]. Stillmore, 195 million people in SSA use charcoal as a primary cooking fuel whilst another 200 million people use it as a secondary cooking fuel [32] . Yet the national governments and multinational sponsors would like to see a tangible transition from traditional biomass to clean fuels especially in the SSA whereby 60% of world's charcoal is being produced [32], [33].

Meanwhile, the energy profiles for Rwanda and Malawi portray unappealing scenarios and paint a gloomy outlook as far as the use of polluting fuels is concerned. For instance, new empirical evidence in Rwanda revealed that income elasticity from electricity is elastic for urban dwellers [34]. This implies that electricity is considered as a luxury good in urban households. Furthermore, [34] found there are significant differences in terms of energy consumption patterns between urban dwellers and rural dwellers. Unfortunately, the use of polluting fuels which still dominate the energy consumption mix in most these Rwandan homes may attract harmful effects towards human health as a result of indoor air pollution via respiratory ailments and others. On the other hand, the Malawian scenario is dire need propelled by persistent power blackouts. The blackouts have led to a growing high demand for charcoal and firewood to cater for power supply disruption that are in form of planned load shedding or localized blackouts across the entire nation [35]. The country statistics show that total charcoal demand in 2016 exceeded 352,000 tonnes and meeting that demand would need 2.35 million cubic meters (m^3) of wet wood at the same time, 25,000 hectares of woodland would have been cleared [36]. Assuming that no action was taken to circumvent this challenge, charcoal demand was bound to double between 2008 and 2023 to reach 606,000 tonnes per annum [36]. The situation on the ground shows that roughly 85 % of Malawi's population of more than 20 million people do not have access to electricity [37]. Moreover, [37] noted that only 3% of the Malawi's population have access to a clean fuel for cooking in their homes. So far, no single energy solution exists in the country as either household face unreliable electricity supply whilst on the other hand, very few households have the courage to use liquefied petroleum gas (LPG) as others are still suspicious of it and also remains costly despite being an efficient clean fuel [38]. But traditional biomass easily addresses family budget challenges including the urban poor whereby it can be bought in little amounts unlike LPG [32]. Unfortunately, there are no studies which have clearly examined energy poverty to get the depth of this problem plus how energy insecurity affects human welfare. As the authors in [37] lamented, the depth of energy poverty for people in Malawi cannot be overstated.

Therefore, against such background, this doctoral study bridges the existing research gap on household energy poverty, inequalities and transitions within two low income developing country contexts in the Sub-Saharan African region. Specifically, this thesis gives a cross country empirical evidence to understand the magnitude of energy poverty problem coupled with challenges associated with energy transitions in the domestic sector. Such investigations are crucial to shape a country's public policies to boost energy transition readiness and also improve on social inclusion in the developing country context. This was done in three related chapters that make up the critical parts of the whole PhD thesis comprising five chapters whereby the first and last chapter capture the introduction and general conclusion of this thesis respectively.

1.3 Objectives of the study

1.3.1 Aim of the doctoral study

This doctoral study's aim was to investigate the state of energy poverty, inequalities and transitions at household level. The study employed different analytical techniques to address specific research objectives i.e to gauge magnitude of energy poverty and also to ascertain whether modern energy services or renewables are utilised using a cross -country comparative approach on two low-income countries namely, Rwanda and Malawi. Embracing such approach, is part of unique contribution to literature instead of focusing only on a single country and only one analytical technique.

1.3.2 Specific Objectives

Specifically, the following broad research objectives were investigated based on paper publications:

(1) To assess the level of energy poverty and its determinants as presented under chapter 2.

(2) To analyse how energy insecurity impacts household development outcomes (education & health) as presented in chapter 3.

(3) To explore energy choices, transitions and inequalities with regard to access to clean energy sources as presented in chapter 4.

1.4 Research questions

The following were the guiding research questions:

(1) What is the current state of energy poverty and its determinants in the two countries?

(2) How does energy insecurity affect the education and the health outcomes?

(3) What factors affect household fuel choices, transitions and inequalities in the two countries?

1.5 Research methodology

To address the three research questions highlighted in the previous subsection, the study gathered and employed different analytical tools and country data sets.

1.5.1 Addressing research question 1: What is the current state of energy poverty and its determinants in the two countries? (Details in Chapter 2)

Firstly, to address the research question number 1 which focuses on examining the status and determinants of energy poverty the following data and tools were used. The study made use of a single wave of the 2016-2017 Rwandan integrated living standard household survey (a nationally representative sample of 14458 households) and also a single wave of 2016 -2017 Malawian fourth integrated household survey (a nationally representative sample of 12361 households). The two surveys collect basic information on different items such as household demographics, expenditures on food, non- food items including energy expenses, housing and utilities, durable assets and many more others. On data analysis, the study employed two analytical techniques to measure the magnitude of the energy poverty. Specifically, the study computed an index through Principal Component Analysis (PCA) under the multi-dimensional approach. The other approach involved using the Unidimensional measure that uses the share of energy expenses data in the total family budget so that emphasis was placed on affordability, accessibility and use modern cooking fuels. In addition, multi-level binary logistic regressions were used to assess determinants of household energy poverty incidences in both countries. These multilevel binary logistic regression models had the ability to have clusters of the standard errors of the survey datasets bearing in mind the nesting structure of households within their respective districts. Furthermore, the nature of the outcome variable (energy poverty incidence) was binary in nature depicting the value of 1 if the household was energy poor and zero otherwise.

1.5.2 Addressing research question 2: How does energy insecurity affect the education and the health outcomes? (Details in Chapter 3)

Secondly, to address the research question number 2, the study also utilised the same secondary datasets as explained already under sub-section 1.5.1. However, the research question 2 largely focused on assessing household characteristics of families which face energy insecurity and also its effect on selected household development outcomes (i.e child's school attendance and health status of family members). Both descriptive statistics and advanced data analysis was conducted. In terms of analytical techniques, probit regressions were employed to assess factors that determine energy insecurity to attest to the preliminary findings from descriptive statistics. To address issue of selection bias of the dependent variables (education and health status outcomes) versus energy insecurity as an independent variable, the study applied the instrumental variable probit regressions in the two countries and other quasi-experimental techniques (i.e., Propensity Score Matching, Inverse Probability Weighting technique) to check the robustness of the results.

1.5.3 Addressing research question 3: What factors affect household fuel choices, transitions and inequalities in the two countries? (Details in Chapter 4)

Thirdly, to address the research question number 3, the study made use of repeated cross-sectional data collected from 28995 Rwandan households under two waves (EICV4-2013/14, EICV5-2016/17) and data gathered from 23,789 Malawian homes under two waves (IHS4-2016/17, IHS5-2019/20). In terms of data analysis, the study employed the Lorenz curves and Gini coefficient to have a visualisation of energy inequalities at different levels to a clear between country and within country comparisons. In addition, the multivariate probit models were used to assess the factors that drive energy choices. Moreover, Seemingly Unrelated Regression models were also used to evaluate household energy consumption intensity in the two countries.

1.6 Organization of the thesis

Chapter 1 presents a general introduction and background information regarding theoretical frameworks. This is followed by chapter 2 which examines the state of energy poverty and its determinants. Thereafter, chapter 3 provides an analysis on how household development outcomes (education and health) are affected by energy insecurity. This is followed by chapter 4 which assesses the key factors that influence household energy choices/ energy transitions and explore the disparities due to the inequality in access to clean energy. Finally, Chapter 5 draws a conclusion and policy recommendations.

1.7 List of publications

Some of the published work that were produced from this thesis and also part of the overall doctoral studies encompassing Rwanda and Malawi as case studies as follows: -

(1) Khundi-Mkomba, F, Saha, A.K. and Wali, G.W. (2023). Social Protection Schemes in Rural Rwanda: A Panacea for Household Energy Burdens? (In press at the Energy for Sustainable Development Elsevier journal, Vol. 74, June 2023, pages 91- 101)

(2) Khundi-Mkomba, F, Saha, A.K. and Wali, G.W. (2021). Examining the status of energy poverty in Rwanda: An inter indicator analysis. https://doi.org/10.1016/j.heliyon.2021.e08441 (Elsevier & Scopus indexed)

(3) Khundi-Mkomba, F. (2021). Are urban Rwandan households using modern energy sources? An exploration of cooking fuel choices. International Journal of Energy Economics and Policy. Vol 11, No 2 (2021). DOI: https://doi.org/10.32479/ijeep.10735 (Scopus indexed).

(4) F. Khundi-Mkomba, A. Saha, and U. Wali, “Household-level effects of Energy Insecurity on Welfare in Southern Africa: A Malawian Case Study,” International Journal of Renewable Energy Development, Vol.10, no.1, pp.105-118, Feb. 2021. https://doi.org/10.14710/ijred.2021.33234 (Scopus indexed).

CHAPTER TWO

ASSESSING ENERGY POVERTY LEVELS AND ITS DETERMINANTS IN RWANDA AND MALAWI

Rwanda and Malawi have experienced rapid urbanisation that is driven by internal migration and population growth in the secondary cities and towns. This has implications on lifestyle changes and energy demand. On the other hand, the two countries have implemented programs to improve access to electricity especially to the rural masses. This study seeks to establish the status of energy poverty and its underlying determinants in the two countries by employing the Integrated Living Standard Survey datasets. Specifically, the study used a nationally representative sample of 14458 households from the Rwandan Integrated Living Standard Survey (October, 2016 to October 2017) and a nationally representative sample of 12361 households from the fourth integrated household survey (April 2016 to April 2017) from Malawi. Two indicators were adopted to measure energy poverty. First, the study computed an index through Principal Component Analysis under the multi-dimensional approach. The other approach involved using the Unidimensional measure that uses energy expenses data by the way of emphasizing affordability, accessibility and use modern cooking fuels. The study findings under multi-dimensional approach different magnitude of energy poverty across the two countries. For instance, Rwanda registered a high rate of the least energy-poor (27.69%) and a high rate of the most energy-poor (24.69%) compared to Malawi, which had registered a lower rate of the least energy-poor (9.31%) and the most energy-poor (7.23%). However, under a modified expenditure-based approach, Malawi (24.47%) had registered a lower national prevalence rate of energy poverty compared to that of Rwanda (39.11%). These preliminary results are a precursor to finding more about the critical factors determining energy poverty phenomenon in the two countries. The concentration of this phenomenon also varied significantly by region in all the two countries. Lastly, the estimates under multi-level binary logistic regressions revealed that socio-economic factors (i.e., household size, monetary poverty, education), and rurality affect energy poverty differently in the two countries.

2.1 Introduction

The key objective running through this chapter is to assess energy poverty levels and its determinants in Rwanda and Malawi based on published paper [39]. In this doctoral study, energy poverty refers to the lack of access to modern energy services that are critical to enhance economic and human development [39], [40], [41].

Rwanda and Malawi are facing rapid urbanisation that has been aggravated by internal migration and population growth that has an implication on energy demand. On the other hand, these countries have also been implementing rural electrification programs as a way of improving energy access to the rural population. Hence, examination of energy poverty status and its determinants will provide timely empirical evidence to understand the magnitude of this problem and also find out more about factors that influence this phenomenon. In this regard, the main research question that guides this chapter is: 'What is the status quo on the energy poverty phenomenon across these two low-income countries within the Sub-Saharan Africa region?' To find an answer for this question, this chapter first presents a global overview of energy poverty concept and how it differs with the fuel poverty concept from both Global North and Global South perspectives. Thereafter, further study was carried out by employing two different approaches that are used to establish the extent of energy poverty, highlighting some strengths plus weaknesses for each metric or indicator. This is followed by a presentation on a short brief summary of energy poverty impacts, its linkage to public policy plus theoretical framework that is associated with energy poverty phenomenon. This chapter weighs in on the continuing debate with respect to the need to eliminate all forms of poverty inclusive of the energy poverty thereby resonating with the Sustainable Development Goals number 1 and 7.

The remaining part of the chapter has been arranged as follows: Section 2 provides for a brief literature review; materials and methods appear in section 3 and section 4 presents the results and discussion. Finally, section 5 highlights the conclusion, policy lessons and areas of further research.

2.2 Literature review

2.2.1 Conceptualisation of energy poverty versus fuel poverty

Globally, scholarly works do not have a generally applicable definition for the concept of energy poverty phenomenon. In most cases, energy poverty definition has revolved around its measurement approaches. Several reports of energy poverty exist depending on the research

context and the country or region reference [42]. Currently, an ongoing debate focuses on defining energy poverty or fuel poverty. The two terms are sometimes used synonymously, just like [43] and [44] who documented more on this as they mainly discuss energy poverty or fuel poverty policies in the United Kingdom, Ireland and also other European countries.

In some cases, other scholars have separated the two terms. For instance, [40] gave an exposition regarding the differences that exist between energy poverty and fuel poverty. Firstly, [45] pioneered the first definition of fuel poverty to mean the incapacity to attain optimum warmth in the home. Other scholars such as [46], [47], [48] have built their definitions from Lewis's original idea of fuel poverty with particular attention to the United Kingdom. [46] earlier modified the fuel poverty concept by categorising households that consume over 10% of their income on fuel expenses as fuel-poor, so they have problems maintaining the recommended indoor temperature. Later on, [47] further modified the fuel-poor concept to imply those households that could not afford adequate energy services during cold season or found themselves in accumulated debts of fuel expenses. [49] developed the fuel poverty concept further by introducing the 'low-income high cost' (LIHC) measure. The LIHC metric is a metric that can be used by researchers to categorize households based on their levels of fuel expenses. Those households that incur more than the median level of the fuel expenses and are likely to, make their disposable income fall below the official monetary poverty threshold are referred as the fuel poor. Moreover, [40] categorised the fuel poor as those households with inefficient housing and heating system under cold climatic conditions and, at the same time, have affordability challenges to access electricity to maintain warmth in homes or modern cooking fuels due to high energy prices. All these fuel poverty concepts have been measured primarily using threshold measures (binary indicator metrics), especially in the Global North context [40], [47], [49].

Secondly, from a political economy perspective, [50] broadly defined energy poverty with reference to electricity access plus total dependence on wood fuels or crop residues and dung. On the other hand, [51] defined energy poverty as a complex phenomenon that encompasses inadequate physical availability of modern fuels, insufficient income and high energy expenses or burdens born by households as they use energy services.

Nevertheless, it is essential to note the differences that may exist between the two concepts, namely: 1) energy poverty concept primarily revolves around inadequate access and erratic

supply of clean fuels and the use of traditional biomass for cooking, within the Global South context. In contrast, fuel poverty revolves around the affordability challenges associated with clearing high fuel expenses due to meagre disposable income despite that modern fuel services might be available within the Global North context. This problem is commonly observed among the underprivileged sections of the society such as the elderly or families with children [40], [44]. Moreover, the energy poverty concept is being measured using both threshold measures and numerical indices, especially within the contexts of the Global South to gauge energy poverty levels [52], [53], [54], [55]. However, these two concepts also have similarities. Both energy poverty and fuel poverty have the following similarities, as highlighted by [40] :1) both deal with energy consumption that is required by the household sector; 2) low income is a significant factor and this often worsens the monetary poverty situation for the two groups; 3) aggravates the health problems, gender or social equity issues within the society regardless whether it is from the Global North or from the Global South contexts thereby retarding social, human and economic development.

However, energy poverty definition continues to evolve depending on the research context. For instance, [42] conceptualized energy poverty takes multiple dimensions that may hinge on food calorific aspects, life expectancy, housing conditions, literacy and access to modern fuels. As a result, the recent scholarly works have expanded the scope of energy poverty by capturing several issues such as access to modern fuels lighting or cooking, use of electronic gadgets that have high energy efficiency, ownership of refrigerators or air conditioners or fans for cooling, ownership of computers, radio or phone for communication, education, and entertainment to lead a dignified life [39], [56], [57], [58], [59], [60]. Further development on the multidimensional energy poverty measurement approach has gained more momentum by applying what is known as capability theory or perspective approach), initially pioneered by Amartya Sen and Martha Nussbaum that postulates ideas of capabilities and functionings on energy poverty phenomenon and also ensuring energy justice based on Rawlsian tradition of justice [61], [62], [63], [64], [65], [66], [67]. Under the capability approach theory, [61] defined energy poverty as a situation where people are not able enhance their full potential as a result of poor capacity attributed indirectly or directly to poor energy services whilst taking cognizance of the alternative means that may be available to enhance these capabilities. This definition shows that energy is essential for sharpening many capabilities from health, education, social life, communication, and even employment that truly resonates in both developing world and the advanced economy contexts.

2.2.2 Understanding the energy poverty metrics/ indicators

To date, most researchers and development practitioners face the daunting task of selecting an energy poverty indicator that can genuinely reflect the conceptual and methodological aspect of energy deprivation at the household level for any specified research context [68]. The evolution of energy poverty statistics got pioneered by [46] . She introduced a simple metric which looks at the share of fuel expenses over the total household budget as a form of economic threshold indicators. For instance, she used the 10 % threshold measure (proportion of energy expenses in the total household income). This indicator examines the linkage between the household energy expenses versus the total household expenditures attracting the issue of energy burden with those spending higher proportions of more than 10% deemed as energy-poor s threshold point.

However, this binary measure had the drawback of being sensitive to different thresholds apart from 10%. It failed to measure the magnitude of the energy deprivation to provide tangible quantitative statistics that can inform and help monitor the public policy decision-making processes. [47] realized that her energy poverty indicator used outdated data which may not reflect the existing business economic trends in different countries, especially in terms of energy prices. As such, she urged scholars to use this measure with caution. Following this caution, the European Commission devised an EU-wide benchmark to gauge the energy poverty threshold at the level of actual energy expense two times the national average in the form of the share of the household income [69]. Unfortunately, this indicator had the shortcoming of underestimating the energy poverty rates for member states that had reported high average energy burdens. Arithmetically, this approach is easily influenced by extreme distribution pattern values [68], [70].

In addition, [71] developed a Low-Income High-Cost indicator (LIHC) which improved the 10 % indicator by utilising thresholds from both income and costs sides. The LIHC is adjusted by considering the household size and composition, commonly called “equivalized”. Under the LIHC measure, the energy poor refers to those homes that incur energy expenses exceeding the median value and its household income balance, after subtracting the energy expenses, falls below the poverty threshold of 60% median income [48]. Hills’ argument primarily focused on the fact that big households require a large amount of money to have similar living standards to small families in a literal sense. The LIHC indicator needs constant updates of the datasets to

reflect the dynamics of the household consumption patterns that may vary due to spatial differences, household typologies, and temporal variations, which remains its drawback [68].

[72] applied the LIHC indicator to assess the linkage between household housing conditions and energy poverty in China using microdata. Their study findings showed that households that live in dilapidated rented dwellings with poor insulation and do not have essential energy service equipment were more likely to face energy poverty. Furthermore, the psychology and behavior of the dwelling occupants play a crucial role. [72] found that those living in poor housing conditions were more likely to reduce their energy consumption, thereby deepening their energy poverty.

Similar to the LIHC measure is what [73] proposed regarding the Minimum Income Standard (MIS), which was used to determine the extent of energy poverty based on works of Bradford & Mills (2009). Initially [74] termed MIS as the primary income that any household would require to grab the opportunities and choices that will make them become active citizens in any given society. [73] capitalised on this idea of income standard and asserted that a household is considered energy-poor if the residual family income after subtracting the utility cost on housing and energy expenses falls short of the MIS, considering various subgroups in a given population. The obvious drawback is that this energy poverty indicator does not consider individual household needs in certain circumstances [70].

Related to these economic threshold indicators are the 'technological threshold' and 'physical threshold' indicator approach, sometimes referred to as engineering-based approaches. The physical threshold approach involves computation of the minimum energy threshold which required to satisfy energy needs at household level (i.e., cooking, lighting, cooling and others) based on engineering standards. Any household that consumes below a stipulated physical threshold is considered energy-poor [75], [76], [77]. Take note also that literature presents different physical threshold levels regarding the required total amount of energy as minimum acceptable levels a given household may need depending on its routine tasks. For example, [78] proposed that there is need for developing countries to have a minimum acceptable level of about 50-kilogram oil equivalents (kgoe) per person per or, say, 58.15 kWh to satisfy basic cooking and lighting needs as opposed to 1200 kWh annum per person per annum as recommended by the [79] to spur development agenda. In Pakistan, the minimum acceptable

level went as higher as 8140.6 kWh to achieve a 0.8 increase on Human Development Index [80].

The technological threshold indicator looks at energy poverty as a phenomenon that arises due to the problem of accessing modern energy services [76]. Modern energy services imply electricity and other non-solid energy sources such as LPG and solar rather than traditional biomasses or other solid fuels. From the technological threshold perspective, the energy-poor household has no access to these modern fuels but only relies on conventional biomass sources to meet its immediate energy needs [81]. Unfortunately, this indicator does not stipulate the information on the level of consumption which is its limitation [76].

As such, a plethora of indicators was developed bearing such purpose in mind and utilising the readily available data sets usually collected for general purposes such as the World Bank Integrated household living standards surveys. For instance, those indicators employ direct approaches by using indoor temperatures based on indoor temperature surveys in a domestic setting. [43] utilised this approach by comparing households that failed to maintain an adequately heated home for vulnerable groups (i.e., the elderly and children) as stipulated by the World Health Organization (WHO). The WHO prescribed minimum indoor temperatures of about 18 to 21 degrees Celsius in former communist countries which fall within the Eastern and Central parts of Europe [82]. The study found that some socio-demographic factors identify the energy-deprived homes from the rest of the general population, coupled with organizational and political dynamics. As such, this demands a holistic approach to address this phenomenon.

Overall, the indoor temperature indicators may go together with consensual-based metrics. The consensual-based metrics capture feelings or perceptions of the dwelling occupants towards their energy consumption. Such measures may give an effective way of understanding perceived energy poverty and more detailed insights than quantitative metrics and primarily depict the proportion of households that live in dwellings that are not comfortably cool during summer or not warm during winter [83].

Despite the advantage that these indicators provide complimentary assessments to other energy poverty indicators, the limitation is that they require survey infrastructure to be in place. In some cases, it may be challenging to quantify. The other energy poverty indicators category is the outcome-based energy poverty metric. These mainly focus on the outcomes of energy poverty either by using utility data or actual health outcomes, such as mortality rates in homes due to

excess cold or heatwave conditions in the homes but do not reflect the affordability or the income dimension of the household [83]. Unfortunately, the drawback of these indicators is that other factors (i.e., income, poverty and other environmental conditions) may also affect the health outcomes.

Finally, note that each set of energy poverty indicators has its strengths and weaknesses. Firstly, the binary indicators (thresholds) are straightforward to use but may not be rational due to disparities in income levels [83]. Nonetheless, the LIHC indicator still provides valuable information by giving a threshold relative to the income levels in households every year, which may allow comparative analysis over time and across countries. Equally, those indicators based on the Minimum Income Standards (MIS) may look the best under the expenditure-based approaches because using a threshold related to minimum income in a given household is critical. Still, unfortunately, this is only possible in the Global North but not in the South due to limited survey infrastructures. Most countries in developing countries do not have an established "minimum income level" per se for a given household [83]. Therefore, this doctoral study did not select the MIS approach due to data limitations.

Energy access has been a proxy measure of energy poverty for several decades. Under this measure, households with a national grid electricity connection and use modern cooking fuels such as LPG are classified as non-energy poor against those with such connection or use solid fuels [84]. The frequent use of this approach is possibly attributed to the easy availability of data that is widely accessible and frequently maintained by global institutions such as the World Bank [58].

[85] further modified this energy access proxy measure by introducing a Multi-Tier Framework (MTF). This MTF measures energy access as a proxy measure of energy poverty beyond the ordinary binary energy access metric. It depicts several aspects of the energy supply. For instance, MTF must indicate hours of energy availability and the amount of energy available to accurately show the number of energy services required for basic household needs and other income-generating activities [58], [85]. Unfortunately, its limitation is that it requires comprehensive datasets, which are not readily available in most developing countries. Many developing countries lack extensive survey infrastructures due to human capacity and also financial constraints despite that it gives a good picture of energy poverty at all levels [58], [85]
.

For new energy poverty measures, [86] highlighted those poor economies with a vast population living below $2 per day were strongly linked to poor access to modern fuels. Another energy poverty metric known as Multi-dimensional Energy Poverty Index (MEPI) captures the multidimensional aspect. This measure was first championed by one of the global research initiatives under the Oxford University to provide timely empirical evidence for public policy decision-making processes on human development outcomes. MEPI was formulated to track how far development interventions could deal with energy poverty issues for sustainable development [58], [87].

However, the energy poverty as a phenomenon has multiple dimensions and exhibits adverse effects not only on human health but also on a wide range of other development outcomes. As a result, several scholars have attempted to devise composite indicators of energy poverty beyond accessibility, affordability and indoor pollution aspects. Usually, composite indicators combine information to highlight multiple facets of energy poverty into a single index or number. For instance, [88] developed another composite index (being referred as Sustainable Energy Development Index) which provides clear insights into energy sustainability and linkage to other indices i.e., the Human Development Index. Already there is also an Energy Development Index (EDI) which was proposed by the International Energy Agency [58].

Both EDI and SEDI have the advantage of explaining the maturity stages of the national energy system and sustainability at a macro level but fail to explain clearly the magnitude of energy deprivation and sustainability at a micro level, such as in households [58] .The previous examples of composite indices do capture the energy deprivation in households but fails to capture sustainability and household energy deprivation for productive purposes such as farming or any other income generating activity.

The preceding literature shows that energy poverty is a complex. As such, a single measure or metric cannot fully measure this complex issue, and the race to develop new energy poverty metrics continues. Therefore, this study adopted two indicators to measure this phenomenon within the Rwandan and Malawian research contexts from the Global South perspective. Hence, this doctoral study opted to use more than one energy poverty metric towards the energy poverty analysis.

2.2.3 The determinants of energy poverty and associated welfare effects

Literature presents a myriad factor that affect energy poverty phenomenon beyond the obvious socioeconomic status (i.e., asset holdings) and demographics (i.e., age) [89]. The existing scholarly works indicate that housing conditions and tenure contributes to this phenomenon [72]. Previous scholarly works revealed that people who live in rented dwellings are more likely to experience this phenomenon compared to the owner-occupants [90]. With regard to how this phenomenon affect the quality of life as a measure of welfare, [91] found that energy poverty phenomenon resulted into deteriorating household well-being in China under a panel data framework. Other similar studies by [56] also revealed that this phenomenon has adverse effects on the physical and mental health and general children's well-being. Specifically, [56] evaluated the effect of this phenomenon on physical and mental well-being using the entropy method based on Chinese General Social Survey data. Their study findings revealed that energy poverty negatively affected the human health.

[92] gave a thrilling example of how energy poverty impacts life expectancy by highlighting that a tripling of energy consumption from 2000 onwards had led to an increase in female life expectancy from 73 years to 78 years in 2014. Their illustration showed that a tenfold increase in electricity access would lead to ten years increase in life expectancy, holding other factors constant [93]. Using the same analogy, poor electricity access was attributed to low life expectancy in Kenya. The Kirinyaga residents had a lower life expectancy of about 63 years compared to the national figure of nearly 67 years [42]. On the linkage of energy poverty and literacy levels, [94] found that electricity promoted digital learning using computers and other electronic equipment. In addition, [95] noted that improved access to modern fuels led to low opportunity costs in gathering wood fuels for school-going children in rural areas. Eventually, this had a positive effect on the learning outcomes. Actually, [96] found significant positive impacts on educational outcomes (i.e., completion of primary school by school-going children in electrified homes) associated with improved electricity access.

2.2.4 Energy poverty in households and the urgent need for effective policies

In the past decade, statistics showed that approximately 4,000,000 persons, especially women and children, were dying yearly, a significantly high number from 1.3 million people in 2007 due to fumes from indoor air pollution in the developing world [97], [98]. He stressed that despite making economic and technological progress, approximately 1.4 billion people from the Global South would not have electricity by 2030. [97] attested that much gains for those with

electricity access would easily be negligible due to population growth, especially in Sub-Saharan Africa (SSA), unlike Asia, which would get the highest reduction in numbers of electricity-deprived persons. Moreover, [97] anticipated that globally in the cooking sector, the number of biomass users would increase significantly to 2.7 billion by 2030 if governments and development partners would not prioritise the energy poverty agenda. This trend is worrisome and will likely jeopardize other United Nations Sustainable Development Goals since SDG number 7 cuts across the other SDGs. Such provision of modern energy services is crucial to improve human development outcomes, especially in the SSA. It is directly linked to social development (Health and Education). For instance, [97] illustrated that if all the traditional biomass users were given improved clean cooking technologies such as LPG cylinders to be used before reaching 2030. That action alone would yield incredible results. This scholar said that this simple action of giving out LPG cylinders would lead to a rise in global crude and fossil fuel demand by 1 % with accompanying cost of approximately $18 billion per annum. In addition, that action alone would improve the social welfare of about 1.3 million persons per annum.

Meanwhile, recent statistics still show that approximately 770 million people globally have no access to electricity but from this 562 million are located in the SSA taking a large share of 52 % [8] [72]. Moreover, International Energy Agency (IEA) reported that roughly 25 million people in low-income countries from Africa and Asia would lose their ability to purchase a basic package of electricity services by the end of 2020 towards its SDG7 tracking progress [99]. So far, over one billion people (over 13% of the global population) are facing energy poverty and lack access to clean energy [100], [101].

To conclude, energy poverty remains a tremendous societal and policy challenge for the global village regardless whether the economies are more advanced or not. On the other hand, the demand to have a universal conventional measure of energy poverty metric is increasingly becoming more inevitable [68]. Energy poverty measures are critical to fully understand this phenomenon, which is a separate and distinct form of human deprivation. Current literature presents different energy poverty indicators considering the scope, limitations, types of data and research contexts, whether carried in the Global North or Global South.

2.3 Materials and Methods

This section presents a summary of materials and analytical techniques that were used to answer the research questions for the current chapter.

2.3.1 Sources of data and description

This section presents the sources of the secondary datasets that were used for econometric analysis to answer the given research questions. The secondary datasets provided a variety information depicting socio-economic features and demographics of the households, access to essential services, household expenditures, dwelling characteristics and other detailed information.

2.3.1.1 Rwandan dataset

This research study used primary datasets collected by national research institutions in Rwanda and Malawi. The datasets are nationally representative and cover all five provinces of Rwanda and all districts within Malawi. For Rwanda, the doctoral research on energy poverty focused on the data from the most recent integrated household living standard survey (EICV 5) that was carried between 2016 and 2017 over a period of one year by the National Institute of Statistics of Rwanda (NASIR) and further detailed information are presented on the Web portal of the same institution [102]. The NASIR shares all the data and obliged to do so using the Creative Commons Attribution 4.0 International (CC BY 4.0) license. However, they still remain the custodians of the data set to give final approval of public use of the data to researchers and scholars to conduct extended research analysis. As such the sampling this doctoral study received an electronical approval to use the dataset for further analysis. Regarding the sampling technique, the NASIR employs a proportional probability sampling (PPS) and involved choosing the district sample villages based on the national master sampling frame under the 2012 Census frame. Further detailed is presented in the published survey reports produced by the NASIR itself [103]. This research only worked on 14458 households as a clean sample and removed other households that did have full information.

2.3.1.2 Malawian dataset

Secondary data was employed in this study as drawn from Malawi's Fourth Integrated Household Survey (IHS4) 2016-2017. In collaboration with the World Bank, the National Statistics Office (NSO) in Malawi regularly conducts such surveys for three years since 1997. The NSO, in collaboration with the World Bank, makes available the datasets as part of the processing of implementing the Living Standards Measurement Study (LSMS) programme

[104] . The survey covers a nationally representative sample tailor-made to bring forth information on Malawi's various aspects of household welfare. The survey involved gathering information from a sample consisting of 12,447 households, but following a data cleaning process, only 12,439 households was used, with all critical variables for analysis. The sample was statistically designed to achieved representativeness, at both national and district as well as urban and rural levels, in the process producing reliable estimates for these levels. The sampling involves a stratified two-stage sample design. The primary sampling units (PSUs) considered at the first stage are the census enumeration areas (EAs) highlighted by the 2008 Malawi Population and Housing Census sampling procedure. Each one of the EAs consists of about 235 households. In total, 768 EAs were considered to draw the final sample for the household survey to represent the whole country. The following subsection presents detailed procedures in terms of the construction of the energy poverty index scores.

2.3.2 Selecting empirical strategies to the current energy poverty study

Considering that the energy poverty concept encompasses different dimensions, different indicators are highlighted to reflect the phenomenon's complexity in the two countries. The following paragraphs present the two analytical techniques that were employed to examine the energy poverty status in Rwanda and Malawi.

2.3.2.1 A multi-dimensional analytical technique to gauge energy poverty levels

A total of eleven indicators categorised based on four dimensions were used to construct an individual household energy poverty index, following [105] and [106]. Such an approach is employed, recalling that energy poverty has multiple dimensions and has many facets. The essence of having the four broad dimensions is to capture different aspects of the energy poverty situation. For instance, electrical appliance ownership projects to potential electricity demand in the nearby future as being presented by [107]. On the other hand, ownership of the communication device (i.e., use of digital device like phones) portrays level of communication by households as implied by the energy poverty situation [108]. Moreover, the use of dirty fuels has an implication on polluting the indoor air that negatively impacts children and women who mostly engaged in cooking and lighting activities in homes especially in the developing world [109]. Lastly, the fourth dimension the intensity levels on use of modern fuels [105]. Computation of the household energy poverty index was done using the Principal Component Analysis (PCA). The PCA is a mathematical technique that help to handle multiple dimensions

of datasets to reduce the effects of the curse of dimensionality statistically as it is used in literature [105], [110], [111], [112]. Partly, the PCA demands that all variables that have continuous values ought to be normalized (they get any value within the range of Zero to One depicting magnitude of energy poverty situation with zero being minimal level and one being maximum level). In this case per capita consumption of LPG and per capita consumption of electricity were assigned with new values using the following expression:

$$x_{mn} = \frac{MAX(X_m) - X_{mn}}{MAX(X_m) - MIN(X_m)} \quad (1)$$

Where m is the per capita consumption of LPG or per capita consumption of electricity and other step by step details are found in the published paper [39]. Briefly, the PCA consists of a determinant equation (Expression 2) that captures the weights of each variable known as eigenvalues and also the principal components as depicted in Expression 3.

$$(R - \lambda_i I)F_i^{\cdot} = 0 \quad (2)$$

where $F_i = [f_{1i} f_{2i} f_{3i}]$ is an eigenvector corresponding to λ_i. Expression 2 depicts all the eigenvalues and main focus is only on those eigenvalues that had roots which were larger than 1.

On the other hand, the principal components are captured in expression 3:

$$P_{1n} = x_n F_1^{\cdot}$$

$$\vdots$$

$$P_{3n} = x_n F_3^{\cdot} \quad (3)$$

Where n shows n^{th} family, x_n represent a specific variable for the n^{th} family. Eventually, $x_n = [x_{1n}\ x_{2n}\ x_{3n}\ x_{4n}\ x_{5n} \dots \dots \dots x_{10n}\ x_{11n}]$. This implies that the final index was captured by adding up all the principal components using intrinsic weights (i.e., intrinsic weights refer to the Variance in the successive components as illustrated by expressions 4 and 5 as detailed in the on published paper [39].

$$HEPIn = \frac{\lambda_1 P_{1n} + \lambda_2 P_{2n} + \lambda_3 P_{3n}}{\lambda_1 + \lambda_2 + \lambda_3} \quad (4)$$

$$HEPIn = \frac{\lambda_1 x_n F_1 + \lambda_2 x_n F_2 + \lambda_3 x_n F_3}{\lambda_1 + \lambda_2 + \lambda_3} \quad (5)$$

2.3.2.2 Employing the unidimensional analytical technique to gauge energy poverty levels

With reference to [113], this research work utilized the Unidimensional analytical technique which focused on the shares of energy expenses to total household expenditures. Firstly, households were put into different income level categories in form of income quintiles (bottom level, poor, middle up to the richest level) and also based on the energy costs expenses expressed in per capita terms which inform resource allocation of a general household basic needs basket. Secondly, households were classified based on whether or not they use clean fuels (i.e., electricity or LPG) for every day cooking activities. As such, in this study, a household was labelled energy poor if it falls in the bottom level of the income quintiles to highlight affordability; had per capita energy costs share larger than 10 % of the household income, and finally did not use clean fuels for cooking (i.e., used wood fuels). The mathematical formulations of these criteria taking the probability form are presented in Expression 6 and Expression 7 respectively as follows:

The probability that household would be energy poor): -

$$\mathrm{P}(Y_i = 1) = f(Y_i = \in_1) + f(Y_i = \{\in_3, \in_4) \;\&\; S > 10\%) + f(Y_i = W_i) \quad (6)$$

$\mathrm{P}(Y_i = 0)$ if otherwise (i.e., not energy poor)

where $\in_1, \in_2, \in_3, \in_4$ depicts income quintile category; S depicts the proportion of energy cots to household income; and W_i depicts whether or not a household used clean fuel for primary cooking activities. $f(.)$ just shows that if all the formulation stands in the parenthesis it gets a value of 1 and 0 otherwise (i.e., if it collapses). Thus, the actual formulated household energy poverty situation is:

$$EP_i = \frac{1}{N}\sum_{i=1}^{n}[f(Y_i = \in_1) + f(Y_i = \{\in_{2,} \in_3, \in_4) \;\&\; S > 10\%) + f(Y_i = W_i)] \quad (7)$$

2.3.3 The determining factors for energy poverty incidences in the households

Furthermore, the research work involved also running out multi-level binary logistic regressions to determine factors that affect household energy poverty incidences in both countries. This type of regression framework was chosen because it is able to clusters the standard errors of the

survey datasets taking into consideration the nesting structure households within their respective districts. Moreover, the nature of the outcome variable (energy poverty incidence) was binary getting the value of 1 if the household was energy poor and zero otherwise. Specifically, the study estimated five multi-level binary logistic regressions to handle each energy poverty group. Four energy poverty groups were created using the computed household energy poverty index under the multidimensional framework whilst the other fifth multi-level binary logistic was based on the energy poverty incidences under the unidimensional approach that capitalized only on the energy costs. With reference to [114], [115] and [116], mathematically the multi-level binary logistic regression model is presented in Expression 8:

$$\text{logit}\,(P_{ij}) = \beta_0 + \beta X_{ij} + \mu_j \qquad (8)$$

where β represents a range of fixed effects regression coefficients household features (X_{ij}); μ_j represents random error term at district level.

2.4 Empirical study findings

This section presents the findings from descriptive analysis and also advanced econometric analyses of the current research study.

2.4.1 Results from descriptive analysis

2.4.1.1 The energy use patterns in the households across the two countries

In general, as reported in Table 1, there seems to be a notable difference between the two countries with respect to utilizing clean fuels for cooking or lighting activities. The descriptive statistics analysis reveals that most households in the samples use dry batteries for lighting seconded by electricity. Furthermore, most households do not use clean fuels instead they are predominantly using dirty fuels for primary cooking activities, particularly firewood for cooking, seconded by transitional fuel, mainly charcoal. A significant number of households are using solar for lighting and gas for cooking in Rwanda compared to Malawi. The differences may be attributed to the availability of such fuels, agro-ecological climatic factors, and some socio-cultural differences between the two countries. For instance, Rwanda belongs to the equatorial climatic zone, whilst Malawi belongs to the tropical climatic zone. However, the results of the descriptive statistics are consistent with the current literature, whereby most households in poor economies, especially remote areas with rural populace, do have challenges in accessing modern clean fuels [117], [118].

Table 1. Percentages of energy sources for lighting and cooking in homes

Fuel type	**Share of fuel type used by the household (%)**	
Lighting fuels	**Rwanda**	**Malawi**
Firewood	4.07	2.10
Crop residue	0.71	2.28
Kerosene	5.10	2.02
Electricity	24.51	12.25
Biogas	-	0.05
Batteries +bulb/Torch/Phones	52.34	75.01
Candles	5.46	5.24
Solar	7.55	1.04
Cooking fuels		
Firewood	83.25	80.73
Crop/plant residue	0.62	1.49
Kerosene	0.03	0.02
Charcoal	14.88	15.48
Electricity	0.06	2.26
Biogas/LPG	1.16	0.02
Sample size	14458	12361

Note: For Rwanda, oil lamp & lantern Agatadowa were under the kerosene category

Table 2 and Table 3 highlight energy expenditures patterns of Rwandan households differentiated by the residence location and monetary poverty status in Rwanda and Malawi, respectively. The urban residents and the non-poor households registered high expenditure values for charcoal and electricity fuels. Electricity is placed on highest rank as clean fuel, whilst

charcoal is regarded as transitional fuel on the energy ladder and offers excellent avenue for mitigating indoor air pollution in homes.

Table 2. Energy expenditure patterns (mean values) in Rwandan homes 2016/2017

Variable	Household residence status		Income-based poverty status	
	Urban	Rural	Non-poor	Poor
LPG expenditure per capita (RWF)	1644.06	67.02	502.06	0.00
Electricity expenditure per capita (RWF)	7914.04	695.99	2805.30	153.64
Kerosene expenditure per capita (RWF)	189.50	253.35	289.45	148.96
Charcoal expenditure per capita (RWF)	21227.87	2180.91	7918.70	407.25
Wood expenditure per capita (RWF)	1266.83	1782.85	2277.51	534.61
Candles expenditure per capita (RWF)	722.79	301.78	465.99	188.03
Energy expenditure per capita (RWF)	32679.21	5228.39	14125.41	1420.68
Total consumption per capita (RWF)	846479.40	264672.30	483586.60	123459.50

Source: Author's analysis based on EICV5

On the contrary, the rural residents' households are predominantly using dirty fuels. However, some households which are not poor by monetary poverty recorded high expenditure values for Kerosene and wood fuels in relative terms to the households that are poor by monetary poverty status. But in general terms, rural residents registered low values on the income levels (proxied by capita total consumption) and energy expenses. These findings are in line with the prevailing scholarly works from developing country contexts (i.e., Vietnam, India) which show that the rural residents are positioned in a disadvantage setup due to urban bias in terms of well-being

[119], [120].

Table 3. Energy expenditure patterns (mean values) in Malawi 2016/2017

Variable	Household residence status		Income-based poverty status	
	Urban	Rural	Non-poor	Poor
Electricity expenditure per capita (MK)	9294.68	485.18	3762.26	45.54
Kerosene expenditure per capita (MK)	61.48	84.91	112.03	41.63
Charcoal expenditure per capita (MK)	14795.31	1559.11	6944.65	322.83
Wood expenditure per capita (MK)	8185.97	21106.06	21224.92	15644.44
Candles expenditure per capita (MK)	2348.20	308.61	1130.28	128.79
Energy expenditure per capita (MK)	34685.66	23543.88	33174.15	16183.23
Total consumption per capita (MK)	447892.00	170338.90	323167.90	94804.33

Source: Author's analysis based on IHS4

2.4.2 Energy poverty incidences under the unidimensional analytical technique

First, considering Rwandan case under the unidimensional analytical technique, study findings showed that the southern (51.13%), western (41.61%) and northern (40.7%) provinces, registered high incidences of energy poverty as highlighted in Figure 1. For the Malawian case, in terms of regions, study findings showed that the northern region (27.66 %) recorded high energy poverty incidences, seconded by the southern region (25.74%) and lastly, the central region (20.86 %) as captured in Figure 2. Nevertheless, the rural residents registered high proportion of energy poverty incidence (27.17%) unlike the urban resident that registered low incidences of energy poverty in relative terms (12. 51%).

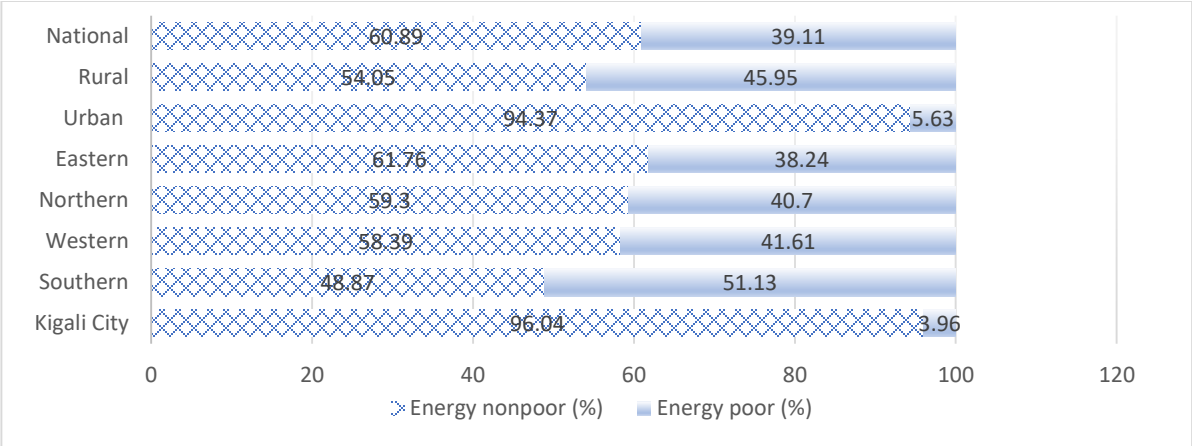

Figure 1. Energy poverty incidences in Rwanda based under unidimensional analytical technique

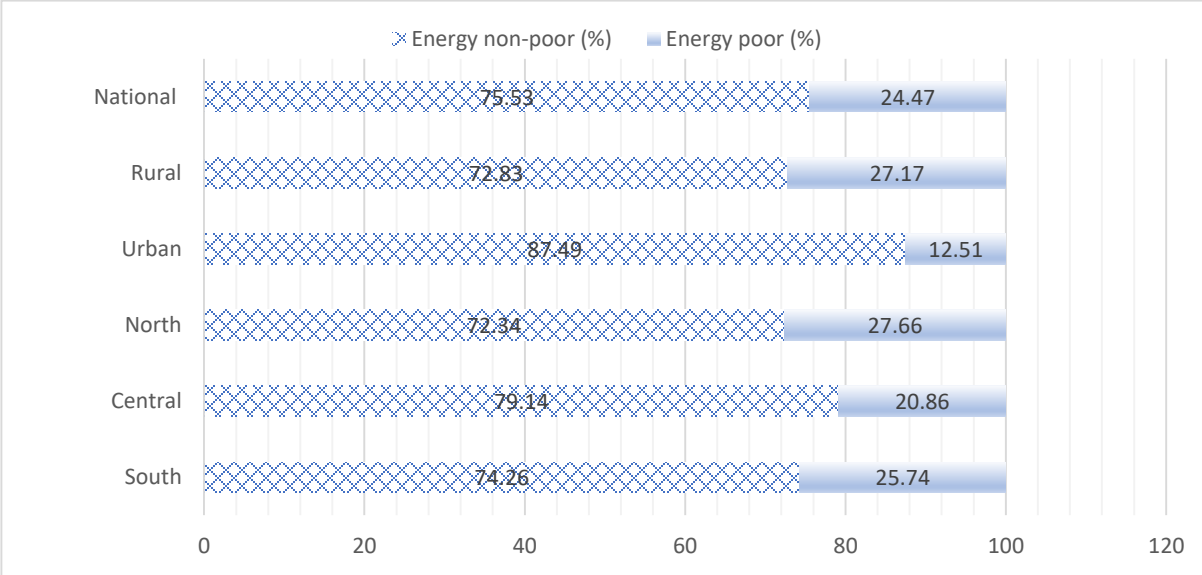

Figure 2. Energy poverty incidences in Malawi based under unidimensional analytical technique

2.4.3 Energy poverty incidences under the multi-dimensional analytical technique

This study utilised the partitioning cluster procedure to create four energy poverty groups namely: - i) the least energy-poor; ii) less energy-poor; iii) more energy-poor; and; iv) the most energy-poor. This process is done using the Stata 15 statistics software whilst using the individual household energy poverty index scores. This procedure permits every observation to fall in a cluster whose mean or median, is near to the observation value whereby new groups can easily be formed using this procedure statistically in Stata statistical software. The drawback to this procedure is that it does not allow values to fall in a neutral category as it is the case with other known standard Likert scales. None the less this procedure is used in the energy studies

as seen in literature [105]. For Rwandan case, estimates of the multi-dimensional analytical technique (Figure 3) revealed that the southern province (30.15%) registered high incidence of multidimensional energy poverty. This was seconded by western province (27.69%) and finally the northern (24.86%) province, as reported in. Finally, rural areas in Rwanda registered a higher rate (28.30%) of multi-dimensional energy poverty than urban areas (7.02%).

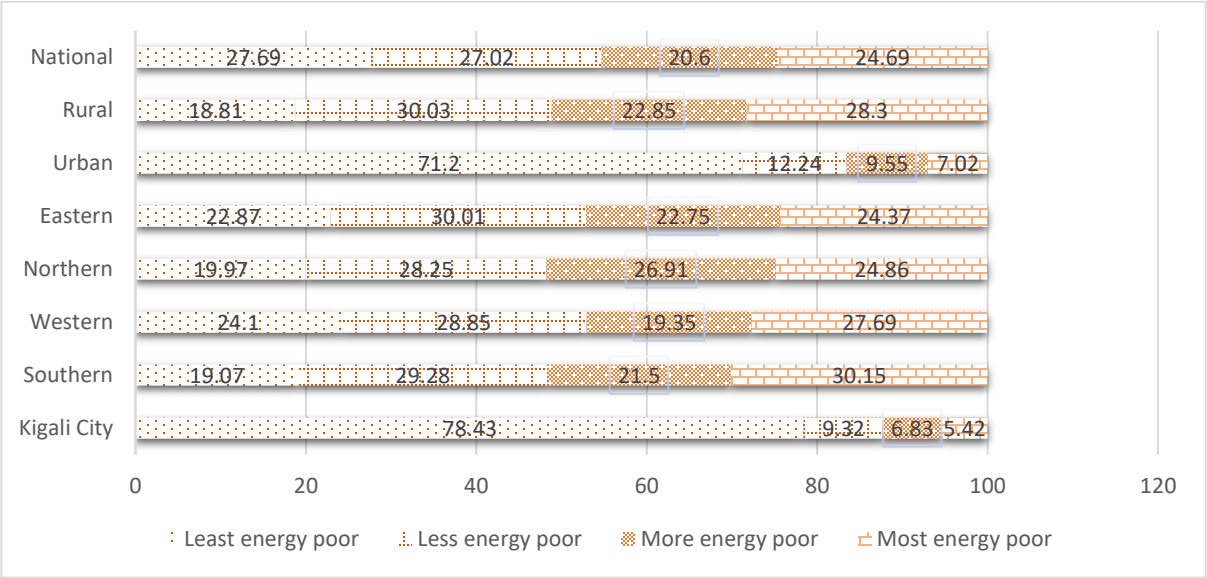

Figure 3. Energy poverty incidences based on a multi-dimensional technique in Rwanda

However, the Malawian case is slightly different. The Figure 4 shows that urban areas had high proportions of households with both the least energy poor (37.74%) and the most energy poor (16.73%) compared to the rural areas, which had the lowest proportions of both the least energy poor (2.91 %) and the most energy poor (5.09%). On regional aspects, the northern region had registered both extremes with a high proportion of least energy poor (12.67%) and most energy poor (12.46%) compared to the remaining two regions. At the national level, Rwanda had registered a high rate of the least energy poor (27.69%) and a high rate of the most energy poor (24.69%) compared to Malawi, which had registered a lower rate of the least energy poor (9.31%) and the most energy poor (7.23%) under the multi-dimensional measure. However, under the unidimensional approach, Malawi had registered low proportions of energy poverty incidence. These preliminary results are a precursor to finding out more about the key factors determining energy poverty phenomenon in these two nations. The subsequent subsection briefly discussed some critical factors that influence energy poverty incidences in the two countries.

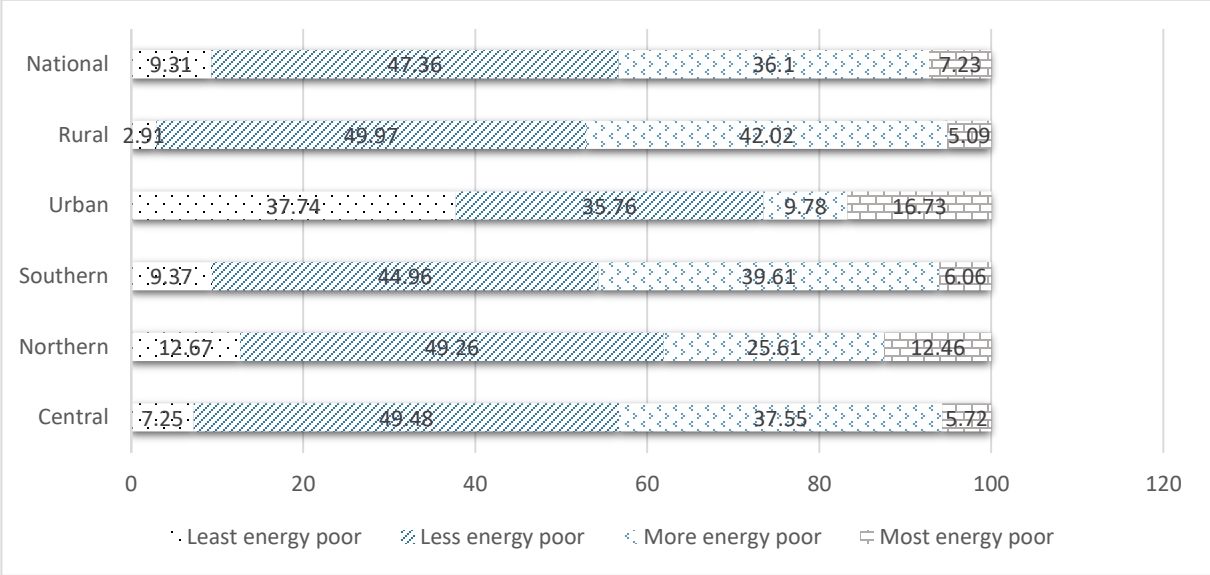

Figure 4. Energy poverty incidences based on a multi-dimensional technique in Malawi

2.4.4 Choosing the explanatory variables to assess factors that affect energy poverty status

The prevailing scholarly works on energy poverty studies guided the selection process of explanatory variables that were used in the multi-level binary logistic regressions (Table 4) regarding determinants of energy poverty [113], [121], [122], [123], [124], [125]. Some of the variables consisted of household characteristics (i.e., age of household head, gender, household size, monetary poverty status, rural residence and the province or the region in which the household resides). The Stata 15 statistical software package was used to carry out all the multi-level binary logistic regression using 5% for testing level of the statistical significance.

Table 4. Summary of the descriptive statistics for explanatory variables

		Rwanda		Malawi	
Explanatory variable	Description	Mean	SD	Mean	SD
Education	Education of household head (1= has formal education)	0.77	0.42	0.14	0.34
Family size	Family size (total number of persons)	4.43	2.11	4.34	1.99
Age	Age of household head (years)	45.24	15.62	43.19	16.08
Poor	Monetary poverty status (1=yes)	0.33	0.47	0.44	0.49
Gender	Sex of household head) (1=male head)	0.74	0.43	0.72	0.45
Rural	Rural residence (1=yes)	0.83	0.37	0.81	0.38
Marital status	The household head is married(1=yes)	0.64	0.48	0.71	0.45
Debt	Presence of any household member who has debts (1=yes)	0.66	0.47	0.25	0.43
Land	Land ownership by any household member (1=yes)	0.82	0.38	0.77	0.42

Source: Author's analysis based on EICV5 and IHS5 except from [39].

2.4.5 Determinants of energy poverty under the unidimensional technique

2.4.5.1 The Rwandan Case scenario

Considering the Rwandan case, Table 5 and Table 7 present estimates from the multi-level binary logistic regression models. To avoid having a lengthy discussion, the discussion has been restricted to those variables that were significant at the 5% level of statistical significance in all the five models. Firstly, the estimates from model 1 showed that the district-level random effects were statistically significant, depicting that the differences in the energy poverty incidences could be attributed to differences that are in the districts under the unidimensional analytical technique that focused on proportion of energy costs to the household income. In this scenario, the district-level random effects explained 16% of the variation in the model and had also

substantial clustering with an intra-class correlation coefficient of 0.05. This intra-class correlation coefficient falls within the range of the conventional threshold of 0.05, that indicates substantial evidence of clustering (Heck et al., 2014). The other model had their district-level random effects as follows: 7% of the variation in Model 2; 2% of variation in Model 3; 3% of variation in Model 4; and 9% of variation in Model 5 with no indications of substantial clustering under the multi-dimensional approach.

Regarding some variables that influenced the energy poverty status, estimates from Model 1, indicated that large family sizes were associated with rising odds of energy poverty incidences (OR= 0.95 CI =0.93-0.97); under Model 2 (OR= 1.10, CI =1.07-1.13); under Model 3 (OR=0.89, CI=0.87-0.91); under Model 4 (OR=0.94, CI=0.92-0.97); and under model 5 (OR=0.97, CI=0.91-1.03). Levels of wealth proxied by asset value also played a critical role and were significant in all the models under the two energy poverty measures. For instance, owning durable assets increased the odds of energy poverty incidence ranging from 0.40 times to1.97 times greater odds under the multi-dimensional energy poverty and 0.90 times more odds under the modified expenditure-based approach. However, land ownership increased the odds of experiencing energy poverty using the unidimensional analytical technique by 1.67 times more than households that did not own land. This finding resonates with the empirical findings of [126] who found that land was closely connected to consumption income of rural households in Rwanda. However, the land ownership factor was not consistent in explaining energy poverty phenomenon under the multi-dimensional approach. The household head's age and education status were only consistent in explaining multi-dimensional energy poverty incidences in Rwanda. Nonetheless, under the Unidimensional analytical technique, educational level and age of the head of the household increased the odds of experiencing energy poverty by 0.80 times and odds by 1.01 times respectively.

Considering the debt status variable, households that had a member with outstanding debts had 0.88 times more odds under the expenditure-based energy poverty and 0.85 to 1.11 times greater odds under the multi-dimensional energy poverty approach compared to households that had members who had no debts. On the household size variable, families with more members had registered 0.95 times more odds from the unidimensional analytical technique. However, household size variable was not consistent in explaining multi-dimensional energy poverty in Rwanda.

Furthermore, rurality played a key role in determining energy poverty status. For example, households residing in the rural areas had 5.32 times more odds of experiencing this phenomenon (OR=5.32, CI= 4.39-6.44) than those households that were residing in the urban areas from Model 1 using the unidimensional measure of energy poverty. The other models under multi-dimensional measure of energy poverty registered the following odds ratios: From model 2 (OR=0.29, CI=0.25-0.34); from model 3 (OR=2.58, CI=2.22-3.01); from model 4 (OR=2.98, CI=2.51-3.54); and from model 5 (OR=2.30, CI=1.56-3.40). There may be different reasons attributed to these empirical findings. For example, Roberts et al. (2015) reported that the strong association of rural residence and energy poverty could be pointing to the low utilisation of modern energy services because of few consumers insinuating low demand and other market related factors that increase production costs on the part of the energy suppliers.

In addition, estimates from Model 1 showed that monetary poverty increased the odds of experiencing energy poverty phenomenon (OR=2.03, CI=1.86-2.22) using the unidimensional technique. On the other hand, varying odd ratios were registered under the multi-dimensional energy poverty measure. For instance, being income poor increased the odds as higher as 2.35 times greater odds, particularly for the less energy-poor group and as low as 0.34 times odds for the least energy-poor group. The study finding resonates with previous study by [127] who had similar empirical results from Kenya. Other scholarly works from Poland by [128], [129] reveal similar sentiments of close relationship of income levels and energy poverty phenomenon. Specifically, [128] noted that families that experience the multi-dimensional poverty are placed in the most challenging set up to fulfill the basic home energy needs. Moreover, the close link between the income and multi-dimensional energy poverty was observed mostly among farming communities in the poor economies that consists of a big population. The same discussion applies to the asset variable that was found to be significant in all the models.

Finally, having residence in the Kigali province attracts both benefits and costs. The estimates revealed different odds ratios for the energy poverty incidences. For instance, households in Kigali province face 0.20 times more odds of experiencing this phenomenon using the unidimensional analytical technique than those residing in the eastern region as a reference. Those households in Kigali were also likely to face 6.25 times greater odds of experiencing multi-dimensional energy poverty than those in the eastern province. This finding shows that urban poor had challenges in accessing and using clean fuels, unlike the wealthy households

that may not find it difficult to access and utilize the clean fuels. In terms of rurality, those households in rural areas registered 5.32 times greater odds of experiencing the energy poverty phenomenon using the Unidimensional technique and as high as 2.98 times more odds of experiencing multi-dimensional energy poverty, especially in the more energy-poor class.

Table 5. Results from the multi-level binary logistic regression for Rwanda

Explanatory variables	Model 1 (Energy poor=1 & 0 otherwise)
	Odds ratio (95% CI)
Land ownership	1.67 (1.46-1.92) *
Education level of household head	0.80 (0.72-0.88) *
Age of household head	1.01 (1.00-.01) *
Income poverty (ref=non-poor)	2.03 (1.86-2.22) *
Asset value (logarithms)	0.90 (0.89-0.91) *
Debt (ref=no)	0.88 (0.80-0.96) *
Rural (ref=no)	5.32 (4.39-6.44) *
Household size	0.95 (0.93-0.97) *
Gender of household head (ref = female)	0.96 (0.83-1.10)
Marital status (ref= not married)	1.10 (0.96-1.25)
Province (ref=Eastern)	
Kigali	0.20 (0.10-0.37) *
Western	0.95 (0.62-1.46)
Southern	1.56 (1.03-2.36) *
Northern	0.97 (0.60-1.54)
Constant	0.11 (0.08-0.17)
District-level random effects	
$\sigma^2_{\mu 0 j}$	0.16 (0.08-0.28) *

Note: * shows the 5% statistical significance level and confidence intervals in the brackets.

Table 6. Results from multi-level binary logistic regression for Malawi

Explanatory variable	Model 1 (Energy poor=1 & 0 otherwise)
	Odds ratio (95% CI)
Land ownership	0.97 (0.84-1.12)
Education level of household head	1.19 (1.02-1.40) *
Age of household head	1.00 (0.99-1.01)
Income poverty (ref=nonpoor)	2.51 (2.27-2.77) *
Asset value (logarithms)	0.96 (0.89-1.04)
Debt (ref=no)	0.78 (0.71-0.88) *
Rural (ref =no)	1.63 (1.31-2.03) *
Household size	1.13 (1.11-1.16) *
Gender of household head (ref = female)	1.02 (0.88-1.19)
Marital status (ref= not married)	0.89 (0.76-1.04)
Region (ref=Northern)	
Central	0.73 (0.51- 1.04)
South	0.90 (0.64-1.25)
Constant	0.07 (0.05-0.11) *
District-level random effects	
$\sigma^2_{\mu 0j}$	0.12 (0.06-0.21) *

Note: * shows the 5% statistical significance level, and confidence intervals are in the brackets.

2.4.5.2 The Malawian Case scenario

For the Malawian case, Table 7 and Table 8 present estimates from the multi-level binary logistic regression models that revealed some of the factors that affect energy poverty in Malawi. As already mentioned in the previous subsections, discussion of these results is restricted only to those variables that were found to be significant at the 5% level of statistical significance in all the five models. The estimates showed that the district level random effects from Model 1 were significant implying that the differences in energy poverty phenomenon would be associated with differences between districts in Malawi. Specifically, under Model 1, district level random effects revealed about 12 % of the variation on the energy poverty incidences and had also an intra-class correlation coefficient of 0.03. The intra class correlation coefficient was within the range of the conventional threshold of 0.05 that depicts that there was substantial clustering [130]. The rest of the models had their district level random effects as follows: Model 2 (21% of the variation with intra-class correlation coefficient of 0.06; Model 3 (7% of the variation without substantial clustering); Model 4 (10% of the variation without substantial clustering); and Model 5 (7% of the variation without substantial clustering).

Several variables showed significant relationship with the energy poverty phenomenon following the results from the two analytical techniques or metrics. Firstly, ownership of a piece of land or a plot for agricultural activity was associated with different odds ratio values under the multidimensional analytical technique. Specifically, the less energy poor registered 1.47 greater odds whilst the more energy poor registered 1.22 greater odds of experiencing multidimensional energy poverty compared to those households which do not own a piece of land or plot for agricultural activity. However, land ownership was not a significant factor in explaining the energy poverty status using the unidimensional metric or analytical technique contrary to what was found under the Rwandan Case study. It is worth noting that land ownership consistently explained the multi-dimensional energy poverty status in Malawi but not in Rwanda.

As already highlighted, land ownership was a significant variable that partly explained energy poverty phenomenon using the unidimensional metric or analytical technique in the Rwandan case. Households headed by individuals with formal education had increased odds of experiencing energy poverty under all the two approaches except the most energy-poor category. For example, under the expenditure approach, households headed by persons with

formal education registered 1.19 times greater odds than those without formal education. Formal education status of the head was statistically significant in explaining energy poverty phenomenon using the multidimensional metric or analytical technique but not under the unidimensional metric. The same applies to asset ownership, male-headed ship, households with married heads, and households in central or southern regions. These factors were not statistically significant in explaining energy poverty phenomenon under the unidimensional metric or analytical technique.

However, the remaining factors that consistently affected energy poverty status under both approaches were income poverty, debt by any household member, rural location and household size. Households with income poverty had increased odds of energy poverty as high as 2.51 times greater odds under unidimensional metric or analytical technique and as high as 3.56 times greater odds using multi-dimensional metric with the class of the more energy-poor category. Debt status by any household member also increased the odds of experiencing energy poverty status under the two approaches, with high values reported under the multi-dimensional energy poverty approach. For example, households that had any member who had outstanding debt had greater odds of energy poverty by 0.78 times under the modified expenditure approach and as higher as 1.18 times greater odds under the multi-dimensional energy poverty approach within the category of the most energy-poor compared to those households that did not have any member who had debts.

On rurality, rural residents registered 1.63 times more odds of experiencing energy poverty under unidimensional metric and as high as 2.88 times more odds of experiencing this phenomenon using the multi-dimensional metric, especially in more energy-poor classes than their urban counterparts. Finally, household size also played a critical role in determining energy poverty under the two approaches. Households with more members registered 1.13 times greater odds under the modified expenditure-based approach and 1.28 times greater odds under the multi-dimensional energy poverty, particularly under the least energy-poor class.

This research study has some drawbacks. The study utilised self-reported data on consumption expenditures subject to recall bias. It may either result in over-reporting or under-reporting of the actual figures. The energy expenditures were also annualized, leading to underestimation or overestimation since the study assumed the same rate over time. The use of cross-sectional datasets in the study does not permit the advanced analysis of energy poverty trends and causal impacts of the findings.

Table 7. Results from Multi-level binary logistic regressions of several energy poverty groups for Rwanda

Independent variables	Model 2 (Least energy poor)	Model 3 (Less energy poor)	Model 4 (More energy poor)	Model 5 (Most energy poor)
	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)
Land ownership	0.69 (0.59-0.81)*	1.12 (0.99-1.28)	1.47 (1.26-1.71)*	1.10 (0.81-1.50)
Education of household head	1.71 (1.46-2.00)*	0.78 (0.71-0.86)*	0.95 (0.85-1.07)	0.79 (0.63-0.99)*
Age of household head	0.99 (0.99-1.00)*	1.00 (1.00-1.00)	1.01 (1.00-1.01)*	1.00 (1.00-1.01)
Income poverty (ref=non-poor)	0.34 (0.30-0.40)*	2.35 (2.14-2.59)*	1.25 (1.12-1.39)*	1.48 (1.19-1.84)*
Asset value (logarithms)	1.97 (1.90-2.04)*	1.17 (1.15-1.18)*	1.30 (1.27-1.32)*	0.40 (0.39-0.41)*
Debt (ref=no)	1.07 (0.95-1.20)*	1.11 (1.02-1.21)*	0.95 (0.86-1.05)	0.85 (0.69-1.05)
Rural (ref=urban)	0.29 (0.25-0.34)*	2.58 (2.22-3.01)*	2.98 (2.51-3.54)*	2.30 (1.56-3.40)*
Household size	1.10 (1.07-1.13)*	0.89 (0.87-0.91)*	0.94 (0.92-0.97) *	0.97 (0.91-1.03)
Sex of household head (ref = female)	1.01 (0.82-1.23)	0.73 (0.63-0.84)*	1.52 (1.29-1.80)*	1.05 (0.77-1.43)
The household head is married (ref= unmarried)	1.08 (0.90-1.29)	1.08 (0.94-1.23)	0.95 (0.81-1.10)	0.86 (0.64-1.17)
Province (ref = Eastern)				
Kigali	6.25 (4.08-9.57)*	0.38 (0.28-0.51)*	0.33 (0.23-0.46)*	0.20 (0.10-0.39)*
Western	2.36 (1.72-3.26)*	1.06 (0.86-1.29)	1.08 (0.87-1.34)	0.65 (0.41-0.99)*
Southern	1.38 (1.02-1.89)*	1.09 (0.90-1.33)	1.20 (0.97-1.48)	0.63 (0.42-0.96)*
Northern	1.39 (0.98-1.97)*	0.96 (0.77-1.20)	1.52 (1.20-1.92)*	0.67 (0.41-1.07)
Constant	0.00 (0.00-0.00) *	0.10 (0.07-0.13) *	0.01 (0.00-0.01)*	11.05 (5.71-21.39)*
District-level random effects				
$\sigma^2_{\mu 0j}$	0.07 (0.04- 0.13) *	0.02 (0.01-0.05) *	0.03 (0.01-0.06) *	0.09 (0.04-0.23) *

Note: * shows the 5% level of statistical significance, and confidence intervals are in the brackets.

Table 8.Results from Multi-level binary logistic regressions of several energy poverty groups for Malawi

Independent variables	Model 2 (Least energy poor)	Model 3 (Less energy poor)	Model 4 (More energy poor)	Model 5 (Most energy poor)
	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)	Odds ratio (95% CI)
Land ownership	0.32 (0.26-0.39)*	1.47 (1.31-1.64)*	1.21 (1.06-1.39)*	0.72 (0.60-0.87)*
Education of household head	0.22 (0.19-0.27)*	1.41 (1.24-1.58)*	2.09 (1.77-2.47)*	1.01 (0.84-1.21)
Age of household head	1.02 (1.01-1.03)*	0.98 (0.98-0.99)*	1.00 (1.00-1.01)*	0.99 (0.98-0.99)*
Income poverty (ref=nonpoor)	0.04 (0.02-0.06)*	0.67 (0.62-0.73)*	3.56 (3.22-3.92)*	0.22 (0.18-0.27)*
Asset value (logarithms)	1.17 (1.10-1.24)*	0.87 (0.81-0.91)*	0.98 (0.90-1.06)	0.96 (0.89-1.03)
Debt (ref=no)	0.81 (0.68-0.96)*	1.15 (1.06-1.25)*	0.83 (0.75-0.92)*	1.18 (1.01-1.38)*
Rural (ref=urban)	0.17(0.13-0.22)*	1.44 (1.22-1.71)*	2.88 (2.29-3.63)*	0.58 (0.45-0.74)*
Household size	1.28 (1.23-1.34)*	1.08 (1.05-1.10)*	0.77 (0.75-0.92)*	1.17 (1.12-1.21)*
Sex of household head (ref = female)	1.23 (0.95-1.59)	1.83 (1.62-2.06)*	0.52 (0.46-0.60)*	0.97 (0.76-1.24)
The household head is married (ref=unmarried)	1.08 (0.83-1.39)	1.11 (0.98-1.26)	0.68 (0.59-0.79)*	1.56 (1.20-2.01)*
Region (ref = Northern)				
Central	0.60 (0.36-1.02)	0.90 (0.68-1.20)	1.84 (1.32-2.57)*	0.42 (0.30-0.58)*
Southern	1.11 (0.68-1.78)	0.81 (0.62-1.07)	1.62 (1.19-2.21)*	0.50 (0.37-0.67)*
Constant	0.34(0.20-0.55)*	0.35 (0.26-0.98)*	0.14 (0.09-0.19)*	0.16 (0.10-0.24)*
District-level random effects				
$\sigma^2_{\mu 0 j}$	0.21(0.09-0.45)*	0.07 (0.04-0.14)*	0.10 (0.05-0.17)*	0.07 (0.03-0.16)*
Icc intraclass correlation coef	0.06	0.02	0.03	0.02

Note: * shows the 5% level of statistical significance, and confidence intervals are in the brackets.

2.5 Chapter conclusion and policy lessons

The chapter investigated the energy poverty phenomenon using two analytical techniques. First the research study employed unidimensional metric that puts emphasis on the affordability aspects to gauge the energy poverty status of households. Secondly, the study also employed the multidimensional analytical technique that focuses on several aspects of energy poverty phenomenon beyond the affordability challenge by the households. The study utilised secondary datasets that were collected by national institutes of statistics in the respective country under the Integrated Household Living Conditions Surveys (EICV5 for Rwanda, IHS5 for Malawi) in collaboration with the World Bank and other development partners. datasets. Preliminary results from descriptive statistics of household energy use patterns showed that batteries plus torches and electricity are primary lighting fuels for both countries. The notable difference is that Rwanda has a higher proportion of solar users than Malawi. However, both countries heavily use firewood and charcoal for cooking, although Rwanda registered minimal LPG users compared to Malawi. Disaggregation of household energy expenditures by monetary poverty and rurality showed that the urban and the non-poor spent more on charcoal and electricity. However, in both countries, some non-poor spend more on kerosene fuel.

The estimates form the multi-level binary logistic regression models showed that the education level of a household head, income level, debt status of the household members, household size and rurality are critical determinants using the unidimensional metric for energy poverty in the two countries. A cross-comparison with the estimates from multi-level binary logistic regression models using the multi-dimensional metric or analytical technique revealed that income levels, assets, rurality and being a Kigali resident were crucial determinants in Rwanda. However, land ownership, age of household head, income level, debt status of the household members and rurality were vital determinants. Moreover, the statistical significance of district level random effects from the multi-level binary logistic regression models implies that the differences across the districts also influence the energy poverty phenomenon.

Regarding policy recommendations, the empirical findings under this chapter emphasize the need to address the energy poverty phenomenon wholistically by paying attention to differences that exist between different affected groups. Energy poverty phenomenon affect all members of society regardless of the socioeconomic status. Note that a single welfare policy instrument cannot address this phenomenon in its entirety. It requires main players to tackle this problem. For example, the governments in question can provide a conducive

business environment by engaging the private multinational and local companies through public private partnerships.

Further studies can employ consensual approaches that capitalizes on self-reported responses and may complement the findings from the approaches that employ the objective tools (PCA tool) which was employed in this doctoral study. The present study could not address this limitation because the secondary datasets especially those in developing context did not capture or do not capture that kind of information. In addition, there is need to carry out a specific household primary survey that will employ the engineering-based techniques that use actual physical quantities to gauge other aspects such as energy efficiencies in the homes or in residential buildings.

CHAPTER THREE

THE EFFECT OF ENERGY INSECURITY ON EDUCATION AND HEALTH

The chapter investigated the economic status and other household features of households that face the energy insecurity and analyzed its impact on education and health in Rwanda and Malawi. Specifically, the study is based on secondary datasets (consisting of samples of 14458 Rwandan families from EICV 5 and 12,439 Malawian families from IHS4). In summary, empirical findings indicated that there are already some notable differences in terms energy choices for cooking and lighting activities between energy insecure and energy secure homes. Other differences arose due to differences in the housing tenure, housing tenure, dwelling characteristics, and geography. The results from probit regressions confirm the preliminary findings from descriptive statistic analysis. In the Rwandan case, statistically significant marginal effects from the probit model suggest that energy insecurity status reflects differences in household demographics, assets, dwelling features and access to basic infrastructure for water and electricity. Additional results from instrumental variable probit regressions in the two countries confirm the negative effect of energy insecurity on child school attendance. Regarding household health status, the results from instrumental variable approach using data from the two countries confirmed that energy insecurity increased the chance of family members falling ill.

3.1 Introduction

This chapter investigated the economic status and other household features of households that face the energy insecurity and analyzed its impact on education and health in Rwanda and Malawi in two developing country contexts based on the published paper [131]. Household Energy insecurity was described as a situation whereby a household is incurring energy costs share of more than 10 % of total household budget [132], [133], [134]. Simply put, a household was labelled energy insecure using the 10% proportion of its energy expenses on the total household income as fully expanded in the published work [131]. There are also other empirical methods that employ engineering-based approaches to label energy insecure homes. For example, [132] studied energy insecurity status of Cambodian homes as those homes that had registered the minimum benchmark of 600 kWh/ year for electricity consumption. In a similar manner, [135] used the benchmark of 2125 kWh in a Guatemala study. The drawback of using these two approaches is that econometric analysis is only feasible for those households that have national grid connections leaving out some households that do not have national grid connections.

The current chapter investigated the following research questions:

1) Which socioeconomic characteristics describe the households labelled as energy-insecure in the two countries?

2) How does energy insecurity affect education and health outcomes in the two countries?

3) What policy recommendations can be drawn for the current empirical study?

The empirical findings from this study found that energy insecurity negatively impacts the child's school attendance and increases the chance for household members to fall ill. Understanding the specific household development outcomes are being affected by this challenge would help to shape not only the energy policy direction but may help to bring synergies amongst different players working towards the sustainable development agenda in both short term and medium-term period especially in poor economies. The remaining part of this chapter is arranged in the following way. Literature review is presented in Section 2 whilst Section 3 highlight methodological aspect of the study. Section 4 highlights the empirical findings and some discussion on the same. Finally, the conclusion of this chapter and areas of further studies is highlighted in Section 5.

3.2 Literature review

The growing literature on energy studies presents a wide array of different terminologies, measures and dimensions that are used to explain the energy insecurity problem and energy issues that are prevalent in the energy literature. Globally, energy access terminology refers to proportion of people that have basic electricity supply either through the national grid connection or through off-grid energy options and is used widely in many public policy platforms by several development practitioners that push for sustainable development agenda with special interest on SDG 11 (focuses on sustainability of cities and communities) and SDG7 (focuses on provision of affordable and clean energy) [136], [137].

On the other hand, the term energy burden refers to a predicament whereby households incur energy costs that exceed 6 % of their total income and is widely debated in the United States of America [138]. The public debate on energy burden largely revolves on the fact that a given household is supposed to spend not more than 30% of its household income on housing expenses and also supposed to spend not more than 20% on utility costs. Stillmore, there is an ongoing debate regarding different thresholds or new propositions of metrics that should be used to measure energy burdened homes in the USA. For example, [139]further brought new categories such as energy-stressed homes (referring to those families that had energy

burden within the range of 4 to 7% of the family budget); energy-burdened homes (referring to those families that had energy burden within the range of 7 to 10% of the family budget); and lastly the energy-impoverished homes (referring to those families that register energy burdens that exceed 10% of the family budget). In simple words, the energy burden term refers to proportion of household income that is used to pay for energy expenses and the poor families usually struggle to meet other basic needs because a large proportion of their income is set aside for energy expenditures [140].

On the other hand, there are several propositions that used to describe the energy insecurity situation. For example, [141] described "energy insecurity" as a predicament whereby a family is not sure whether it will be able to settle its utility costs, and might end up having disruptions on its energy supply services due to disconnections that may occur in short- or long-term period. [142], [143] documented that energy security description usually differ when considering the specific research study context. To emphasize this point, the International Energy Agency (IEA) highlighted another proposition of energy security terminology, and described energy security as uninterrupted availability of energy sources at an affordable price [144]. Noting the fact that there are plenty descriptions on energy insecurity terminology, the current chapter defined 'energy-insecure homes' as those families that spend greater than 10 % of family budget on to settle energy bills as earlier mentioned in the introduction section [132], [133], [134].

Looking at the existing literature, there is still research gaps on documenting the effects of energy insecurity at micro level. Bearing this in mind, this chapter focused on analysing the effects of energy insecurity on household development outcomes (health and education) using the nationally representative samples from the Integrated household living standard surveys in Malawi and Rwanda. Utilising such extensive sample datasets, is one way of contributing to limited scholarly works that investigate energy insecurity and its impact on development outcomes at the micro level in the Eastern and Southern Africa context.

3.3 Materials and methods

This section highlights briefly the sources of data, data description, and different analytical methods that were used to address the research question of this chapter.

3.3.1 Sources of data and description

This section presents the sources of datasets that were used in the current study.

3.3.1.1 Malawian dataset

As already mentioned in the previous chapter, this research study used secondary datasets that are collected by the National Statistics Office in Malawi. This office conducts integrated household surveys regularly in collaboration with the World Bank and other development partners. This chapter focuses on a nationally sample dataset of 12, 439 families that had full information variables of interested collected between 2016 and 2017 under the Fourth Integrated Household Survey [104]. This sample of households is selected following a stratified two stage sampling procedure so that it reflects information at all levels from national level, district levels, and also taking into consideration of the rural-urban strata. The initial stage involved clearly marking the primary sampling units based the census enumeration areas of the 2008 Malawi Population and Housing Census. The whole country is demarcated with 768 enumeration areas whereby, within each enumeration area, a total of 235 families are considered. Roughly, a district needs to have 24 enumeration areas whereby 16 families are considered in each of the enumeration area.

3.3.1.2 Rwandan dataset

The study used primary datasets consisting of 14456 families that had full information on variables of interest collected by National Institute of Statistics of Rwanda (NASIR) between 2016 and 2017 under the EICV5 with assistance from the World Bank and other development partners. The datasets are nationally representative of and cover all five provinces of Rwanda and covered the basic information on access to essential services, household expenditures, dwelling characteristics and other detailed information. The NASIR in close links with the World Bank through its internet websites allows the public to use its datasets provided that they seek permission from them because they are the data custodians. In the current study, authorisation to use the datasets were approved electronically. The NASIR employs a Proportional Probability Sampling procedure to get final sample using the 2012 census frame to make sure that it is a reflection of the whole country, provinces, districts, rural-urban strata and finally at village level as documented by the NASIR's survey report [102].

3.3.2 Data description

3.3.2.1 Dependent and Independent variables

[145] noted that children time use on wood fuel collection was negatively related to their school attendance. In other words, energy poverty is associated with school absenteeism and the incidence of illness [146], implying that energy security is crucial to improve schooling outcomes and reducing the incidence of illness. Previous literature shows that school

absenteeism is widespread among impoverished students [147]. In these studies, school absenteeism refers to "any illegitimate absence from school for at least a day" [148], [149]. [150] noted that inadequate access to modern energy services may be considered as deprivation just like any other poverty since it hinders people from utilising their human capabilities to reach their full potential. Therefore, this study focused on child school attendance and household health status as main outcome variables or say dependent variables. The two variables would stand for household development outcome and household well-being outcome respectively. as "proxy" for household human development and welfare outcomes, respectively. A dependent variable (binary) for education outcome is school attendance by 7 to 18-year-old school-going children in Rwanda; for Malawi, it was school attendance by 6 to 18-year-olds due to differences in the official primary school entry ages. In the Rwandan case, school attendance takes a value of 1 in the case a seven-year-old child registered an absenteeism during school days in the past week and zero if otherwise. For the Malawian case, school attendance takes a value of 1 if a child aged 6 to 18 is reported to have temporarily withdrawn from school for two weeks in the past year. On health outcome, household health status was captured as "the number of household members who have been sick and sought medical attention for past four weeks" for the Rwandan case. In the Malawian case, it was captured as the number of family members who have been ill in the past fortnight period (2 weeks).

As already indicated, a key independent variable of interest was energy insecurity, and more details are presented in the following subsection. In addition, choosing the other key regressors of independent variables in the final regression models was guided by the prevailing literature on similar studies [119], [132], [133], [151].

3.3.3 Empirical models

Statistically and economically, following [131], [132], [146] and [152], to test the relationship between energy insecurity and human development outcome through child school attendance is formulated as follows: -

$$\mathrm{P}(E_i = 1) = \mathrm{Q}(E_i = SE > 10\%) \text{ if household is not energy secure;}$$

$$\mathrm{P}(E_i = 0) \text{ if otherwise} \qquad (1)$$

From expression (1) SE depicts proportion of energy expenses in the total family budget, Q(.) depicts final expression with the value of 1 if the whole expression in the parenthesis holds and zero otherwise. This shows how the household's energy insecurity (EI) impacts

the development outcome in question whenever Q(.) takes the value of 1 and zero otherwise and hence summarizing everything here is as follows:

$$\mathrm{EI_i} = \frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{n}}[\,\mathrm{Q(E_i = SE > 10\%)}] \qquad (2)$$

Energy insecurity is suspected to be endogenous to the child's school attendance. As such, finding some variables that can act as "instruments" is imperative. Instruments (Z_i) in this case, are the exogenous variables in the dataset which were associated and linked with energy insecurity incidence (EI_i) and had no correlation with the random term (u_i) of expression (3) [132], [153]. It is very challenging to get a valid instrument in empirical studies, and some scholars have resorted to a falsification test suggested by [154]. However, [132] and [146] highlighted some variables that can act as "instruments", such as dwelling characteristics and others. Therefore, an Instrumental Variable Probit model (IV-Probit) was used because the outcome variable was binary and two equations were formulated as follows:

$$H_i = \phi_0 + \phi_1 EI_i + \phi_i X_i + u_i \qquad (3)$$

$$EI_i = \gamma_0 + \gamma_i Z_i + \varepsilon_i \qquad (4)$$

The expression (3) shows that household energy insecurity incidence ($\mathrm{EI_i}$) is one of the independent variables that influence the household well-being. On the other hand, $\mathrm{H_i}$ is a latent variable (dependent variable) depicting child school attendance (education outcome). In equation (4), $\mathrm{EI_i}$ is the dependent variable which takes the value 1 if the family is found to be energy-insecure and takes the value of zero if otherwise. Finally, $\mathrm{X_i}$ represents all the independent variables that were used in the regression model such as demographics (i.e., age of household head, education level and others); $\mathrm{u_i}$ or ε_i depict the random disturbance terms that have a normal distribution, statistically $\mathrm{u_i}$ or $\varepsilon_i \backsim \mathrm{N}(0,1)$ and ϕ, γ depict estimated coefficients from the regression models. Stata 15 statistics software package was used for all statistical analysis.

Now, to assess the relationship between the energy insecurity and household health outcomes, the following statistical models were employed, referring to [146]:

$$\mathrm{W_i} = \phi_0 + \phi_1 \mathrm{EI_i} + \phi_i \mathrm{X_i} + \mathrm{u_i} \qquad (5)$$

$$\mathrm{EI_i} = \gamma_0 + \gamma_i \mathrm{Z_i} + \varepsilon_i \qquad (6)$$

The equation (5) shows that household energy insecurity incidence (EI_i) is one of the independent variables that affect the family health status. Equation (5) depicts a Two Stage Least Square Model (2 SLS) that have capacity of handling the potential endogeneity between energy insecurity and household health status, w_i is a latent variable (dependent variable) which depicts household health status (number of household members sick and sought medical attention for past four weeks) in Rwandan case and Malawian case, number of family members who reported to be ill in previous fortnight period (past 2 weeks). As for equation (6), it still depicts a probit model, EI_i is the dependent variable which takes the value of 1 if the home is energy-insecure and zero if otherwise. As already mentioned in previous paragraphs, X_i represents all the independent variables that were used in the regression model such as demographics (i.e., age of household head, education level and others); u_i or ε_i depict the random disturbance terms that have a normal distribution, statistically u_i or $\varepsilon_i \backsim N(0,1)$ and ϕ, γ depict estimated coefficients from the regression models. Stata 15 statistics software package was used for all statistical analysis.

3.3.3.1 Robustness Check

The study suspects that there are many areas where endogeneity can arise. Unobserved differences hidden among the household head and other household features may influence energy insecurity in homes. In addition, the different challenge is reverse causality between energy insecurity and household health status, making it difficult to get one plausible instrument variable. Hence, this study also considered some quasi-experimental techniques, such as propensity score matching (PSM), that control for observed features to match observable features of energy-secure and energy-insecure households to get estimated propensity scores. PSM was employed to test the robustness of the results from the IV -2 SLS model. Following, [155], [156] a propensity score refers to a probability of getting selected into a treatment based on stipulated predefined or pre-treatment conditions (variables of interest prescribed by the researcher) as set by the researcher and is mathematically expressed in the following way: -

$$P(X) \equiv Pr\{EI_i = 1|X\} = E\{EI_i|X\} \qquad (7)$$

Where $EI_i = \{0,1\}$ depicts the treatment indicator (energy insecurity status), and X represents the predefined or pre-treatment conditions (variables of interest prescribed by the researcher). So, the assumption here is that if the treatment is a random event based on the predefined conditions of the X variables, therefore, the anticipation here is that the values of the propensity scores P(X) would be random as initially proposed by [155]. This gives the

following proposition regarding the population of units of interest which is denoted by I. Suppose, the propensity P ($X_{i)}$) is established beforehand, the researcher can get the estimate of e average treatment effect on the treated (ATT) in the following expression:

$$ATT = E\{W_{1i} - W_{0i}|EI = 1\} = E(W_{1i}|EI = 1) - E(W_{0i}|EI = 1)$$

$$= E(W_{1i}|EI = 1, p(X) - E(W_{0i}|EI = 1),\ p(X)) \quad (8)$$

On the other hand, the study also employed the Inverse Probability Weighting (IPW) technique that ensures that observed characteristics between the treated and control group are almost same in their probability distribution to overcome the problem of selection bias as it is postulated in literature [157]. IPW technique makes an artificial sample whereby selection into the treatment is not directly dependent on the observables; instead, it weighs observations of the inverse probability of being treated to generate a pseudo-random sample [157], [158]. Clearly, this procedure consists of two steps to realize the actual treatment effects and is specified as follows: -

1) The probability [now depicted as $p_i(x)$] of selected into the treatment is estimated through probit or logit model. From the estimates of the probit or logit model, the researcher gets the probability weights. The inverse of the estimated probability weights is what generates the artificial random sample known as the new pseudo-random sample in the literature. Then weights (g_i) from the probit or logit models are built in the following way:

   $g_i = 1$ if $EI_i = 1$

   $g_i = \frac{p_i(x)}{1-p_i(x)} 1$ if $EI_i = 0$

2) The second step involves computation of Average Treatment on the Treated using the artificial sample or say the new pseudo random sample by running a probit or logit regression of the outcome variable and the intercept and whilst incorporating the weights that generated in step one. Technically, the estimated coefficient on the treatment variable in the regression model is referred as the ATT.

3.4 Empirical findings

3.4.1 The characteristics of households that face the energy insecurity

H1: Households with poor social and economic status (lack ownership of assets such as land and livestock) and poor dwelling characteristics have a high likelihood of being energy-insecure

3.4.1.1 Prevalence rates of energy insecurity status in the two countries

Energy insecurity in homes may also be a result of an outcome of poverty because poor people may not afford modern energy services due to limited financial budgets or limited in terms of income-generating activities that require power and other productive activities [159]. Other factors affecting energy security include geographical location, agro-ecological factors, climatic variables, population and other infrastructures [160]. Furthermore, noted that having a grid connection does not necessarily imply that a household has energy. In some cases, issues of affordability and reliability of the grid energy supply may play a critical role such that having a connection does not automatically imply that the household will have energy access that can satisfy the minimum thresholds. On the other hand, it may also indicate an overestimation as some households may have a wide range of backup sources, such as solar panels with high-energy-efficient appliances. As such, this study considered two measures of energy insecurity following [132], [146], [161].

The estimates of energy insecurity are presented in Table 9. First, energy insecurity (1) targeted those households whose energy expenditures exceeded 10% of the total household expenditures. Secondly, energy insecurity (2) targeted those households that have a national grid connection in their homes. The prevalence rates show Rwandan families have lower energy insecurity incidences (22.48%) compared to Malawian households (42.58%) using the first measure. However, within Rwanda, off-grid households (12.64%) are less energy-insecure than on-grid families (52.79 %), which are energy-insecure, may be due to high electricity tariff. This implies that the off-grid homes may be utilizing other off-grid energy solutions. It is precisely the opposite with Malawian households. The on-grid households (30.32%) are less energy insecure compared to off-grid homes (44.29%). The case of Malawi implies that the off-grid households have limited off-grid energy solutions, which could have reduced their energy burdens. Despite that, the study highlighted two measures of energy insecurity in this subsection; to maintain brevity, the advanced econometric analysis focused on the first measure. The second measure of energy insecurity only focused on the subsample of grid-connected homes, which is a limitation because it excludes other households.

Table 9. Prevalence of household energy insecurity in the two countries

Energy secure status	EICV5-2016/17 (Rwanda)			IHS4 -2016/17 (Malawi)		
	Full sample (n=14458)	Off-grid (n=10914)	On-grid n=3544)	Full sample	Off-grid (n=10922)	On-grid (n=1517)

				(n=12439)		
Energy insecurity (1)[a]						
Secure	77.52	87.36	47.21	57.42	55.71	69.68
Insecure	22.48	12.64	52.79	42.58	44.29	30.32
Energy insecurity (2)[b]						
Secure	-	-	8.47	-	-	79.10
Insecure	-	-	91.53	-	-	20.90

Source: Author's computations from EICV5 and IHS4.

An "a" using 10% measure for Full samples whilst "b" using 100 kWh per capita per year for grid-connected subsamples

3.4.1.2 Mean comparisons and other distribution charts (Radar charts, binscatter plots)

The household were assessed based on the following factors namely: (a) energy choices and electricity status, (b) geographic variables (regional or district location), (c) demographic variables and (d) housing tenure, dwelling status and asset variables. The mean tests were conducted between the energy-insecure and energy-secure groups. The results of the mean tests revealed that two groups registered differences in terms of primary energy sources for lighting and cooking activities (Table 10). Table 10 highlights the values of the means for lighting and cooking fuel choices between the two groups justified by the significant P-values. For example, the energy-insecure homes seemed to use tend to use kerosene and fuel wood as their lighting fuels more than the energy-secure in the Malawian case study, unlike Rwanda in relative terms. Regarding the cooking fuels, the results of the mean tests showed the two groups did not have notable differences when it comes to modern cooking fuels and this is common in both countries.

The study also plotted some bar charts and radar charts for the two countries using Microsoft Excel software (specifically on electricity access and also power outages) to see the differences between the two groups. There were truly differences in terms electricity access from the national grid as graphically presented in Figure 8A and Figure 8B the full samples whilst Figure 9 and Figure 10 highlighted power outages for the sub-sample homes that had national grid connection. The results are in tune with postulation of [162] said that energy insecurity may be a temporary of a long-term phenomenon depending on several factors.

This phenomenon might be perpetuated because of inadequate access to modern energy infrastructures leaving households in despicable condition for longer period. In contrast, in the short-term, it stems from other circumstances such as natural disasters that disturb the energy supply.

Table 10. Results of means tests in terms of lighting and cooking fuels

Variable	The difference in means (Malawi)			The difference in means (Rwanda)
	(Energy secure)-(energy-insecure)	P- value of diff.	(Energy secure)-(energy-insecure)	P- value of diff.
Lighting fuel choices				
Biogas, Solar & grid electricity (1 =yes)	0.063	0.000	-0.396	1.000
Kerosene (1=yes)	-0.029	0.000	-0.090	1.000
Fuel wood (1=yes)	-0.014	0.000	0.051	0.000
Torches (1 = yes)	0.002	0.766	0 .435	0.000
Others fuels	-0.022	0.000		
Cooking fuel choices				
Gas or electricity (1= yes)	0.027	0.000	-0.012	1.000
Kerosene & charcoal (1=yes)	0 .058	0.000	-0.402	1.000
Fuel wood (1=yes)	-0.102	0.000	0.414	0.000
Other fuels (1=yes)	0.017	0.000		
Observations (samples)	12,439		14,458	

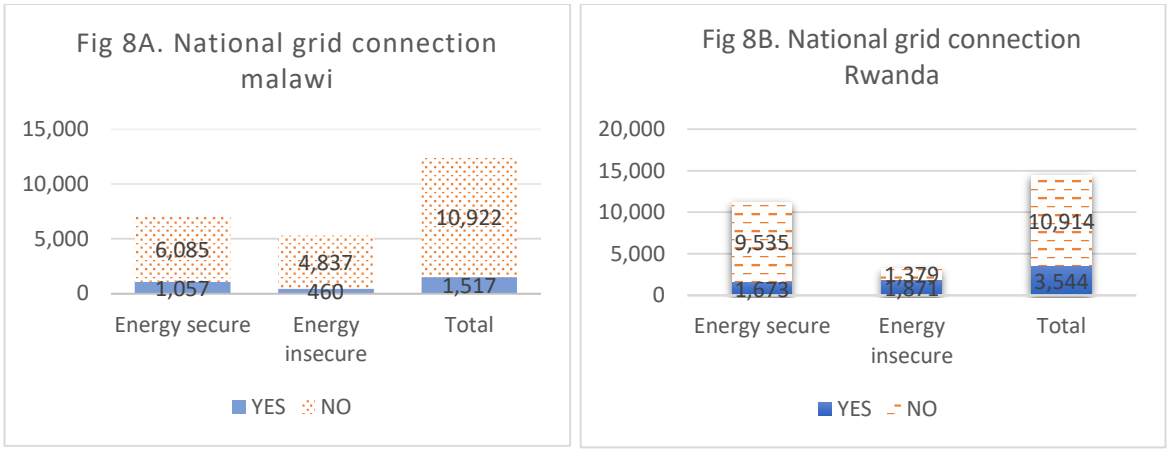

Figure 5A & 8B. Graphical representation for electricity access by energy insecurity status. (Source: Author's computation from IHS4 & EICV5 data respectively).

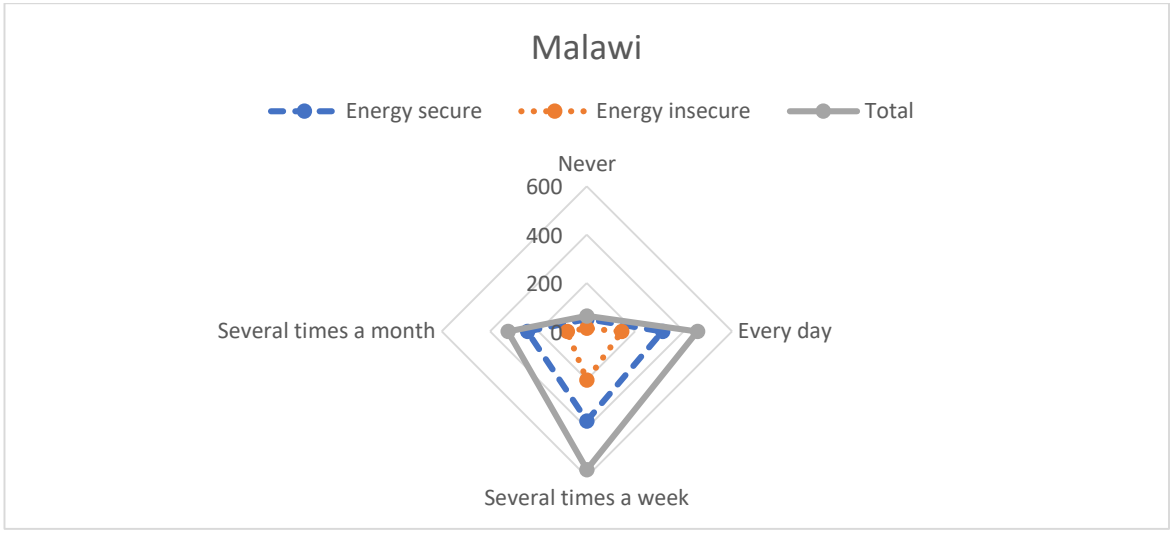

Figure 6.A Radar chart for blackout patterns, by energy insecurity status in Malawi (Source: Author's computation from IHS4 data)

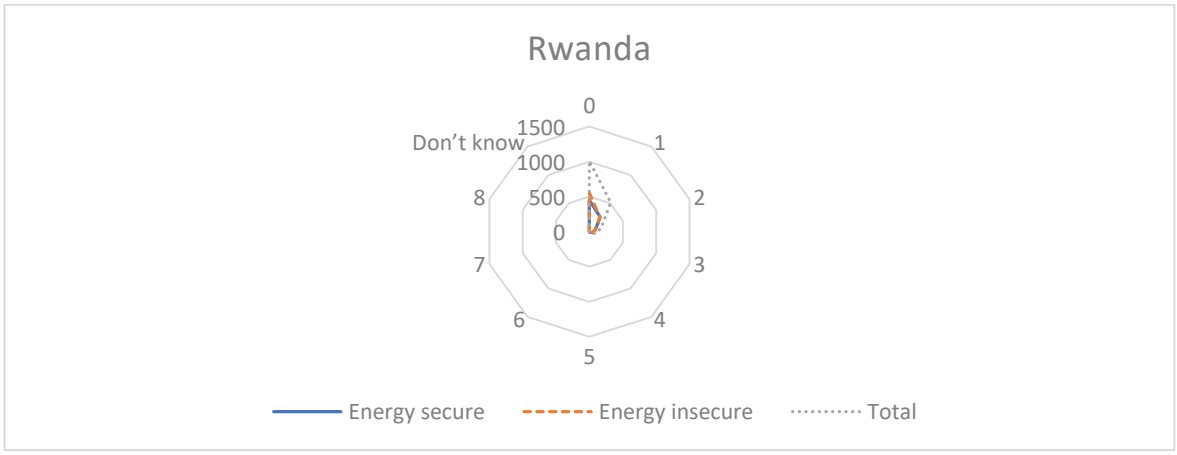

Figure 7. A Radar chart for blackout patterns, by energy insecurity status in Rwanda Source: Author's computation from EICV5 data)

It is worth noting, this study did not do further assessment on fuel stacking hypothesis (term that depicts multiple fuel use of clean and dirty fuels) using the IHS4 dataset since the survey just focused on the primary energy sources for cooking and lighting activities but there was no provision for secondary energy sources. Fuel stacking or energy shelving occurs in most homes because of variety of reasons that range from social norms or security despite of having improved social economic status [163], [164]. Other literature has found that culture and other social fabric play a critical role towards multiple fuel use in homes in the developing country context [165], [166]. However, such information was not readily available in the secondary datasets from the two countries. Therefore, the study only present binscatter plots that were employed to test the energy ladder hypothesis for the sampled households based on their energy security status in the two countries [167], [168]. The energy ladder hypothesis postulates that income levels or say economic factors play a pivotal role in the energy switching process from using dirty fuels to start using clean fuels. In other words, households are likely to make changes regarding their energy choices to step up on the imaginary energy ladder steps once their income levels improve (i.e., from traditional fuels such wood fuel to transitional ones such as charcoal or up to the modern ones such as solar or national grid) [169].

Figure 11 and Figure 12 are binscatter plots that were plotted to assess the lighting fuel choices of the sampled households taking consideration of their energy insecurity status in Malawi and Rwanda, respectively. Firstly, in the Malawian case, Figure 11 reveals that there were no clear differences on lighting fuel choices taking into consideration of the income quintiles between the two groups with exception of the choice for other fuels such as grass. The graphical illustration of Figure 11 shows that energy secure was negatively associated with other dirty fuels for lighting whilst the energy insecure had positive association with this fuel source.

Secondly, with regard to cooking fuels, Figure 13 and Figure 14 illustrate that only the energy-secure had high propensity to use modern fuels (gas and electricity) in relative terms compared to energy insecure counterparts with increases in the income levels. Further analysis on transitional fuels, both groups had same relationship with the use of transitional fuels such as charcoal or kerosene with increases in the income levels. Finally, both the energy -secure homes and energy-insecure homes had less propensity to use traditional fuels as their income increased. Only the energy -insecure homes had a constant relationship with use of other fuels such as crop residues and grass as their income rises. These results resonate with the prevailing literature that might imply that energy insecurity could be a challenging

phenomenon which may be affected by other deprivations such insufficient food [170], water challenges [171] and housing tenure challenges [172] other unknown social problems [139].

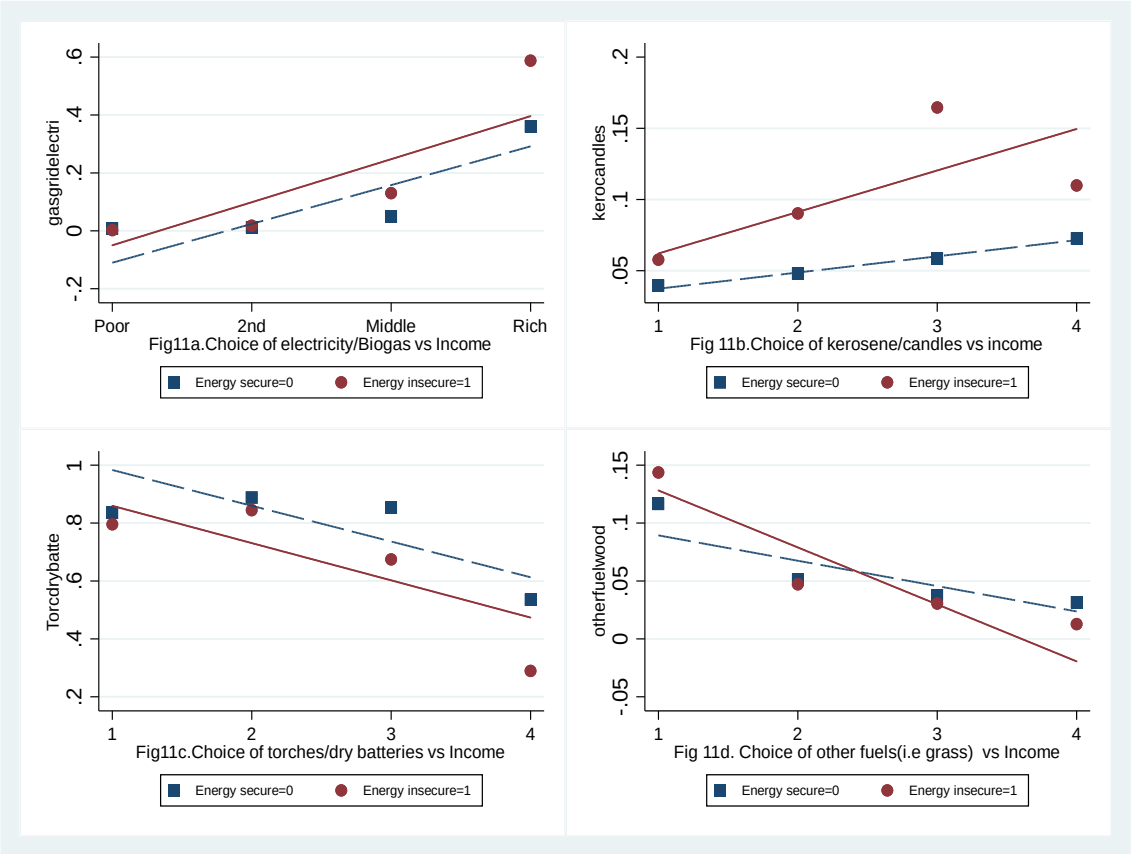

Figure 8. Fuel choices for lighting and Income by energy security status in Malawi

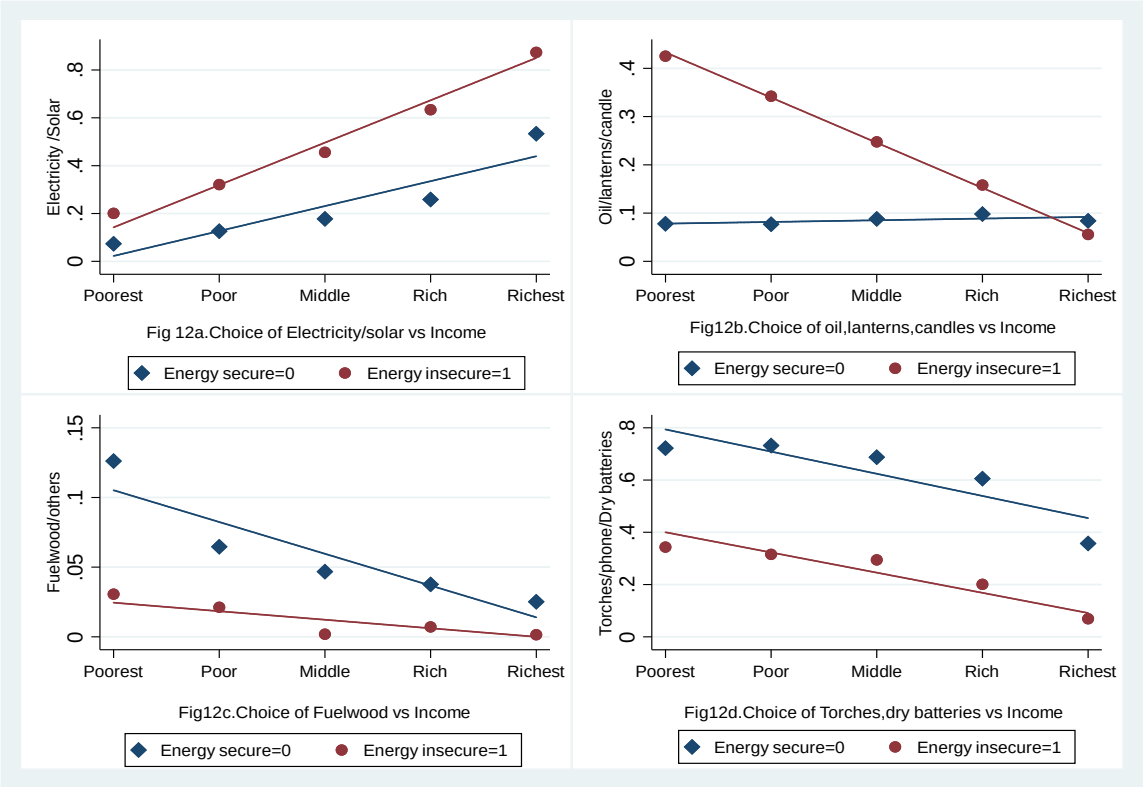

Figure 9. Fuel choices for lighting and Income by energy security status in Rwanda

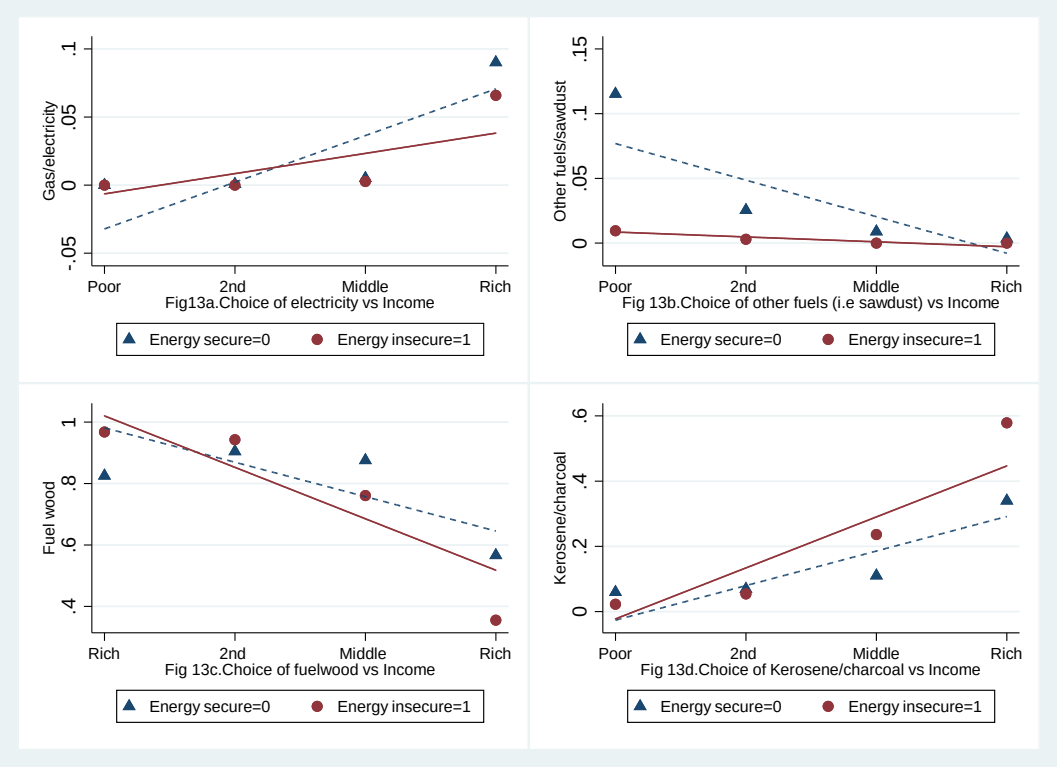

Figure 10. Fuel choices for cooking and Income by energy security status in Malawi

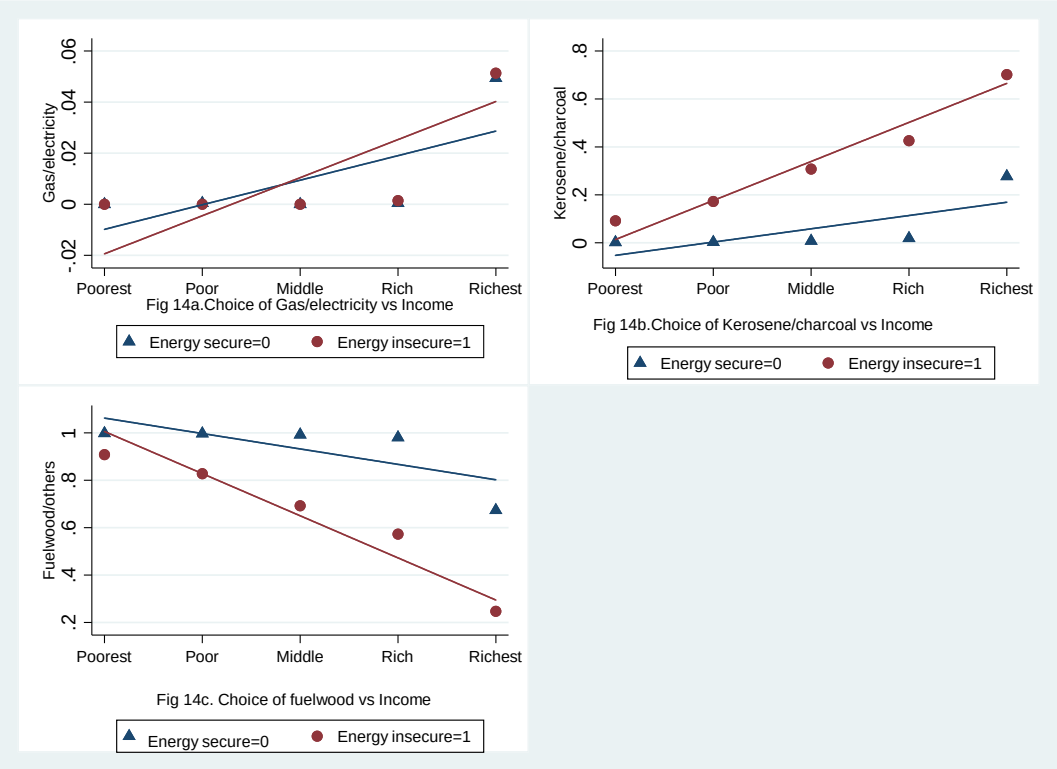

Figure 11.Cooking fuel choices and Income by energy security status in Rwanda

Apart from energy choices and services, differences between the two groups are seen in demographic variables, geographical variables, and dwelling features, as highlighted in Table 11 and Table 12 for Malawi and Rwanda, respectively. In the Malawian case, the result Welch t-tests produced significant P-values which imply that the two groups were different in terms of demographic variables such as age. For example, the energy-secure homes were likely to be those that were having a household head that was young in age and were likely to be males, [133], [173], and finally were likely to headed by those that had attended formal schooling [174].

As for the Rwandan case, the mean tests on geographical variable revealed that energy-secure were more likely to be found in the urban areas or location. This empirical result is in line with those from developed countries. The spatial inequality and disparity contribute to the energy insecurity phenomenon by widening the gap in terms of basic access towards the modern energy services due to urban bias [162], [175].

Finally, the energy-secure had a high probability in dwelling in permanent buildings that were made with modern materials, buildings with iron roofs and cemented floors with burnt bricks unlike the energy insecure ones under the Malawian case study. On housing tenure, the energy secure were mostly the owner occupants living in their own houses unlike the

energy-insecure who were mostly living as tenants in rented homes. In some cases, the energy insecure were found to be living buildings which they did not pay rentals depending whether they had approvals from the true owners or they just occupied without approval from the owners. Literature reveals that housing tenure play a critical in dealing with energy security problem because tenants might not be willing to invest in modern energy facilities or install energy efficient facilities that are not portable [162], [167]. On the other hand, owner occupants of buildings have added advantage of not facing the challenge of the restrictions that may be put by landlords if it were a rented building [176]. As already mentioned, it may be difficult on the part of poor tenants to adopt any strategy that could lead to energy efficiency upgrading that may be demanded by landlords from time to time [177]. Under the Malawian scenario, the situation is even more complicated since some of the energy insecure settled in buildings without having an approval of the true owners which imply that they are so many factors that may be at interplay. The study found that energy secure were more likely to own other off grid energy solutions such as solar panels unlike the energy insecure counterparts. Such empirical result is key to address the challenge of energy transition in the domestic sector because income levels may play a pivotal role, solar home system investments to deal with this problem of energy insecurity [178]. So far,

Table 11. Mean comparison for variables in Malawi (Difference in mean)

Variable	Malawi IHS4 2016/17			
	Energy insecurity (1)		Energy insecurity (2)	
	(Energy secure)-(energy insecure)	p-value of diff	(Energy secure)-(energy insecure)	p-value of diff
Family size (number)	0.994	0.0000	-0.055	0.8203
Age of the head of the family (years)	-0.886	0.9987	-1.503	0.9989
Head with formal education (1=yes)	0.073	0.0000	0.389	0.0000
Head of the family is male (1=yes)	0.113	0.0000	0.073	0.0000
Married household head (1=yes)	0.143	0.0000	0.032	0.0085
Rural location (1=yes)	-0.067	1.0000	-0.634	1.0000

Number of rooms	0.425	0.0000	0 .502	0.0000
Tenancy (1=renting)	0.038	0.0000	0.391	0.0000
Fetch water outside yard/plot (1=yes)	-0.063	1.0000	-0.679	1.0000
The asset value of durable items (logarithms)	1.082	0.0000	-2.663	1.0000
Dwelling floor (1= smoothed mud)	-0.135	1.0000	-0.719	1.0000
Dwelling wall (1=burnt bricks)	0.143	0.0000	0.246	0.0000
Dwelling roof (1=grass thatched)	-0.166	1.0000	-0.546	1.0000
Toilet (1= traditional toilet)	0.048	0.0000	-0.190	1.0000

already documented six factors that are connected to energy vulnerability in the domestic sector namely benefits and costs of the energy supply; quality of the residential building; fluctuation of the family income, housing tenure, health status of the household and social network.

Table 12.Mean comparison for variables in Rwanda (Difference in Mean)

Variable	Rwanda EICV5-2016/17			
	Energy insecurity (1)		Energy insecurity (2)	
	(Energy secure)-(energy insecure)	p-value of diff	(Energy secure)-(energy insecure)	p-value of diff
Family size (number)	-0.804	1.000	1.405	1.000
Age of the head of the family (years)	4.358	0.000	1.527	0.966
Head with formal education(1=yes)	-0.126	1.000	0.050	0.001
Head of family is male (1=yes)	-0.094	1.000	-0.051	0.983
Married household head (1=yes)	-0.108	1.000	-0.244	1.000
Rural location (1=yes)	0.346	0.000	-0.390	1.000
Number of rooms	-0.261	1.000	0.018	0.421
Tenancy (1=renting)	-0.188	1.000	0.216	0.000
Fetch water outside (1=yes)	0.193	0.000	-0.410	1.000
The asset value of durable items (logarithms)	-2.571	1.000	2.316	0.000
Dwelling floor (1= beaten earth)	0.348	0.000	0.235	1.000
Dwelling wall (1=oven or cement bricks)	-0.310	1.000	0.168	0.000
Dwelling roof (1=local clay tiles)	0.236	0.000	0.111	1.000
Toilet (1= traditional toilet)	0.067	0.000	-0.027	0.998

Table 13. Probit model results showing determinants of energy insecurity status in Malawi

Explanatory variable	Co-efficient	Z	Marginal effects (dy/dx)
Family size (number of persons)	-0.1304**	-19.03	-0.050
Age of the head of the family (in years)	0.002**	3.23	0.001
Head with formal education (1=yes)	-0.321**	-8.16	-0.121
Head of the family is male (1=yes)	-0.128**	-3.37	-0.050
Married household head (1=yes)	-0.083*	-2.07	-0.032
Rural location (1=yes)	0.045	1.08	0.017
House with grid connection (1=yes)	-0.022	-0.43	-0.008
Number of rooms	-0.097**	-7.58	-0.038
Tenancy (1=renting)	-0.069	-1.53	-0.026
Fetch water outside yard/plot (1=yes)	0.035	0.75	0.013
The asset value of durable items (logarithms)	-0.044**	-13.66	-0.017
Dwelling floor (1= smoothed mud)	0.162**	4.70	0.062
Dwelling wall (1=burnt bricks)	-0.120**	-4.11	-0.046
Dwelling roof (1=grass thatched)	0.104**	3.17	0.040
Toilet (1= traditional toilet)	-0.059*	-2.36	-0.023
Intercept	0.820**	10.04	
Logistic regression	No of observations = 12,439 LR chi2(15) = 1602.84		
Prob>Chi2=0.0000	Log likelihood = -7683.30		

3.4.1.3 Determinants of energy insecurity status in the two countries

Taking the case of Rwanda, the results of marginal effects from the probit model (Table 14) suggest that energy insecurity status reflects household demographics, assets, dwelling features and infrastructure differences across the sampled households. Households with grid connection (17.2%), large household sizes (3.1%), married heads (4.8%), living in rented dwellings (7.5%), who fetch water outside their yards or plot (2.6%), households that live in permanent structures (i.e., those having oven bricks or cement walls were strongly associated with energy insecurity status. All these factors achieved the statistical level of significance at the 1% and 5% levels, as shown in Table 14. Hence these findings confirm the descriptive statistical analysis results in the two countries.

3.4.2 The role of energy security on education and health outcomes

H2A: Household energy insecurity status is negatively associated with child school attendance.

H2B: Household energy insecurity status is positively associated with poor household health status.

3.4.2.1 Effect of energy insecurity on child school attendance.

Recalling the descriptive findings, mean comparisons using "t-tests" indicate differences in household characteristics between the energy-secure homes and energy-insecure homes. This study further carried out instrumental variable probit regressions to statistically confirm these differences and assess energy insecurity's effect on household development outcomes. The empirical results from the Instrumental Variable Probit regression models are presented in Table 15 and Table 16 for Rwanda and Malawi respectively. For the Rwandan case, as anticipated, energy insecurity negatively affects school attendance for school-going children at the 1% level of statistical significance. It implies that children in energy-insecure households are likelier to not attend school than those from their energy-secure counterparts. In addition, families with aged household heads, large household sizes and also residing in rural areas were some of the significant variables and had a high likelihood of contributing to absenteeism by school-going children based on the 1% level of statistical significance with exception of rural residence variable which was found to be significant based on the 5% level of statistical significance. These findings resonate with those of [179] , who found that poverty and geography (rural spaces) play a role and are highly correlated with being out of school.

Table 14. Probit model results showing determinants of energy insecurity status in Rwanda

Explanatory variable	Co-efficient	Z	Marginal effects (dy/dx)
Family size (number of persons)	0.118**	16.21	0.031
Age of the head of family (years)	-0.007**	-6.72	-0.001
Head with formal education (1=yes)	-0.008	-0.23	-0.002
Head of the family is male (1=yes)	-0.116*	-2.46	-0.031
Married household head (1=yes)	0.189**	4.37	0.048
Rural location (1=yes)	-0.681**	-17.43	-0.212
House with grid connection (1=yes)	0.582**	15.62	0.172
Number of rooms	0.031*	2.53	0.008
Tenancy (1=renting)	0.264**	6.16	0.075
Fetch water outside (1=yes)	0.103*	2.15	0.026
The asset value of durable items (logarithms)	0.011*	2.50	0.002
Dwelling floor (1= beaten earth)	-0.148**	-4.12	-0.040
Dwelling wall (1=oven/cement bricks)	0.164**	4.97	0.044
Dwelling roof (1=local clay tiles)	-0.279**	-9.26	-0.070
Toilet (1= traditional toilet)	-0.059	-1.22	-0.015
Intercept	-0.871**	-8.68	
Logistic regression	No of observations = 14,458		LR chi2(15) = 3470.79
Prob>Chi2=0.0000	Log likelihood = -5969.31		

Table 15. Effect of energy insecurity on school attendance in Rwanda

Variable	IV-Probit Model[1]	Probit model[2]
	Coefficient (St. Error)	Coefficient (St. Error)
Energy insecurity status	-0.896** (0.340)	-0.011 (0.033)
Age of the head of the family	0.003 ** (0.001)	0.003** (0.00)
Family size	0.291** (0.007)	0.278 ** (0.006)
Assets value (Logarithm form)	-0.013** (0.004)	-0.018** (0.003)
Electricity access	0.068 (0.107)	-0.185** (0.037)
Formal schooling status of the head of the family	-0.014 (0.029)	-0.015 (0.029)
Head of the family is male	-0.327** (0.043)	-0.307** (0.045)
Head of the family is married	0.078 (0.044)	0.033 (0.042)
Rural location	0.180* (0.091)	0.371** (0.043)
Household raised livestock past year	0.074 (0.040)	0.145** (0.027)
Household owns land	0.020 (0.052)	0.106 ** (0.038)
Intercept	-1.706** (0.200)	-2.082** (0.074)
/athrho	0.318 (0.121)	
/insigma	0.355 (0.002)	

Note: ** p-value < 0.01 * P-value <0.05

[1]Instrumental Variable Probit regression with instruments: 14458 observations;

Wald test of exogeneity (Corr=0); Chi2 (1) =5.93; Prov>Chi2=0.0149

[2]Probit regression: LR Chi2(11) =2774.62; Prob>Chi2=0.000; Pseudo R -squared=0.1530

Table 16. Effect of energy insecurity on school attendance in Malawi

Variable	IV-Probit Model[1]	Probit model[2]
	Coefficient (St. Error)	Coefficient (St. Error)
Energy insecurity status	-1.204** (0.136)	-0.069** (0.025)
Age of the head of the family	0.001 (0.000)	0.000 (.001)
Family size	0.209** (0 .020)	0.315** (0.007)
Assets value (logarithm form)	-0.011** (0.004)	0.007* (0.003)
Electricity access	0.101* (0.044)	0.014 (0.046)
Formal schooling of the head of the family	-0.124** (0.041)	0.030 (0.039)
Head of the family is male	-0.146** (0.038)	-0.116** (0.041)
The head of the family is married	-0.067 (0.041)	-0.031 (0.044)
Rural location	0.002 (0.038)	-0.073 (0.040)
Household-owned livestock past year	-0.067* (0.030)	0.065* (0.026)
Household owns land	0.018 (0.034)	-0.048 (0.035)
Intercept	-0.600** (0.169)	-1.519** (0. 096)
/athrho	0.538 (0.064)	
/Insigma	0.461 (0.002)	

Note: ** p-value < 0.01 * P-value <0.05

[1]Instrumental Variable Probit regression with instruments: observations;

Wald test of exogeneity (Corr=0); Chi2 (1) = 43.87; Prov>Chi2= 0.0000

[2]Probit regression: LR Chi2(11) = 2542.32; Prob>Chi2=0.000; Pseudo R -squared= 0.1509

Table 17. Effect of energy insecurity on household health status in Rwanda

Variable	OLS results (a)	IV-2SLS (c)
Energy insecurity	0.038 (0.025)	0.717** (0.269)
Age of the head of the family	0.003*** (0.001)	0.004*** (0.001)
Family size	0.121*** (0.005)	0.102*** (0.009)
Asset value (logarithms)	0.011*** (0.002)	0.008** (0.003)
Electricity access	0.045 (0.028)	-0.132 (0.076)
Formal schooling of the head of the family	0.037 (0.024)	0.038 (0.024)
Head of the family is male	-0.047 (0.031)	-0.022 (0.034)
Head of the family is married	0.082** (0.029)	0.049 (0.033)
Rural location	0.132*** (0.033)	0.253*** (0.058)
Household raised livestock	0.078*** (0.021)	0.125*** (0.028)
Land	0.013 (0.028)	0.068 (0.036
Number of rooms in the house	0.017* (0.008)	0.010 (0.009)
Fetch water	0.012 (0.038)	-0.006 (0.039)
Kigali	-0.291*** (0.040)	-0.358*** (0.049)
Northern	-0.371*** (0.029)	-0.353*** (0.031)
Southern	-0.071** (0.026)	-0.062* (0.027)
Western	-0.343*** (0.027)	-0.373*** (0.030)
Intercept	-0.073 (0.067)	-0.229* (0.092)

Standard errors in brackets * p<0.05, ** p<0.01, *** p<0.001 Source: Authors' calculation from EICV5

a. Linear regression (OLS): Number of obs = 14,458; F(17, 14440) = 91.41 ; Prob > F = 0.0000; R-squared = 0.0972; Adj R-squared= 0.0961; Root MSE = 1.0832

c. IV regress 2sls regression: Number of obs = 14,458; Wald chi2(17) = 1487.32; Prob > chi2 = 0.0000; Root MSE = 1.1091. Tests of endogeneity, Ho: variables are exogenous. Durbin (score) chi2(1) = 6.76326 (p = 0.0093); Wu-Hausman F (1,14439) = 6.7575 (p = 0.0093)

Table 18. Effect of energy insecurity on household health status in Malawi

Variable	OLS results (a)	IV-2SLS (c)
Energy insecurity	0.042* (0.021)	0.760** (0.247)
Age of head of the family	-0.000 (0.001)	-0.001 (0.001)
Family size	0.196*** (0.005)	0.228*** (0.013)
Asset value (logarithms)	0.021*** (0.002)	0.032*** (0.004)
Electricity access	0.052 (0.041)	0.015 (0.045)
Formal schooling of the head of the family	0.112*** (0.031)	0.191*** (0.043)
Head of the family is male	-0.067* (0.032)	-0.033 (0.035)
Head of the family is married	0.007 (0.033)	0.028 (0.036)
Rural location	0.076* (0.034)	0.033 (0.038)
Own livestock	0.058** (0.022)	0.117*** (0.030)
Land	0.052 (0.028)	0.027 (0.031)
Number of rooms in the house	-0.044*** (0.010)	-0.022 (0.013)
Fetch water	0.086* (0.039)	0.084* (0.041)
Northern	-0.032 (0.028)	0.056 (0.042)
Central	0.205*** (0.022)	0.177*** (0.025)
Intercept	-0.120 (0.080)	-0.610** (0.188)

Standard errors in brackets * p<0.05, ** p<0.01, *** p<0.001 Source: Authors' calculation from IHS4

a. Linear regression (OLS): Number of orbs = 12,439; F (15, 12423) = 125.13; Prob > F = 0.0000; R-squared = 0.1313; Adj R-squared= 0.1302; Root MSE = 1.0917.

c. IV regress 2sls regression: Number of orbs = 12,439; Wald chi2(15) = 1727.36; Prob > chi2 = 0.0000; Root MSE = 1.139. Tests of endogeneity, Ho: variables are exogenous. Durbin (score) chi2(1) = 9.2946 (p = 0.0023); Wu-Hausman F (1,12422) = 9.28883 (p = 0.0023)

3.4.2.2 Effect of energy insecurity on household health status

The regression estimates in Table 17 and Table 18 confirm that energy insecurity leads to poor health status among household members in the two countries. Specifically, energy insecurity

increases the chance for household members in energy-insecure homes to get sick by 72% in Rwanda and 76 % in Malawi compared to the energy-secure counterparts at the 1% level of statistical significance. It points to the fact that these energy-insecure households may have limited access and may not afford modern and clean fuels. In the Rwandan case, poor health status in homes was associated with old household heads, large family sizes, wealthy ones, those who raised livestock, and those who were rural-based. In contrast, for the Malawian case, poor health status is also associated with large family sizes and households that own livestock and fetch water outside their yards or plot. Poor health status was also strongly associated with the central region.

Table 19. Effect of energy insecurity on household health in the two countries

Matching algorithm	Household health in Rwanda		Household health in Malawi	
	ATET	Robust standard error	ATET	Robust standard error
Propensity Score Matching (PSM)	0.075**	0.036	0.060**	0.026
Inverse Probability Weighting (IPW)	0.057**	0.027	0.040**	.019

Source: EICV5 data, 2016-2017 *** = significant at the p =0.001 ** = significant at the p =0.05 * = significant at the p=0.10

3.4.2.3 Robustness Check for IV 2SLS Regression results

As part of a robust check for the results from the IV 2 SLS model, this study also employed the matching algorithm techniques, which help to account for selection bias due to observed and non-observed features between the treated (energy-insecure) and the control (energy-secure) [155]. Table 19 presents ATE estimates for the impact of energy insecurity using alternative matching algorithm techniques that differ in magnitude from those of regression estimates; however, qualitatively, they are similar. Specifically, the results indicate that energy insecurity significantly reduces good health by increasing the health risk probability of being sick by 5.2 % under PSM and 4.2 % under inverse probability weighting. In other words, the results from all the matching methods showed that the coefficients of the energy insecurity variable remain significantly positive. The differences in the magnitude from these alternative matching algorithms result from unobserved heterogeneity between the treated and the control categories as well expounded in the literature [180].

3.5 Chapter conclusion and policy recommendations

3.5.1 Concluding remarks

The objectives of this chapter were to assess the characteristics of households that face energy insecurity and also examined the relationship between energy insecurity and developmental outcomes (education, health status) at household level —using a nationally representative sample datasets in two developing contexts under a micro-economic perspective. Overall, the prevalence rates showed that Rwandan households have lower incidences of energy insecurity (22.48%) than Malawian households (42.58%). Within Rwanda, off-grid homes (12.65%) have lower energy insecurity incidences than on-grid households (52.79%) which were energy-insecure. Further investigation sub-sample of grid-connected households using 100 kWh per capita per year revealed that most of them (91.53%) consume below the minimum threshold. In contrast, within Malawi, off-grid homes (44.29%) have high levels of energy insecurity compared to on-grid households (30.32%).

Further inquiry on grid-connected households using 100 kWh per capita per year revealed that the majority (79.10%) can afford to meet the minimum threshold. Simple mean comparisons showed that energy insecure homes are different from energy secure homes in several ways. The two groups differ in demographical variables, housing tenure, quality of the houses and also in terms of rurality. Regarding lighting and cooking fuel choices, the two groups had significant differences in terms of fuel choices for lighting but not for cooking. For example, binscatter plots revealed positive correlation on use of the transitional fuels (charcoal and kerosene) and the income levels regardless of the energy insecurity status. It was interesting to note that the energy-insecure households were less likely to use fuel wood, which shows the complexity of this phenomenon as it is influenced by other social burdens (water, housing, food, etc.). Regarding lighting fuels, the energy-insecure and the energy-secure in the two countries seem to have a negative relationship with fuel wood and other fuels. But, regarding clean cooking, the two countries need much effort to have fully fledged modern cooking infrastructures.

The Probit regression results confirm the preliminary findings from descriptive statistics analysis on energy insecurity determinants. In both countries, statistically significant marginal effects from probit models suggest that differences influence energy insecurity status in household demographics, assets, dwelling characteristics and access to basic infrastructures on water and electricity. Finally, the results from instrumental variable probit regressions in both

countries confirm the negative effect of energy insecurity on child school attendance. Furthermore, the results from instrumental variable -2SLS regressions in the two countries confirm that energy insecurity increases the chance of family members falling ill, thereby leading to poor health status.

3.5.2 Lessons for policy implications

This chapter presents three policy lessons. Firstly, the two governments in question, need to join hands with the multinational companies and local companies to scale up off-grid energy solutions to reach majority of the rural population that seem to struggle to have access to modern energy services especially for lighting homes. Secondly, this needs to be complemented with public awareness campaign on the benefits of using clean energy sources and also in terms of available options on off-grid energy sources which consumers can buy in the two countries.

Lastly, since clean cooking still remains a challenge for both countries, there is need to devise strategies that encourage adoption of energy efficient appliances such as improved cook stoves to encourage clean cooking which is still lagging behind. This call is pertinent for Malawian households that continue to depend on wood fuels and charcoal for cooking activities and are reluctant to use LPG and certified cook-stoves for fear of human catastrophe and other harm coupled with insufficient technical knowledge [181], [182].

CHAPTER FOUR

AN EXPLORATION OF FUEL CHOICES, TRANSITION AND INEQUALITY IN RWANDA AND MALAWI

Socio-economic factors may either drive or hinder the progress of household energy transitions in developing countries. This chapter investigated factors that influence household fuel choices, transition and inequality in Rwanda and Malawi using repeated cross-sectional data collected from 28995 Rwandan households under two waves (EICV4-2013/14, EICV5-2016/17) and data gathered from 23,789 Malawian homes under two waves (IHS4-2016/17, IHS5-2019/20). The study used Lorenz curves and Gini coefficient to have a visualisation of energy inequalities at different levels to a clear between country and within country comparisons. Multivariate Probit models were employed to assess the factors that drive energy choices, while Seemingly Unrelated Regression models were estimated to evaluate household energy consumption intensity in the two countries. Results from the study findings show that household consumption was more equal than energy inequality in the two countries as revealed by the Gini coefficients. The Lorenz curves of different fuels in the two countries showed that there are inter-country and intra-country differences on energy inequalities. The study findings do not support the energy ladder hypothesis in Rwanda. In contrast, the study findings from the Malawi scenario affirm the energy ladder hypothesis. Some factors contributing to these differences are wealth status, household sizes, dependents, gender and regional differences.

4.1 Introduction

This chapter assessed factors that affect household fuel choices, transition and inequality in Rwanda and Malawi and part of the study is based on published work [183], [184]. The persistent use of dirty fuels by many families in the developing world is a growing concern because this has a deadly short term and long-term consequences towards human health through indoor air pollution and also high opportunity costs especially for women and children to time use for productive activities [185]. Moreover, energy is becoming a rare good and some scholarly work shows that limited use of modern energy services is associated with poor income levels [186]. Unfortunately, the Sub-Saharan Africa region remains one of the most deprived regions in the world with poor access to clean fuels to meet the basic energy needs. The statistics shows that approximately 2.5 billion people still rely on traditional energy sources to fulfil their energy basic needs in homes yet these dirty fuels are a health hazard [187]. Furthermore, future projections shows that the number of solid fuel users might reach 2.7 billion by 2030, which has

detrimental effect on forest resources and general environmental challenges and hence calling for urgent policy actions [188]. Promoting the adoption and use of modern energy services is critical to accelerate smooth and just energy transitions especially in the domestic sector. At the same time, ensuring that "just energy transition partnerships" (which address social burdens associated with energy transitioning process) take central focus not only at global level but at different levels may help in closing the existing gaps that divide the solid fuels users and clean fuel users as the race to achieve the Sustainable Development Goal number 7 and 10 continues [189], [190].

This chapter adopts the definition of energy transition proposed by [119] and [191], which refers to changes toward higher use of clean fuels such as electricity whilst reducing the use of traditional fuels. At macro level, energy transition refers to a strategic way of ensuring that national energy sectors are making huge investments towards use of renewable fuels or energy efficiency strategies instead of the conventional fossil fuels with the aim of decreasing the carbon emissions by second half of the present century [6], [192]**.** On the other hand, energy inequality refers to how access to clean fuels is unfairly apportioned by different groups in a given population [119].

4.1.1 Rwanda's research context

In recent decades, Rwanda has improved its citizens' welfare and poverty alleviation. Its population was projected to reach 11.3 million in 2015 and is likely to be 16.3 million by 2032, whilst its economy grew at a steady average rate of 7.9 per cent between 2001 and 2016, leading to a rise in per capita GDP from 211 USD to 729 USD [13]. The country's poverty statistics show that income poverty does follow similar patterns in urban and rural areas and among provinces [193]. The poverty panel report indicates that only 12.6 per cent of the urban population stayed in poverty between the 2013/14 and 2016/17 study period; the majority were never poor (71 per cent). There were more winners than losers (5 per cent became poor and 11.3 per cent moved out of poverty). The net reduction in poverty in urban areas was 6.3 percentage points. In contrast, 89 per cent of the total persons who stayed in poverty live in rural areas, and 91 per cent of persons who fell into poverty live in rural areas, noting that the rural population constitutes 78 per cent of the total population. At the provincial level, most (71%) of those in the City of Kigali were "never poor" between the 2013/14 and 2016/17 study periods. The Southern and Western provinces experienced increases in net poverty rate (by 4.7 and 3.6

percentage points, respectively). The proportion of people who graduated from monetary poverty (winners) was more in the City of Kigali, Northern and Eastern provinces, revealing declining poverty rates.

Renewable energy production has been featured highly in Rwanda's national energy policy agenda to curb the growing concerns over fossil fuel scarcity, energy security, plus climate change to induce green economic growth [194]. In 2015, the country was considered a "large gap" country by Sustainable Energy for All (SE4ALL) based on the statistics that the country provides 62 % of electricity to urban areas whilst the rural areas get only 8% [12]. Rwanda embarked on a critical ongoing initiative to support the deployment of $50 million in Climate Investment Funds via the Scale-up Renewable Energy program (SREP) through off-grid solar solutions to meet Rwanda's target of electrifying 70% of households by mid-2018. The project aimed at addressing financial bottlenecks for solar home system distributors to act as a stimulus for providing off-grid solar systems in unelectrified localities [195]. The government clearly stated its intention in the rural electrification strategy paper to phase out oil lamps, forcing households to switch to other energy alternatives [196].

Recent statistics in Rwanda indicates that the country has registered a rapid population growth whereby urban residents' numbers increased from 4.6% in 1978 to 16.5% in 2012, whilst having an urban density of 1871 persons per square kilometer in 2012 [197]. The latest urban population growth rate was pegged at 4.1%, with the anticipation that the urbanisation growth rate would reach 35% in 2020 based on the initial vision 2020 strategy paper [198]. According to the department of urban and building in Rwanda, a city consists of a grouping of at least 200,000 dwellers, a municipality consists of at least 30,000 dwellers but below 200,000 dwellers, and an agglomeration consists of at least 10,000 but below 30,000 dwellers. As using this classification, by the end of 2012, Rwanda recorded 21 urban areas, 10 municipalities, and 10 agglomerations with seven emerging urban areas [199]. Urbanisation plays a pivotal role in changing human lifestyles which in the end induces growing demand for basic necessities including the demand for energy to fulfil basic energy needs. The urban residents do stand at an advantageous position compared to rural counterparts because they do face few hurdles to access readily available modern commercial fuels that easily lead to energy transition process [200]. Therefore, the domestic sector remains a great niche that can accelerate the energy transition process via adoption and diffusion on modern and clean commercial fuels. However, literature shows that

several factors may affect the energy transition process and is not limited only to fuel choices that are made at micro level based on a cross-sectional energy ladder [201], [202].

4.1.2 Malawi's Research Context

Malawi as a country faces the challenge of having limited generation capacity of hydro power (around 361MW) and fails to match with growing energy demand form the residential and commercial sectors (over 1000 MW), and is labeled as one of the most energy deprived nations in the Sub-Saharan Africa [203]. The in-country study on clean cooking revealed that there are few users of clean fuels for cooking activities (i.e., approximately 2 % of the population of the urban residents used Liquid Petroleum Gas (LPG) despite the fact that it is considered as the most efficient fuel for cooking [181]. Another study by [182] found that rural residences had the highest impact on choosing firewood as cooking energy. The study further showed that demographic variables such as age, education play a critical role toward cooking fuel choices.

Renewables such as solar are seen as best alternatives for dirty fuels to get socio-economic benefits and reduced environmental pollution [30]. The drawback is that the renewables attract huge financial investments which is deterrent to most consumers in the domestic sector because they do require settlement of up-front costs associated with initial connections plus basic equipment be it national grid or stoves in the case of the LPG. In addition, fuel choices by domestic consumers are affected by many factors that are not limited only to economic or technical in nature but also other social cultural issues that are bound by the study context [31].

Furthermore, Malawi's urbanisation growth rate grew steadily from 3.7 to 3.9 per cent, registering an increase in the urban population of approximately 2.8 million in 2008 and was labeled as modest urban growth rate [3]. Moreover, the World Bank report documented a moderate annual net migration inflow through rural-urban migration (i.e., approximately 14,000 working-age migrants moved from rural areas to urban areas between 2006 and 2010 in search of piece works). Such an urbanisation drive can be used to drive the energy transition process since new urban dwellers are likely to adopt new lifestyles that befits urban living forgoing the old rural lifestyles. Specifically, new urban dwellers may form new agglomeration that may act as a market niche for renewables such as solar and others.

At the moment, Malawi has four cities (namely Lilongwe, Zomba, Mzuzu, and Blantyre) and are key in driving economic growth in the country (i.e. 33 per cent as a share of the national

growth domestic product). On the other hand, the rural sector contributes 62% of the national growth domestic product and registers a share of 85% for the whole Malawian population [204]. In addition, some rural growth centers have been transformed into secondary towns registering inhabitants of about 3 per cent of the total population and contributes about 6 per cent to the national GDP. Meanwhile, the national population has drastically risen from 13,077,160 persons in 2008 to 17,563,749 persons in 2018, of which 16 per cent makes up the urban population [22]. These statistics show that the urban dweller can significantly impact sustainable development agenda through specific national development growth strategies. Unfortunately, the coming in of secondary towns is driving out rural dwellers farm from their original places. As a result, some rural dwellers are becoming landless whilst other have resorted to intensify forest resource extraction to adapt to the social-economic challenges associated with the rural-urban drive [23].

So far, there is scanty literature regarding household energy transitions, choices and inequality in Rwandan and Malawian contexts. Therefore, this study explored the fuel choices, transition and inequality based on the energy ladder hypothesis. To capture temporal effects and get more insights, the study used the most recent cross-sectional datasets over two periods in each country. It used data collected from 28995 Rwandan households under two waves (EICV4-2013/14, EICV5-2016/17) and data gathered from 23,789 Malawian households under two waves (IHS4-2016/17, IHS5-2019/20). In terms of methods, chapter presents estimates from the multivariate probit models that have ability to handle simultaneous fuel choices selected by the household. In addition, Seemingly Unrelated Regression (SUR) models were estimated to also capture household energy consumption intensity and its drivers.

The remaining parts of this chapter are arranged in the following way. The next section highlights the literature review. Materials and methods are presented in section 3, whilst section 4 highlights empirical findings. Section 5 wraps up with a conclusion and policy lessons.

4.2 Literature Review

This section presents an overview of theoretical explanations and literature on household fuel choices and energy consumption.

4.2.1 Theoretical explanations

There are two schools of thought on revolving around the household fuel choices. The first line of thinking is known as the energy ladder hypothesis which postulates an imaginary energy

ladder and that households can step up and down the energy ladder (fuel switching) based on the changes of their income levels with the highest ladder portraying clean fuels and the lowest ladder portraying dirty fuels [164]. In other words, the expectation is that poor households are more likely to use dirty fuels due to low-income levels whilst wealthy households are expected to use clean fuels because of their high-income levels. The contrary line of thinking is referred as the fuel stacking or energy shelving hypothesis which postulates that multiple fuel uses takes place in homes because of different factors especially in the poor nations. This hypothesis emphasises that there both economic and non-economic factors that determine fuel choices and have close links to social-cultural factors and also security reason to make sure that the home is never short of energy supply to meet it energy needs to satisfy its dynamic energy demand [165], [166].

4.2.2 Analytical approaches on fuel choices

The prevailing literature on fuel choice present two categories of the analytical techniques (in terms of methodology) that are employed to assess household fuel choices so far in different parts of the world. The first category of analytical techniques consists of econometric techniques that involve computation of future scenarios through simulations to gauge energy demand [205], [206] or and also to get optimal fuel choices [207], [208]. The drawback of these techniques is that they are not able assess the fuel stacking hypothesis which is common in poor nations [164]. However, recent scholars have devised what is known as the MESSAGE-Access model (energy demand model), that have features that allow processing of household survey information (i.e., fuel prices) on multiple fuel uses to assess fuel choice and has already been applied to the case study of South Asia and Central America [209], [210]. This study did not employ the newly developed energy demand model because some data on energy prices were not readily available in the secondary datasets from the two counties in question.

The other category of analytical techniques focuses on assessing the energy ladder hypothesis by employing the discrete choice frameworks [163], [187], [200]. Empirical findings from discrete choice framework point to mixed evidence in terms of the role played by income levels to determine fuel choices. The existing empirical evidence reveals that fuel choices are affected by an interplay of different factors that range from socio-economic features, geographical differences, level of modern energy infrastructures and also consumer preferences to mention a few [196]– [199].

The current chapter looks at household energy transition towards clean fuels and energy use patterns in Rwanda and Malawi. These two nations are some of the low-income countries in the Sub-Saharan African region and have set ambition to become middle income countries in few decades to come. As such this study aims at examining the prospects of facilitating smooth and just energy transitions (one that deals with social burdens that arise in the course of transitioning) in the residential sectors of these two countries. This unique cross-country case study presents empirical evidence that is critical in the energy policy design with aim of finding out ways of championing the sustainable development goal number 7 agenda (affordable and clean energy for all). The study capitalized on the recent household survey data collected by the national institutes in the two countries to provide country empirical evidence that urgently needed. The main research question which was addressed in this chapter is: "Which factors affect household energy choices, transitions and inequalities in the two countries?" This was the main guiding research question while investigating the two countries' energy transitions, inequality and choices.

The analysis was done using repeated cross-sectional data sets to capture the energy transition overtime by the households. The energy transition in this study was captured through the differences in individual proportion of a given fuel source over the family energy expenditure energy over time. In simple words, this chapter examined further differences in using a specific fuel and its share in the household energy family budget over time, making it easier to gauge if there was fuel switching taking place. Following [119], the study used the following groups of energy indicators were used: (a) Proportion of individual fuel source (%); (b) per capita expenditure of each energy category (local currency); (c) proportion of individual fuel costs in the total energy budget (%); and per capita fuel cost of a specific fuel (local currency). It was impossible to use both quantity and expenditure data in the analysis because datasets just captured expenditure data in monetary values without capturing physical energy quantities.

4.3 Materials and Methods

4.3.1 The conceptual research framework

Referring to [119], [183],and taking into consideration that multi-fuel users choose to use different fuels simultaneously for various reasons, this study focused on four fuels based on the cross-sectional energy ladder. The first fuel from the traditional category was firewood;

kerosene and charcoal from the transitional category; and electricity from the modern fuel category. Firewood remains one of the traditional fuels associated with pollution and inefficiency commonly used in developing countries like Rwanda and Malawi, especially in the Sub-Saharan African region [5]. Reflecting on the energy shelving hypothesis, the household energy transition may be reflected by differences registered in terms of how households use different fuels with corresponding proportions in the total family energy budget. Hence, assessing the differences on usage of these various fuels and differences in proportions of family energy budget between time periods may help to gauge fuel switching from dirty fuels towards the clean ones [119]. In this study, some of the energy transition indictors were: the proportion of users of each of the four fuels in percentage terms; per capita expenditure of each fuel and per capita total energy expenditure measured in local currencies of the two countries, namely Rwandan Francs (RWF) and Malawian Kwachas (MK) and also adjusted to reflect different household sizes; and proportions or shares of each fuel expenditure in the total household energy expenditure were measured in percentage terms. All the monetary values were adjusted based on the local inflation using the consumer price index constructed by the national institute of statistics in Rwanda and the national statistics office in Malawi.

4.3.2. Data sources and research design

4.3.2.1 Rwandan datasets

The study used secondary datasets for the years 2013/14 (EICV4) and 2016 /17 (EICV5), whose custodian is the NASIR as already explained in the previous chapters. These surveys were conducted throughout 12 months calendar[184]. The EICV5 survey data constituted 14580 families [102] whilst the data set from the EICV4 survey constituted 14,419 families making a final dataset of roughly about 28995 families under two rounds (EICV4-2013/14, EICV5-2016/17) after excluding those households with missing information [102], [215]. As already mentioned earlier on, the National Institute Statistics of Rwanda followed a national master sampling frame to choose villages that were sampled per district. At district level, a probability proportional sampling (PPS) procedure was also followed to arrive at the final number of households based on the 2012 Census frame whilst taking into consideration of urban-rural strata. Further details are fully documented in the survey report by NASIR [193]. Meanwhile, the Rwandan population has reached 12.93 million, in which 70 % are rural dwellers [216]. EICV4 and EICV 5 did not collect information on fuel prices and fuel physical quantities. But

both datasets captured various basic household information in terms of socio-economic features and others living standards information that was used to conduct advanced econometrics analysis.

4.3.2.2 Malawian datasets

Likewise, this study also used secondary datasets collected under the Malawian Integrated Household Living Survey in the years 2016/17 (IHS4) and 2019/20 (IHS5), whose custodian is the National Statistics Office of Malawi (NSO) in collaboration with the World Bank. These two institutions publish the datasets as a way of monitoring household welfare in the country [104], [217]. The NSO gathered information from a sample of 12,447 households under IHS4 and 11434 households in the IHS5 [104], [217]. The final dataset consisted of 23,789 households under two rounds (IHS4-2016/17, IHS5-2019/20 after excluding some households that had missing information on key variables. As already mentioned, the samples for IHS4 and IHS5 were representative at all levels. The NSO followed a stratified two-stage sampling mechanism to choose the primary sampling units in initial stage based on the census enumeration areas (EAs) as stipulated in the were representative 2008 Malawi Population and Housing Census. Form each enumeration area 235 families are chosen for interviews. Further details had already been highlighted in the previous two chapters. Please take note that income poverty was measured using household consumption expenditure and was annualised. The NSO computed the per capita expenditure variable for each household whilst considering different household sizes [217], [218]. There are two criticisms of using this measure as a welfare indicator. Mussa (2013) highlighted that this measure ignores that different individuals have different needs depending on age and gender, and other factors that are often overlooked, implying that it is cheaper to put two people in one house than to put each of them in a different house. This measure is widely used in developing countries as a monetary measure of household welfare [219], [220] .

4.3.3 Empirical models

4.3.3.1 Energy inequality

Literature provides a variety of techniques to measure inequalities be it for income or living standard indicators such as health [221], [222]. [223] pioneered using Lorenz curve and the Gini

coefficient to measure energy consumption inequality. Scholarly works by [119] and [224] also employed these two approaches to measuring energy inequalities in Vietnam and China, respectively. Therefore, this chapter adopted the two approaches to measure energy inequality in the two country contexts [119], [224]. This chapter estimated the Gini coefficients and Lorenz curves for all energy consumption indicators and the household's per capita total consumption. Following [119], the mathematical expression (equation 1) for calculating Gini coefficients and Lorenz curves is presented as follows:

$$\mathrm{Gi} = 1 - \sum_{g=1}^{N}\left(V_g - V_{g-1}\right)\left(T_g + T_{g-1}\right) \qquad (1)$$

Where Gi denotes the Gini coefficient for a specific year; V denotes the overall share of whole population, and T denotes overall share of energy costs. V represents how many fuel users in population group g divided by the total population, whereby V_g is indexed in a non-decreasing way. T represents per capita energy costs used by population group g divided by energy costs of the total population, whereby T_g is arranged from the lowest to the highest.

4.3.3.2 Energy choices and energy transitions

The sampled households are analysed based on utility maximisation behaviour, whereby households select fuel from a wide range of alternative fuels to maximise its utility, considering their budget constraints [225]. The individual household utility maximization considers a given range of a set of "J" alternatives from which a given household makes a choice "i" to maximise household utility [226]. In some cases, the individual's energy choice is arranged considering efficiency aspect, level of comfort or ease of use depending on household preference following a natural progression pattern [200]. The probit or logit model can be used to estimate ordered or unordered energy choices depending on the assumptions of the disturbance terms [153], [227]. The disturbance terms from the logit model follows logistic distribution whilst that of the Probit model follows a normally distribution. It is also possible for households to be multi-fuel users, implying that households may use two or more fuels for different reasons to satisfy their energy needs. For example, households may simultaneously use electricity for lighting and other energy sources for cooking. Following [225], multi-fuel use can be represented as follows:

$$F_{ij} = f(X_{ij}) \qquad (2)$$

Where the unobservable $(F_{i=} F_{1,} F_2, \ldots . F_j)$ is a vector representing multi-fuel use and $(i_= 1, 2, 3, \ldots N)$ represents different households. The X vector depicts all factors that affect the

fuel choices [225], [228]. Some of the factors include demographic variable such as education levels, assets, geographical differences and others [19], [196]– [199], [214]. An in-country study on exploration of cooking fuel choices for urban dwellers by [183] revealed that wealth status, housing tenure, off- farm work was some of factors that significantly influenced cooking fuel choices in Rwanda. On the other hand, after changing the discrete choice framework by considering the natural order of progression, the empirical evidence showed that household income levels did not matter for multiple fuel users requiring further investigations on the fuel stacking hypothesis.

This study handled the simultaneity issue attributed to multiple fuel usage using a multivariate probit model [230]. The multivariate probit model is expressed as follows:

$$F_{imt} = \phi_0 + \phi_1 \text{Lnhhinc}_{imt} + \phi_2 \text{ruralD}_{imt} + \phi_3 \text{hhsize}_{imt} + \alpha_i \text{HHdemos}_{imt} + \sum_{i=1}^{5} \vartheta_d (\text{ProviD})_d + \phi_4 \text{year}_i + u_{imt} \quad (3)$$

Where ϕ_0 is constant, ϕ_i, α_i, ϑ_d were parameters be estimated and u_{imt} is the disturbance term. F_{imt} is the regressant and would be 1 when the household uses electricity and zero otherwise; would also be taking the value of 1 if the household uses kerosene and zero if otherwise; would also be taking the value of 1 if the household uses charcoal and zero if otherwise; would also be taking value of 1 if the family uses wood fuel and zero otherwise. year_t depicts 2013/14 and 2016/2017 for Rwanda, while for Malawi, it was 2016/17 and 2019/20. On the other hand, m depicts four equations because the study considers four types of fuels, and fuel users are those households that incurred fuel costs and had positive values on the expenditures of a specific fuel. Lnhhinc_{imt} = Log of real household per capita annual consumption as a proxy of household income. ProviD = depicts the vector of either the five provinces of Rwanda, taking the Eastern province as a reference or three Malawi regions with the Central region as a reference to control for regional effects or agro-ecological zones. ruralD_{imt}= Rural dummy taking the value of 1 if the household is located in rural and zero otherwise. year_i= is the year dummy for sampled years, where 2013/14 is the reference for the Rwandan dataset while 2016/17 is the reference for the Malawian dataset to control for temporal effects. HHdemos_{imt}=depicts a vector of household features and household head demographics (age, gender, marital status, four dummies of education level for Household head where head with no formal education is reference, head with primary qualification, head with secondary

qualification, head with tertiary qualification, tenancy status). $\mathrm{HHdemos}_{\mathrm{imt}}$=depicts a vector of household features and household head demographics (age, gender, marital status, four dummies of education level for Household head where head with no formal education is reference, head with primary qualification, head with secondary qualification, head with tertiary qualification, tenancy status). $\mathrm{hhsize}_{\mathrm{imt}}$=depicts family size measured in numbers.

The study further analysed the factors that influence household fuel use intensity. Referring to [225] and [230] , the fuel use intensity is measured by dividing the expenditures of each fuel by the total energy expenditure for an individual household. The fuel use intensity also reveals the household's dependency on a given fuel [225]. The explanatory variables highlighted in equation 2 (i.e., family size, educational status and others), were included to assess factors influencing household energy consumption and energy transition. The study further incorporated other explanatory variables, namely: Employment status [231]; share of dependents (family members who were less than 15 years old or above 60 years old [119]; wealth status of household and was proxied by the real value of durable household assets instead of actual income to avoid econometric issues [119], [232]. The econometric reasons are as follows: Household income fluctuates a lot over time and is deemed as a temporary metric for well-being; it can also be endogenous with other independent variables in the empirical model; it may cause a simultaneity problem whereby fuel use affects household income and vice versa [119]. The other stage involved testing both the linear and nonlinear linkages between fuel choices and independent variables in question. The last stage of the analysis involved robustness testing of the results. Since per capita energy expenditure would represent energy consumption, an ordinary least squares (OLS) model was estimated as depicted in equation 4 [119].

$$E_{imt} = \beta + W'_{it}\mathcal{B} + \mu_{imt} \qquad (4)$$

Where E_{imt} is Log of per capita fuel costs of an individual family i in time t; W'_{imt} is a vector of socio-economic status and demographic variables, employment status, residence features, dwelling characteristics, wealth status; μ_{imt} is the random error term with the following properties $\mu_i \backsim$ N $(0, \sigma^2)$, whilst $\mathcal{B}$ and β are estimated coefficients that are supposed to be linear.

Regarding the energy transition, per capita expenditures on traditional fuels such as wood fuel (E_{1t}), transitional fuels like kerosene (E_{2t}) or charcoal (E_{3t}), clean fuels such as electricity (E_{4t}) and their proportions in the total household energy expenditure (%) were used to track

transitioning from traditional fuels to modern ones. The consumption of traditional fuels may be associated with the consumption of electricity, thereby leading to the correlation of the disturbance terms in the respective regression models. This study employed "Seemingly Unrelated Regression (SUREG)" [1] to take care of the correlation between the disturbance terms in the regression's equations [119] .

The specification of the SUREG regression models for sources of the four fuels as follows: -

$$E_{imt} = \beta + W'_{it}\beta + IMR_{imt} + \mu_{it} \quad (5)$$

The regressors employed in the SUREG regression models are the same as those already employed in equation 4. The only difference is the new addition of the generalized inverse Mill's ratio (IMR) that was incorporated to cater for the unobservable that may influence fuel consumption [225]. This study did not consider energy prices, which can also affect energy choice and consumption and is one of the limitations for this study. These Household Integrated living standard surveys did not gather such information in both countries, and there were no alternative sources to collect such critical information for the study period. Regional and rural dummies variables were used to capture the heterogeneity of energy prices and availability. The statistical analyses were possible using the Stata software version 15 and Microsoft Excel for other graphical illustrations.

4.4 Empirical findings

This section presents the findings for the current research topic.

4.4.1. Energy transition in Rwanda vs Malawi

4.4.1.1 At national levels

Table 20 and Table 21 highlight an overview of energy transitions in Rwanda from 2013 to 2017 and the energy transitions in Malawi from 2019 to 2020. Focusing on the Rwandan scenario, the proportions of firewood and kerosene users dropped by 0.53% and 19.13%, respectively. But users of charcoal and electricity rose by 1.42% and 6.89%, respectively. The per capita expenditure on kerosene was reduced by RWF 168.74 whilst per capita expenditure on charcoal and electricity rose by RWF 438.43 and RWF 195.08, respectively. The proportion of kerosene

[1] The study conducted Breusch–Pagan tests to see the association of the disturbance terms of equations depicted by equation 5 to validate whether SUREG models were necessary indeed with the empirical data sets.

expenditure in the energy expenditure fell by 12.65%. The proportions of other dirty fuels like firewood and clean fuel like electricity in the energy expenditure increased by 1.99% and 4.45%, respectively.

Table 20.Energy transition in Rwanda from 2013-2016.

Variable	Rwanda		
	2013	2017	Δ 2013–2017
Share of wood users (%)	25.37	24.84	-0.53
Share of kerosene users (%)	28.60	9.47	-19.13
Share of charcoal users (%)	22.51	23.93	1.42
Share of electricity users (%)	16.25	23.14	6.89
Wood expenditure/capita (RWF)	700.52	828.80	128.28
Kerosene expenditure/capita (RWF)	306.03	137.29	-168.74
Charcoal expenditure/capita (RWF)	2490.86	2929.29	438.43
Electricity expenditure/capita (RWF)	1318.25	1513.33	195.08
Proportion of wood in energy expenses (%)	14.43	16.42	1.99
Proportion of kerosene in energy expenses (%)	18.31	5.66	-12.65
Proportion of charcoal in energy expenses (%)	12.57	14.48	1.91
Proportion of electricity in energy expenses (%)	8.04	12.49	4.45
Energy expenditure per capita (RWF)	5068.37	5785.75	717.38
Total consumption per capita (RWF)	286852.50	291316.30	4463.80

The study findings show that the transition from dirty to clean fuels is unclear, contrary to our expectations. There might be substitution and income effects at play here, leading to an ambiguous case between the two periods of 2013 and 2017.

Now considering the Malawi scenario, the proportions of fuel wood and kerosene users reduced by 3.83 % and 1.36 %, respectively. On the other hand, users of charcoal and electricity rose by 4.15 % and 0.95 %, respectively. The per capita expenditure on kerosene was reduced by MK65.89 whilst per capita expenditure on charcoal and electricity rose by MK 1574.27 and MK320.32, respectively. The proportion of fuel wood and kerosene expenditures in the energy expenditure fell by 6.28% and 0.32 %, respectively. The proportion of clean fuels like electricity in the energy expenditure dropped by 0.13 %, but the proportion of charcoal expenditure in the energy expenditure increased by 3.21%. The findings show that the transition from dirty to clean fuels is unclear and maybe a challenge associated with the reliability of the electricity supply in Malawi coupled with affordability and accessibility reasons towards other clean fuels such as LPG over the two periods of 2016 and 2020.

4.4.1.2 At provincial or regional levels

Further disaggregation of the energy transition at regional levels was carried out in the two countries, and results are presented in Table 22 and Table 23 for the two countries. For the Rwandan case, Table 22 shows that fuel wood and kerosene were less prevalent in all the provinces except the Southern Province users increased significantly by 4.24 % in the Sothern Province, whilst the rest of the four provinces recorded a reduction in the proportions of fuel wood users. The proportions of kerosene users decreased steadily in all the provinces, with the largest drop recorded in the Eastern Province (26.79%), seconded by the Southern Province (23.21%). In terms of the clean energy transition, the Northern Province experienced a substantial increase in electricity users (7.37%), seconded by the Western Province (5.99%). The Southern Province recorded a big reduction in kerosene expenditure and a big increase in fuel wood expenditure. The province also seems to experience high-income poverty levels, as indicated by the largest decrease on income levels between 2013 and 2017.

Table 21. Energy transition in Malawi from 2016-2020

Variable	Malawi		
	2016	2020	Δ 2016–2020
Share of wood users (%)	85.46	81.63	-3.83
Share of kerosene users (%)	1.75	0.39	-1.36
Share of charcoal users (%)	18.42	22.57	4.15
Share of electricity users (%)	10.26	11.21	0.95
Wood expenditure/capita (MK)	18780.17	22546.18	3766.01
Kerosene expenditure/capita (MK)	80.05	14.16	-65.89
Charcoal expenditure/capita (MK)	3963.652	5537.92	1574.27
Electricity expenditure/capita (MK)	2089.32	2409.64	320.32
Proportion of wood in energy expenses (%)	79.00	72.72	-6.28
Proportion of kerosene in energy expenses (%)	0.38	0.06	-0.32
Proportion of charcoal in energy expenses (%)	10.63	13.84	3.21
Proportion of electricity in energy expenses (%)	4.88	4.75	-0.13
Energy expenditure per capita (MK)	25591.63	31791.12	6199.49
Total consumption per capita (MK)	220511.90	282804.00	62292.10

Table 22. Energy transition at the regional level in Rwanda

Variable	2013					Δ 2013–2017				
	Kigali	South	North	West	East	Kigali	South	North	West	East
Share of wood users (%)	10.22	19.82	29.63	31.69	28.42	-2.38	4.24	-1.50	-2.34	-1.37
Share of kerosene users (%)	15.81	31.75	17.02	24.12	42.86	-10.93	-23.21	-11.81	-14.92	-26.79
Share of charcoal users (%)	82.57	11.05	14.09	22.08	17.92	-3.25	2.6	2.54	-0.20	-1.67
Share of electricity users (%)	70.51	7.76	9.05	13.15	12.40	5.85	5.65	7.37	5.99	5.01
Wood expenditure/capita (RWF)	118.44	525.73	438.92	1069.32	952.13	85.51	451.94	-15.95	-22.10	79.29
Kerosene expenditure/capita (RWF)	147.70	347.23	81.17	230.46	558.67	-95.95	-233.46	-51.95	-139.09	-230.14
Charcoal expenditure/capita (RWF)	11814.08	1334.08	869.65	2135.26	1580.74	2816.71	-320.33	417.07	174.69	-311.46
Electricity expenditure/capita (RWF)	5749.48	819.95	714.66	1044.52	812.25	1313.02	-51.97	87.29	-164.28	18.6
Proportion of wood in energy expenses (%)	1.18	10.46	19.75	20.02	14.87	0.07	6.47	-0.95	-0.46	3.43
Proportion of kerosene in energy expenses (%)	3.13	24.00	8.86	11.81	31.13	-2.08	-19.01	-6.34	-7.71	-18.68
Proportion of charcoal in energy expenses (%)	55.36	5.21	7.22	11.69	8.45	-0.99	1.55	2.46	1.84	0.01
Proportion of electricity in energy expenses (%)	25.83	4.77	6.17	6.98	7.00	3.25	3.65	5.29	4.17	4.20
Total consumption per capita (RWF)	588340.40	269753	226841.30	251509.30	263488.40	149913.30	-33800.50	-694.60	-28988.40	-9041.70

For the Malawian case, Table 23 shows that fuel wood and kerosene were less prevalent in all the regions.

Table 23. Energy transition at the regional level in Malawi

Variable	2016			Δ 2016–2020		
	North	Central	South	North	Central	South
Share of wood users (%)	84.54	87.61	84.27	-4.12	-7.21	-1.23
Share of kerosene users (%)	0.32	0.47	3.31	-0.23	-0.39	-2.57
Share of charcoal users (%)	18.79	17.37	19.02	5.92	4.85	2.93
Share of electricity users (%)	14.45	7.20	10.69	3.19	0.60	0.43
Wood expenditure/capita (MK)	16068.52	19991.75	19066.45	6291.92	-781.02	6047.39
Kerosene expenditure/capita (MK)	40.12	18.02	143.04	-21.79	-14.20	-122.89
Charcoal expenditure/capita (MK)	4904.21	3817.04	3662.99	2436.97	1310.33	1438.50
Electricity expenditure/capita (MK)	2075.17	1474.19	2548.10	1044.35	795.47	-326.44
Proportion of wood in energy expenses (%)	76.96	82.19	77.53	-7.53	-11.82	-1.69
Proportion of kerosene in energy expenses (%)	0.08	0.07	0.74	-0.06	-0.06	-0.61
Proportion of charcoal in energy expenses (%)	12.04	10.38	10.21	3.51	4.52	2.12
Proportion of electricity in energy expenses (%)	6.67	3.37	5.23	0.38	0.14	-0.50
Energy expenditure per capita (MK)	23592.64	26036.53	26132.52	10846.01	2187.55	7231.72
Total consumption per capita (MK)	208929.7	209591.6	233578.10	159308.40	39474.60	39218.80

4.4.1.3 By rurality, income poverty, and gender

The other disaggregation of energy transitions was done by rurality, income poverty and gender to get further insights as discussed in this section. Table 24 (see Appendix 1) presents the Rwandan case. There was a reduction in the proportion of wood users in urban spaces (6.70%) compared to rural counterparts, which registered an increase in wood users (0.77%). There was a reduction in the share of kerosene users regardless of urban-rural strata whilst both areas experienced increases in the proportion of electricity users, with the highest proportion recorded for rural areas. There was also an increase in per capita energy expenditure for urban and rural households.

On the other hand, urban households recorded a reduction in per capita total consumption. On income poverty, both non-poor and poor groups recorded an increase in the proportions of electricity and charcoal users. These groups also recorded increases in the proportions of energy expenditures for using fuel wood, charcoal and electricity but a decrease in the proportion of energy expenditure for using kerosene. Regarding gender, male-headed households recorded a large proportion of electricity and charcoal users. A high reduction in the proportion of kerosene users was recorded amongst female-headed households and registered a considerable increase in the per capita total consumption.

For the Malawian case, the results in Table 25 (see appendix 2) showed a reduction in the proportion of wood users and kerosene users regardless of the urban-rural strata, with the highest decrease in wood users recorded in urban areas (10.01%) compared to 2.38% by rural counterparts. Urban and rural areas experienced increased electricity and charcoal users, with the highest proportions recorded for rural areas. There was also an increase in per capita energy expenditure for urban and rural households, although rural households recorded a slight increase in per capita total consumption.

In terms of income poverty, both non-poor and poor groups recorded a decrease in the proportions of fuel wood and kerosene users, and both groups also recorded increases in the proportions of charcoal users. Only the poor group recorded a rise in the share of electricity users, while the non-poor group registered a decrease in electricity users. Power outages may have forced non-poor groups to use alternative energy sources such as solar or generators. Regarding gender, male-headed households recorded a large proportion of electricity and charcoal users. A high reduction in the proportion of kerosene users was observed amongst female-headed households. Female-headed households had registered an increase in per capita energy expenditure and total consumption.

4.4.2 Energy vs household consumption inequalities

4.4.2.1 At national levels

Table 26 highlights the Gini values for household consumption and energy inequalities disaggregated by fuel type in the two countries. In the Rwandan case, the findings showed that inequality slightly increased between 2013 and 2016, except for charcoal and electricity expenditures, as captured by the Gini coefficients. Household consumption was more equal compared to energy expenditures. In addition, electricity expenditure inequality decreased more than charcoal expenditure inequality. In the case of Malawi, Table 26 again reveals that inequality slightly decreased between 2016 and 2020 for consumption, total energy expenditures, and charcoal expenditures, whilst that of electricity expenditure inequality remained constant as reflected by the Gini coefficients. As mentioned earlier, despite having different magnitudes, household consumption was more equal than energy expenditures in both countries. In addition, fuel wood expenditure inequality and kerosene expenditure inequality slightly decreased in the Malawian case.

4.4.2.2 At provincial or regional levels

At the provincial level in the Rwandan case, Table 27 shows that energy inequality drastically increased only in the Eastern Province, remained constant in Kigali and Northern Provinces whilst it decreased in the Southern and Western provinces. Further disaggregation indicates that energy inequality also rose amongst the poor, female-headed households and urban areas. Figure 15 depicts the Lorenz curves for energy expenses in 2013 and 2016 and clearly reveals the differences in the inequalities for the specific fuels. For instance, the Lorenz curve of electricity expenditures moved nearer to the perfect equality line, while the Lorenz curves of LPG, kerosene and candles moved far away.

These results imply that on electricity expenditure inequality, both the poor and the rich may benefit from increased electricity access and more electricity programs are needed or need to continue, especially in rural areas. The LPG expenditure inequality may imply that the wealthiest proportion of male-headed households mainly utilised it. The kerosene and candle expenditure inequalities may mean that the poorest category of female-headed families, especially those in the eastern province, and the urban poor may have increased use of kerosene or candles. As such, energy policymakers need to take a policy action on this. A group may be in an advantageous position regarding consumption and energy use. On the other hand, vulnerable groups like female-headed households and the urban poor may be

disadvantaged due to inadequate access to clean fuels and affordability challenges due to consumption poverty.

At regional level, in the Malawi case, Table 28 shows that energy inequality drastically increased in the Northern and Central parts whilst it dropped in the southern part. The disaggregation reveals that energy inequality remained constant among the income non-poor, rural, and female-headed households. At the same time, it increased among male-headed households and urban areas. Energy inequality fell among low-income families. Figure 16 depicts the Lorenz curves for energy expenses in 2016 and 2020 and shows the differences in terms of the disparities for the specific fuels. For instance, Lorenz curves for electricity expenditures remained constant while candle expenditures moved far away. Lorenz curves for kerosene expenditures stayed far from equality. In contrast, fuel wood remains closer to the perfect line of equality between 2016 and 2020.

These findings suggest two issues of electricity expenditure inequality; both poor and the rich may not benefit from electricity access due to power outages. Much effort is required to ensure that electricity programs achieve the intended purpose, especially in rural areas. The kerosene and candle expenditure inequalities may imply that the poorest proportion of the urban poor, male-headed households and those of Northern and Central regions may have increased their use of kerosene. As such, energy policymakers need to take a policy action on this. The rich and the poor need access to clean energy fuels. Currently, the urban poor and those in Central and Northern regions require much more attention to improve their energy access and affordability issues.

Table 24. Household consumption and energy inequality in Rwanda from 2013 -2017 and Malawi from 2016 -2020

Gini coefficient	Rwanda			Malawi		
	2013	2017	Δ 2013–2017	2016	2020	Δ 2016–2020
Household consumption inequality	0.46	0.47	0.01	0.41	0.37	-0.04
Total Energy expenditure inequality	0.81	0.82	0.01	0.43	0.42	-0.01
Wood expenditure inequality	0.93	0.94	0.01	0.50	0.51	0.01
Kerosene expenditure inequality	0.89	0.97	0.08	0.98	0.99	0.01
Charcoal expenditure inequality	0.91	0.90	-0.01	0.89	0.86	-0.03
Electricity expenditure inequality	0.90	0.87	-0.03	0.94	0.94	0.00

Table 25. Energy inequality in Rwanda from 2013-2017 at the regional level

Gini coefficient	2013	2017	Δ 2013–2017
Province			
Kigali	0.49	0.49	0.00
Southern	0.88	0.87	-0.01
Northern	0.87	0.87	0.00
Western	0.82	0.81	-0.01
Eastern	0.79	0.83	0.04
Income poverty			
Non- poor	0.75	0.75	0.00
Poor	0.84	0.87	0.03
Rurality			
Urban	0.50	0.52	0.02
Rural	0.84	0.85	0.01
Gender			
Male-headed household	0.81	0.80	-0.01
Female-headed households	0.83	0.85	0.02

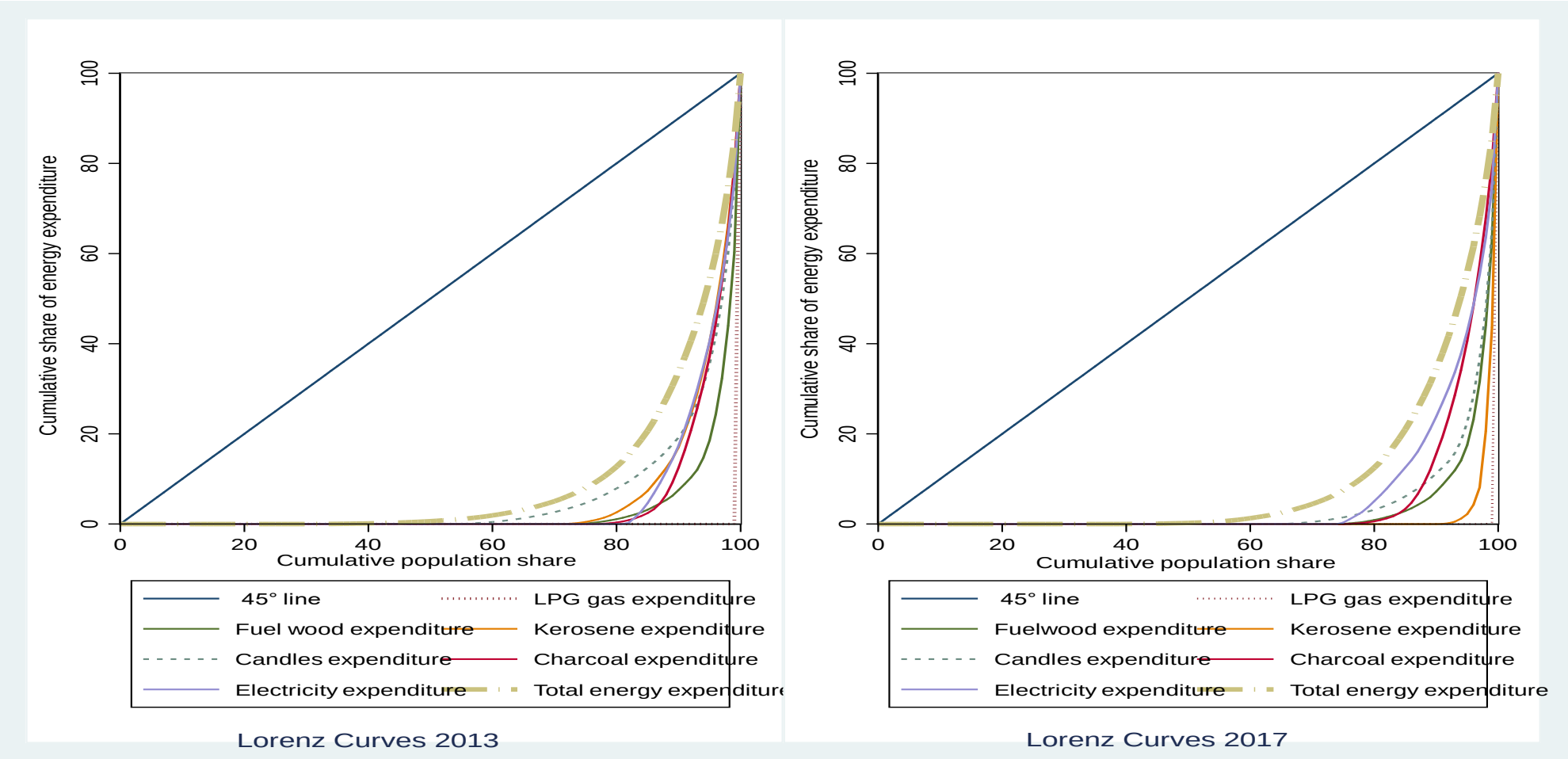

Figure 12. Lorenz curves of energy consumption expenditure in Rwanda between 2013 and 2017

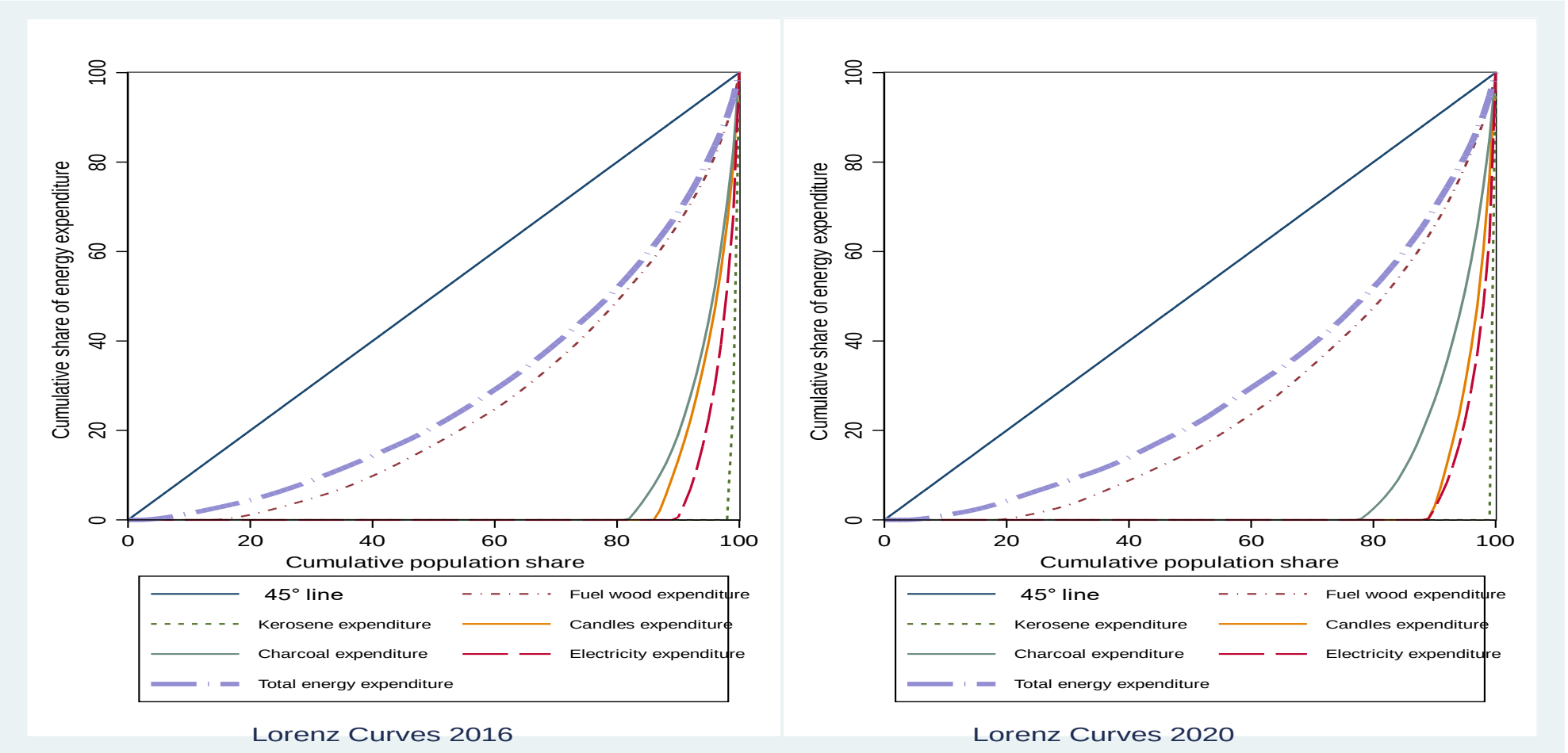

Figure 13. Lorenz curves of energy consumption expenditure in Malawi between 2016 and 2020

Table 26. Energy inequality in Malawi from 2016-2020

Gini coefficient	2016	2020	Δ 2016–2020
Region			
Northern	0.44	0.45	0.01
Southern	0.43	0.41	-0.01
Central	0.42	0.43	0.01
Income poverty			
Non-poor	0.43	0.43	0.00
Poor	0.41	0.39	-0.02
Rurality			
Urban	0.40	0.44	0.04
Rural	0.42	0.42	0.00
Gender			
Male-headed household	0.42	0.43	0.01
Female-headed households	0.43	0.43	0.00

4.4.3 Driving factors of fuel choices and fuel consumption intensity

4.4.3.1 Driving factors of fuel choices in Rwanda using a multivariate probit model

The estimates of drivers of fuel choices from the multivariate probit model are presented in Table 29 (see appendix 3) for the Rwandan case. Contrary to our expectation, the increase in wealth status proxied by "asset value" does not reduce the likelihood of using traditional fuels (firewood or kerosene). These results indicate that even the richest families are more likely to use clean and dirty fuels. The coefficients of the rural household dummy are statistically significant and have a negative sign for using charcoal, kerosene and electricity. Rural families are less likely to use these fuels than the urban residents. This finding resonates with the prevailing literature from developing economies which shows that rural households tend to use

fuel wood rather than clean fuels such as LPG or electricity[186], [202], [233], [234], [235]. It is an issue of access and resource availability whereby households may get fuel wood quickly and free of charge compared to urban counterparts with a wide range of options, including clean fuels. Families with aged household heads are more likely to use kerosene, unlike what [225] found. Household size is statistically significant and negative on charcoal use but positive on electricity use.

High levels of education for household heads positively influence the use of charcoal and electricity but negatively affect the use of firewood and kerosene. Households' high number of dependents is associated with using traditional fuels such as firewood and transitional fuels such as charcoal. These families have high propensity to depend on firewood but less likely to use electricity, as reflected by the statistically significant positive and negative coefficients. Off-farm work also plays a crucial role, as households with heads engaged that were not engaged in off-farm work had low propensity to depend on electricity, charcoal, and firewood. Regional differences also influence fuel choices. For instance, families residing in Kigali Province and the Western Province had high propensity to depend on electricity than those residing in the Eastern Province. On temporal aspects, with reference to the year 2013 /14, the coefficient for the year dummy of 2016/17 was statistically significant and had positive coefficient on electricity use and also statistically significant and having a negative coefficient on kerosene use. This shows that households have a high preference for clean fuels over time, which aligns with what [225] found amongst Sri Lankan households.

4.4.3.2 Driving factors of fuel consumption in Rwanda under SUR model

As part of robustness checking, the study also estimated Seemingly Unrelated Regression models to assess household energy consumption intensity drivers in the two countries. The estimates from the SUR model under the Rwandan case are presented in Table 30 (see appendix 4). The results showed that high wealth status was associated with energy consumption of both clean fuels (i.e., electricity) and traditional fuels (i.e., firewood). This implies that wealthy households can spend substantial amounts to cater for energy costs incurred from using clean and dirty fuels. This finding shows that affluent families do not abandon traditional fuels entirely for numerous reasons, ranging from cultural and social to security considerations. On the rurality aspect, the rural households recorded a higher proportion of energy expenditure on firewood and kerosene rather than other fuels such as electricity and charcoal. This result may be

attributed to easy access to firewood in rural settings. Tackling the age of family heads, families with older heads have high proportions of energy expenditure on kerosene and electricity rather than firewood and charcoal.

Regarding household size, larger families attract lower energy expenditure on firewood and charcoal. On the education variable, households with more educated heads recorded high proportions of energy expenditure on charcoal and electricity, unlike dirty fuels. In terms of dependents, families with many dependents recorded lower proportions of energy expenditure on electricity. Still, they would likely consume high proportions of other fuels such as firewood, kerosene and charcoal. On gender, male-headed households spend considerable energy on firewood and small proportions on charcoal. On off-farm work, families with heads who are involved in off-farm work are likely to spend substantial income on expenditures on charcoal and a smaller proportion on kerosene.

Finally, regarding regional differences, with reference to the Eastern Province, households in Kigali province spend considerable proportions of energy expenditure on charcoal and electricity but smaller proportions on firewood and kerosene fuels. Households in the Western Province spend high income on firewood, charcoal and electricity but smaller proportions on kerosene fuel. However, it is interesting that families in the Southern Province registered lower proportions for energy expenditure on all four fuels (firewood, charcoal, kerosene, and electricity). Households in the Northern Province recorded high firewood proportions and smaller kerosene proportions. Regarding temporal differences, with reference to 2013/14 year, families still show a degree of dependency on traditional and modern fuels, as depicted by significant and positive coefficients on firewood, charcoal and electricity. It implies that households spend big proportions of their income on these three fuels, as mentioned earlier. Still, they continue to allocate smaller amounts of money to kerosene. These findings from both the energy choice and SUR models do resonate with the energy ladder line of thought under the Rwandan case study.

4.4.3.3 Driving factors of fuel choices in Malawi using the multivariate probit model (MVP)

The multivariate Probit model was employed to assess the drivers of fuel choices in Malawi between 2016 and 2020 and estimates are presented in Table 31 (see appendix 5). The results showed that the increase in wealth status as proxied by "asset value" reduced the likelihood of

using dirty fuels such as firewood but increased the likelihood of using electricity. These results suggest that Malawi's richest families had high propensity to use modern energy sources. On the other hand, the rural residence variable registered a significant negative sign for using charcoal, kerosene and electricity, implying that rural residents had low propensity to uses these fuels compared to urban residents. However, the rural residence variable registered a significant positive sign for using firewood, confirming what is already reported in the literature. Households were likely to use this fuel type due to accessibility and affordability challenges associated with clean fuels in rural settings [233]. Households with aged family heads had low propensity to use charcoal but had high chance of using firewood, kerosene and electricity may be because of convenience. Compared to the Rwandan case, household size is statistically significant and positive in using all four fuels: Firewood, charcoal, kerosene and electricity. On the education variable, families with highly educated heads registered significant positive sign implying that these families had high propensity use charcoal and electricity but were less likely to use dirty fuels (i.e., firewood and kerosene).

Contrary to the Rwandan case, the high number of dependents in a household in the Malawian case is only associated with using traditional fuels such as firewood. Furthermore, the male-headed households in Malawi registered high propensity to use charcoal and electricity but not firewood. This finding suggests there are gender differences that are country-specific. The households with heads engaged in the off-farm work had high propensity to use electricity and charcoal but not firewood. On the regional differences, with reference to the central part of Malawi, families located in the southern Malawi had high propensity to use charcoal, kerosene and electricity.

On the other hand, families in the Northern Region had high propensity to use firewood and electricity but not charcoal. These findings suggest that regional differences play a critical role in household fuel choice decision-making due to accessibility challenges and resource constraints. With reference to the year 2016/17, the coefficient for the year 2019/20 is significant and positive for using charcoal and electricity and also statistically significant and negative for using firewood and kerosene. Likewise, with the Rwanda case, this finding suggests that households may have a high preference to use clean fuels rather than dirty fuels over time, and this resonates with literature [225].

4.4.3.4 Driving factors of fuel consumption in Malawi under the SUR model

Secondly, looking at the case of Malawi, the estimates from the SUR model reveal that high wealth status is associated with high proportions of fuel expenditure using clean fuels like electricity but smaller proportions of expenditures on dirty fuels such as firewood. Thus, wealthy households highly depend on using clean fuels rather than dirty fuels like firewood. Regarding rurality, families in rural areas recorded a higher proportion of using firewood than electricity and charcoal. The reason could be because of easy availability of wood fuels in rural parts unlike in the urban setup. This may be attributed to easy firewood access in rural areas, unlike urban ones. As for the age of household heads, households with older heads spend big proportions of energy expenditure on firewood, kerosene and electricity rather than on charcoal. Looking at the family size variable, families with large family sizes spend big proportions of fuel expenditure on firewood and electricity but smaller proportions on charcoal in Malawi.

Regarding educational qualifications, families with more educated family heads spent big proportions of expenditures on electricity and charcoal but smaller proportions on dirty ones like firewood. In addition, like the Rwandan scenario, households with many dependents spent smaller amounts of expenditures on electricity but big proportions of expenditures on firewood. Considering gender, male-headed families in Malawi spent big proportions of expenditure on charcoal but smaller proportions on firewood and kerosene. Like in the Rwandan case, households with heads involved in the off-farm work spent big proportions on electricity and charcoal but smaller proportions on firewood.

Considering regional differences, with reference to the Central Region, households in the Southern Region spend big proportions of energy expenditure on kerosene and electricity but smaller proportions on charcoal. As for those found in the Northern Region, they spend big proportions of energy expenditure on firewood and electricity but smaller proportions on charcoal. On the temporal differences, with reference to 2016/17, households show a high degree of dependency on charcoal as a transitional fuel, attracting big proportions of energy expenditure, unlike other fuels. Due to continuous power outages, smaller proportions of energy expenditure for electricity consumption are not even significant. Much work is required to have a vibrant energy sector in Malawi. Overall, the findings from the multivariate probit model as an energy choice model and estimates from the SUR model to assess fuel consumption intensity seem to resonate with energy ladder hypothesis under the Malawian case.

4.5. Chapter conclusion and policy implications

This chapter used secondary datasets for the years 2013/14 (EICV4) and 2016 /17 (EICV5), whose custodian is the NASIR whilst in the Malawian case study, this chapter used secondary datasets for the years 2016/17 (IHS4) and 2019/20 (IHS5), whose custodian is the NSO. The chapter investigated driving factors that influence fuel choices, transition and inequality in the two countries over two time periods. Multivariate probit models were estimated to analyse factors that drive energy choices. On the other hand, Seemingly Unrelated Regression models were estimated to assess household energy consumption intensity drivers in the two countries.

In a nutshell, the study findings showed that households with more educated heads and high levels of wealth in Rwanda still use traditional and modern clean fuels supporting the energy stacking hypothesis. On the contrary, study findings from Malawi revealed that households with more educated heads and affluent families use clean fuels rather than traditional ones, supporting the energy ladder hypothesis as reported in the literature [225]. Some significant factors contributing to these differences apart from wealth status include household sizes, dependents, gender and regional factors. These study findings have shown that regional and gender discrepancies, including temporal aspects, influence household energy choices and transition. This may be attributed to social factors that induce different cultural habits and norms, influencing household energy choices depending on the country's context [227], [229], [234].

Comparing household consumption and energy inequalities, the study findings show that household consumption was more equal than energy inequality in the two countries as revealed by the Gini coefficients. The Lorenz curves of different fuels in the two countries showed that there are inter-country and intra-country differences on energy inequalities. For Rwanda case, during 2013/14 survey period, the distribution curves of kerosene, candles, charcoal and electricity closely followed each other in the top quintiles. The situation changed during 2016/17 survey period whereby distribution curve of electricity closely followed that of charcoal while that of candles followed that of fuel wood in the top quintiles. Under Malawi case, the distribution curve of the charcoal expenditure closely followed that of candles in the top quintiles. This suggests that these two fuels may be used as copying fuels during electricity power outages which worsened in 2016. The situation is different between 2019 and 2020 period

whereby distribution curve of charcoal is isolated but distribution curve of candles follows closely that of electricity expenditure.

Future research in the two countries should address these social-cultural factors requiring in-depth investigation. This study is also limited because it lacked real-time data from the supply side, such as energy prices and availability, influencing energy choices from perspectives of resource constraint and accessibility challenges. On policy recommendations, under the Rwandan case, there is a need to intensify awareness campaigns on the dangers of using dirty fuels since the results showed that even households with educated heads and affluent ones still use dirty fuels. For the Malawi case, much more work is required to develop the energy sector so that modern and clean fuels are readily available to households and also need income-generating activities to increase the wealth status of poverty-stricken families coupled with awareness campaigns that can act as an incentive to accelerate household energy transitions. These countries must develop tailor-made energy programs to reduce regional and gender discrepancies in energy inequalities. On temporal aspects in the two countries, this study also recommends policy action points that support improved and efficient cook-stoves that promote energy efficiency of biomass energy sources and transitional fuels such as charcoal and kerosene.

Table 27. Estimates from the SUR model depicting household fuel consumption intensity in Malawi

Regressors	Dependent variables (Proportion: expenditure on specific fuel/total fuel expenses)			
	Firewood	Charcoal	Kerosene	Electricity
Family asset value (MK) (logarithm)	-0.0013** (0.0002)	-0.0004* (0.0002)	-0.0000 (0.0000)	0.0017 ** (0.0001)
Rural dummy (Yes=1)	56.9487** (0.5082)	-35.5525** (0.4024)	-0.0408 (0.0564)	-14.1876** (0.2643)
Age of family head (years)	0.0315* (0.0126)	-0.0936** (0.0099)	0.0042** (0.0014)	0.0626** (0.0065)
Family size (number of persons)	0.3260** (0.0972)	-0.3283** (0.0770)	0.0003 (0.0108)	0.2334** (0.0506)
Family head only with primary school level	-1.8804* (0.8417)	1.3481* (0.6664)	0.0763 (0.0934)	1.4394** (0.4376)
Family head with secondary school level	-14.3563** (0.7446)	4.9282** (0.5895)	-0.0634 (0.0827)	8.7554** (0.3871)
Family head with tertiary school level	-23.8205** (1.3796)	-1.5707 (1.0924)	-0.2388 (0.1531)	26.1299** (0.7173)
Proportion of the dependent in HH size (%)	0.1123** (0.0086)	-0.0370** (0.0068)	-0.0009 (0.0010)	-0.0593** (0.0045)
Male-headed family (1=yes)	-4.7801** (0.4558)	2.4337** (0.3408)	-0.1165* (0.0478)	0.4331 (0.2238)
Off-farm work (1=yes)	-4.7801** (0.4558)	4.7634** (0.3609)	0.0067 (0.0506)	0.7003** (0.2370)
Southern	-0.3506 (0.4166)	-0.8073* (0.3299)	0.3950** (0.0462)	1.6089** (0.2166)
Northern	2.4373** (0.5270)	-1.6244** (0.4173)	-0.0035 (0.0585)	1.1459** (0.2740)
The year 2020 (1=yes)	-5.7468** (0.3694)	2.7329** (0.2925)	-0.3238** (0.0410)	-0.2235 (0.1921)
Constant	27.4966** (0.9258)	44.8702** (0.7330)	0.1929 (0.1028)	13.1606** (0.4814)
No. Of observations	23,789	23,789	23,789	23,789
R squared, F (13, 23789)	0.4471	0.3136	0.0076	0.2469
Chi2	19236.12	10868.56	181.12	7799.18
Prob > Chi2	0.0000	0.0000	0.0000	0.0000

*Significant at the 5% level. **Significant at the 1% level. Source: Authors' computation using IHS4 & IHS5. Standard errors are in brackets.

CHAPTER FIVE

SUMMARY OF THE STUDY FINDINGS, CONCLUSIONS AND POLICY RECOMMENDATIONS

Rwanda and Malawi are low-income countries in the Sub-Saharan Africa that have a common ambition of becoming middle-income countries in the coming decades. Aside that, they have also laid down strategies in places to facilitate implementation of activities that aim at achieving the sustainable development goals by 2030. At the center of all the SDGs is the sustainable development goal number 7 dealing with affordable and clean energy and remains the central hub to spearhead the other SDG especially SDG 10 that deals with inequalities, SDG 11 that deals with sustainable cities and communities and SDG 3 that aim at good health and well-being. Both countries have implemented electrification programs and other programs that ensure provision of modern energy services.

This doctoral study examined the household energy poverty, inequalities and transitions to understand the magnitude of energy poverty problem coupled with challenges associated with energy transitions in the domestic sector. Specifically, the doctoral study addressed the following objectives; to examine the state of energy poverty and its determinants; to analyse how energy insecurity influence education and health outcomes; and to explore energy choices, transitions and inequalities with regard to access to clean energy sources. The study used secondary datasets from the nationally representative samples collected under household integrated living standards surveys by the countries' national statistics offices on regular basis to address the study objectives. Empirical evidence from this investigation is crucial to shape two countries' public policies to boost energy transition readiness and also improve on social inclusion within the developing country contexts.

5.1.1 Energy poverty and its determinants in Rwanda and Malawi

The second chapter examined energy poverty status by adopting an 'inter-indicator analytical approach. The study employed two cross-indicators: A unidimensional metric that emphasizes on affordability and accessibility of clean fuels and also a multidimensional metric that involved computing household energy poverty index through principal component analysis to capture the multi-dimensional aspects of the energy poverty. Such approach was necessary in order to have a deeper understanding of the prevalence and intensity of the energy poverty problem in the

developing country contexts. So, the energy poverty metrics were applied to the two countries' recent Integrated Household Living Conditions Survey datasets. Preliminary results from descriptive statistics analysis on household energy use patterns revealed that batteries plus torches topped the list of lighting fuels seconded by electricity as primary lighting fuels for both countries. The notable difference in terms of lighting fuels is that Rwanda has a higher proportion of solar users than Malawi. However, both countries still depend on solid fuels such as firewood and charcoal for cooking, although Rwanda registered substantial LPG users compared to Malawi. Further disaggregation of household energy expenditures by monetary poverty and rurality indicated that the urban and the non-poor spent more on charcoal and electricity. However, in both countries, some non-poor spend more money on kerosene fuel. Regarding prevalence rates of energy poverty, the results from the unidimensional metric indicated that Rwanda had registered a higher national energy poverty rate of about 39.11% compared to that of Malawi which was at 24.47%. However, under the multi-dimensional analysis, the results revealed that Rwanda registered a high rate of the least energy-poor (27.69%) and also a high rate of the most energy-poor (24.69%) compared to Malawi which seemed to have more deprivation in multi-dimensional energy poverty whereby it registered a smaller proportion of the least energy-poor (9.31%) in spite of registering a lower rate of the most energy-poor (7.23%).

Furthermore, the estimates from the multi-level binary logistic regression models revealed that the education level of the head, income level, debt status of the family members, family size and rurality were the key determinants of expenditure-based energy poverty (unidimensional approach) in the two countries. A cross-comparison with the estimates from multi-level binary logistic regression models under multi-dimensional energy poverty metric showed that income levels, assets, rurality and being a Kigali resident were crucial determinants in Rwanda. However, land ownership, age of household head, income level, debt status of the family members and rurality were key factors in determining multi-dimensional energy poverty in Malawi. In additions, the district-level random effects of the multi-level binary logistic regression models were all significant, indicating some differences regarding energy poverty status across districts in the two countries.

Drawing policy lessons, the empirical evidence from this study suggests the need to carefully address the heterogeneity of energy poverty groups by implementing tailor-made policy instruments that must resonate with the country contexts. This requires a more collaboration

with non-state actors and other private stakeholders to implement various energy interventions depending on the availability of the local natural and physical resources. For instance, the governments in the two countries may consider introducing energy poverty schemes. These schemes may be accessed within groups under community financial group savings and loans revolving funds. Such an approach can address the challenges of affordability and accessibility for vulnerable groups that cannot afford individual Pay-As-You-Go schemes in the country. In addition, the government should consider prioritising and intensifying decentralised energy projects (i.e., through mini-grids depending on the local resources) in the three provinces with high energy poverty incidences.

5.1.2 Energy insecurity and its effects on education and health in the two countries

The objectives of the third chapter were to characterise the families which face energy insecurity and also analyse the effect of energy insecurity on education and health—using a nationally representative sample datasets and from two low-income country contexts under a micro-economic perspective. Overall, the prevalence rates showed that Rwandan households registered lower incidences of energy insecurity (22.48%) than Malawian households (42.58%). Within Rwanda, off-grid homes (12.65%) registered lower energy insecurity incidences than on-grid households (52.79%) which were energy-insecure. Further investigation by sub-sample of grid-connected households using 100 kWh per capita per year revealed that most of them (91.53%) consume below the minimum threshold. In contrast, within Malawi, off-grid homes (44.29%) have high levels of energy insecurity compared to on-grid households (30.32%).

Further inquiry on grid-connected households using 100 kWh per capita per year revealed that the majority (79.10%) can afford to meet the minimum threshold. Simple mean comparisons revealed that the energy-insecure are a heterogenous group who differ from their energy-secure counterparts in terms of demographics, socio-economic status, household energy use patterns, housing and dwelling status, and geographical location. For instance, the energy use patterns of the two groups were unbalanced concerning clean cooking. The two countries need much effort to have fully fledged modern cooking infrastructures. Binscatter plots showed that the energy-secure and energy-insecure positively correlated with transitional fuels (charcoal and kerosene) as income increased. It was interesting to note that the energy-insecure households were less likely to use fuel wood which shows the complexity of this phenomenon as it is influenced by other social burdens (water, housing, food, etc.). Regarding lighting fuels, the

energy-insecure and the energy-secure in the two countries seem to have a negative relationship with fuel wood and other fuels.

The Probit regression results confirm the preliminary findings from descriptive statistics analysis on energy insecurity determinants. In both countries, statistically significant marginal effects from probit models suggest that the differences in energy insecurity status were largely contributed by differences in household demographics, assets, dwelling characteristics and access to basic infrastructures on water and electricity. Finally, the results from instrumental variable probit regressions in both countries confirm the negative effect of energy insecurity on child school attendance. Furthermore, the results from instrumental variable -2SLS regressions in the two countries confirm that energy insecurity increased the propensity for family members to fall ill, thereby leading to poor health status. The study findings suggest that there is need to intensify awareness campaign on the need to use modern energy sources and also for the two governments to continue engaging with the private sector to scale up off grid energy solution i.e., micro solar grids and other alternative renewable energy sources for the rural populace.

5.1.3 An exploration of fuel choices, transition and inequality in Rwanda and Malawi

The fourth chapter also investigated factors that influence household fuel choices, transition and inequality in Rwanda and Malawi using repeated cross-sectional data collected from 28995 Rwandan households under two waves (EICV4-2013/14, EICV5-2016/17) and data gathered from 23,789 Malawian homes under two waves (IHS4-2016/17, IHS5-2019/20). The study used Lorenz curves and Gini coefficient to have a visualization of energy inequalities at different levels. Multivariate Probit models were employed to assess the factors that drive energy choices, while Seemingly Unrelated Regression models were estimated to evaluate household fuel consumption intensity in the two countries. Results from the study findings show that household consumption was more equal than energy inequality in the two countries as revealed by the values of the Gini Coefficients. The Lorenz curves of different fuels in the two countries showed that there are inter-country and intra-country differences on energy inequalities. The study findings do not support the energy ladder hypothesis in Rwanda, whereas the study findings from the Malawi case study affirm the energy ladder hypothesis.

In summary, the empirical evidence revealed that households with more educated family heads and high levels of wealth in Rwanda used both the traditional and modern clean fuels resonating with the energy stacking hypothesis. By contrast, empirical evidence from Malawi showed that

households with more educated family heads and affluent families used clean fuels rather than traditional ones, resonating with the energy ladder hypothesis [225]. Driving factors that influenced the fuel choices are the wealth status, family sizes, number of dependents in the family, sex of the family head and regional differences. The empirical evidence from this study indicates that regional and gender discrepancies, including temporal aspects, play a critical role in shaping the household fuel choices and transition. There might also be other social factors that shape energy choices i.e., cultural habits and norms that may differ depending on the country's context [227], [229], [234].

Comparing household consumption and energy inequalities, the study findings show that household consumption was more equal than energy inequality in the two countries as revealed by the Gini Coefficients. The Lorenz curves of different fuels in the two countries showed that there are inter-country and intra-country differences on energy inequalities. For Rwandan scenario, during 2013/14 survey period, the distribution curves of kerosene, candles, charcoal and electricity closely followed each other in the top quintiles. The situation changed during 2016/17 survey period whereby distribution curve of electricity closely followed that of charcoal while that of candles followed that of fuel wood in the top quintiles. Under the Malawian scenario, the distribution curve of the charcoal expenditure closely followed that of candles in the top quintiles. This suggests that these two fuels could have been used as coping fuels during electricity power outages which worsened in 2016. The situation is different between 2019 and 2020 period whereby distribution curve of charcoal is isolated but distribution curve of candles follows closely that of electricity expenditure.

5.1.4 Future research works

Future research needs to be carried out to examine the role of energy efficiency, energy prices, and other subjective measures that influence energy poverty using consensual approaches. The consensual approach is based on self-reported assessments and helps address the limitation of using the PCA tool in this study. This current investigation was limited by the unavailability of relevant information in the dataset. As such, additional research in this field would greatly help address these limitations by also utilising more recent datasets especially in Rwanda. In addition, there is need to carry out a particular primary survey to get primary data that will help in employing the physical threshold approach and demand-based approach to fully comprehend

the complexity of energy poverty between these two countries bearing in mind that Covid-19 pandemic disrupted many economic lives and lifestyles could have changed.

Furthermore, the two countries should address other social-cultural factors that require in-depth investigation. This study is also limited because it lacked real-time data from the supply side, such as energy prices and availability, influencing fuel choices from perspectives of resource constraint and accessibility challenges. On policy lessons, under the Rwandan case, there is need to intensify awareness campaigns on the dangers of using dirty fuels since the results showed that even households with educated family heads and affluent ones still used dirty fuels. For the Malawian case, much more work is required to develop the energy sector so that modern and clean fuels are readily available to households especially those located in rural areas and also need for income-generating activities to increase the wealth status of poverty-stricken families. This ought to be accompanied with awareness campaigns that can act as an incentive to accelerate household energy transitions. These countries must develop tailor-made energy programs to reduce regional and gender discrepancies in energy inequalities. On temporal aspects in the two countries, this study also recommends policy action points that support improved and efficient cook-stoves that promote meaningful use wood fuels and transitional fuels such as charcoal.

LIST OF PUBLICATIONS

(1) Khundi-Mkomba, F, Saha, A.K. and Wali , G.W. (2023). Social Protection Schemes in Rural Rwanda: A Panacea for Household Energy Burdens? (In press at the Energy for Sustainable Development Elsevier journal, Vol. 74, June 2023, pages 91- 101)

(2) Khundi-Mkomba, F, Saha, A.K. and Wali , G.W. (2021). Examining the status of energy poverty in Rwanda: An inter indicator analysis. https://doi.org/10.1016/j.heliyon.2021.e08441 (Elsevier & Scopus indexed)

(3) Khundi-Mkomba, F. (2021). Are urban Rwandan households using modern energy sources? An exploration of cooking fuel choices. International Journal of Energy Economics and Policy. Vol 11, No 2 (2021). DOI: https://doi.org/10.32479/ijeep.10735 (Scopus indexed).

(4) F. Khundi-Mkomba, A. Saha, and U. Wali, “Household-level effects of Energy Insecurity on Welfare in Southern Africa: A Malawian Case Study,” International Journal of Renewable Energy Development, Vol.10, no.1, pp.105-118, Feb. 2021. https://doi.org/10.14710/ijred.2021.33234 (Scopus indexed)

REFERENCES

[1] E. Joergensen and E. Heines, “Rwanda country strategic plan (2019-2023),” Nov. 26, 2018

[2] World Bank, “The Malawi Electricity Access Project,” Washington DC, May 2019.

[3] The World Bank, “Malawi Urbanization Review: Leveraging Urbanization for National Growth and Development,” 2016.

[4] Government of Malawi, “ Malawi’s Vision 2063: An Inclusively Wealthy and Self reliant Nation. ,” Lilongwe , 2020.

[5] V. R. Nalule, *Energy Poverty and Access Challenges in Sub Saharan Africa. The role of regionalism*. Palgrave Macmillan Cham, 2019.

[6] V. Nalule and T. Acheampong, “ Energy Transition Indicators in African Countries: Managing the Possible Decline of Fossil Fuels and Tackling Energy Access Challenges,” *The Journal of Sustainable Development, Law and Policy*, vol. 12, no. 1, pp. 1–48, 2021.

[7] World Bank, “Report: COVID-19 Slows Progress Toward Universal Energy Access,” Washington DC, Jun. 2022. Accessed: Oct. 31, 2022. [Online]. Available: https://www.worldbank.org/en/news/press-release/2022/06/01/report-covid-19-slows-progress-towards-universal-energy-access

[8] P. Casati, M. Moner-Girona, S. I. Khaleel, S. Szabo, and G. Nhamo, “Clean energy access as an enabler for social development: A multidimensional analysis for Sub-Saharan Africa,” *Energy for Sustainable Development*, vol. 72, pp. 114–126, 2023.

[9] G. Prasad, “ Improving access to energy in sub-Saharan Africa, Current Opinion in Environmental Sustainability, Volume 3, Issue 4, 2011,” *Curr Opin Environ Sustain*, vol. 3, no. 4, pp. 248–253, 2011.

[10] S. Bimenyimana, G. N. Asemota, and L. Li, “The state of the power sector in Rwanda: a progressive sector with ambitious targets,” *Front Energy Res*, vol. 68, 2018.

[11] K. H. Jean de Dieu and H. T. Kim, “ Peat briquette as an alternative to cooking fuel: A techno-economic viability assessment in Rwanda,” *Energy*, vol. 102, pp. 453–464, 2016.

[12] E. R. Yasemin, “Webinar : Toward Universal Energy Access by 2020 in Rwanda : The Role of Government , Multilateral and Private Sector,” 2017.

[13] UNFPA, “Unlocking Rwanda’s potential to reap the demographic dividend,” Kigali, Oct. 2017.

[14] UNDP, “Human Development Indices: A statistical update 2019.”

[15] J. Munyaneza, M. Wakeel, and B. Chen, “Overview of Rwanda Energy Sector: From Energy Shortage to Sufficiency,” *Energy Procedia*, vol. 104, pp. 215–220, 2016.

[16] REG, “Electricity Access.”

[17] Government of Malawi, “Support to SE4ALL Country Actions processes in Malawi. Action Agenda,” 2017

[18] SEALL, “Energy safety nets. A guide for policy makers,” 2020

[19] Government of Malawi, “National Energy Policy,” 2018

[20] Mo Ibrahim, “The Road to COP27: Making Africa’s case in the Global Climate debate,” Dakar, Jul. 2022.

[21] IOM, “DTM Malawi -Flash Report Update 1 - Tropical Storm Ana (31 January 2022),” Feb. 2022.

[22] NSO, “The Malawi Population and Housing Census 2018 Report,” 2019.

[23] L. C. Stringer, J. C. Dyer, M. S. Reed, A. J. Dougill, C. Twyman, and D. Mkwambisi, “Adaptions to Climate change, Drought, and Desertification: Local insights to Enhance Policy in Southern Africa,” *Environmental Science & Policy* , vol. 12, pp. 748–765, 2009.

[24] B. . H. M. Tchereni, “A Microeconomics Analysis Of Energy Choice Behaviour in South Lunzu Township, Malawi,” *Mediterr J Soc Sci*, 2013.

[25] World Bank, “Malawi Economic Monitor – Unleashing the Urban Economy.” Macroeconomics and Fiscal Management Global Practice,” Washington DC, 2017.

[26] Oxfam, “A Dangerous Divide: The State of Inequality in Malawi. Oxfam in Malawi,” Lilongwe , 2015.

[27] UNDP, “The Human Development Index 2018 report,” 2018.

[28] T. Meng, W. J. Florkowski, D. B. Sarpong, M. Chinnan, and A. V. A. Resurreccion, “Cooking Fuel Usage in Sub-Saharan Urban Households,” *Energies* , vol. 14, p. 4629, 2021.

[29] S. Shanmuga Priya, E. Cuce, and K. Sudhakar, “A perspective of COVID 19 impact on global economy, energy and environment,” *International Journal of Sustainable Engineering*, vol. 14, no. 6, pp. 1290–1305, 2021.

[30] A. Shoaib and S. Ariaratnam, “A study of Socioeconomic Impacts of Renewable Energy Projects in Afghanistan.,” *Procedia Engineering* , vol. 145, pp. 995–1003, 2016.

[31] Y. Lv, C. Si, and S. Zhang, “Impact of Urbanization on energy intensity by adopting a new technique for regional division: Evidence from China. ,” *Environ Science Pollution Research*, vol. 25, no., pp. 36102–36116, 2018.

[32] J. Rose, G. Bensch, A. Munyehirwe, and J. Peters, “The forgotten coal: Charcoal demand in sub-Saharan Africa,” *World Dev Perspect*, vol. 25, 2022.

[33] IEA, “World Energy Outlook 2019,” 2019.

[34] A. Nsabimana, B. J. Rukundo, A. Mukamugema, and J. C. Ngabitsinze, “Residential energy demands in Rwanda: Evidence from Robust models,” *Energy Policy*, vol. 160, 2022.

[35] V. Brailovskaya, “Essays in Development Economics, Case of Malawi. ,” UC Santa Cruz, 2018.

[36] Malawi government, “National Charcoal Strategy 2017-2027,” 2017. Accessed: Feb. 05, 2024. [Online]. Available: http://cepa.rmportal.net/Library/government-publications/national-charcoal-strategy-2017-2027/view

[37] L. Atherton and D. Brenner, “Meeting the Future of Energy Access in Malawi,” 2023.

[38] L. Zulu, “The Seven Pillars of Sustainability: Charcoal, Alternative Energy, and Forest Management in Malawi,” *Year of Global Africa*, 2018.

[39] F. Khundi-Mkomba, K. A. Saha, and G. U. Wali, “Examining the state of energy poverty in Rwanda: An inter-indicator analysis,” *Heliyon*, 2021.

[40] kang Li, B. Lloyd, L. Xiao-Jie, and W. Yi-Ming, “Energy poor or fuel poor: What are the differences?,” *Energy Policy*, vol. 68, pp. 476–481, 2014.

[41] R. Parajuli, “Access to energy in Mid-Far west region-Nepal from the perspective of energy poverty,” *Renewable Energy* , vol. 36, no. 9, pp. 2299–2304, 2011.

[42] C. W. Njiru and S. C. Letema, “Energy poverty and its implication on standard of living in Kirinyaga, Kenya.,” *Journal of Energy*, 2018.

[43] S. Buzar, “Energy poverty in Eastern Europe: hidden geographies of deprivation,” 2007

[44] S. Bouzarovski, S. Petrova, and R. Sarlamanov, “Energy poverty policies in the EU: a critical perspective,” *Energy Policy* , vol. 49, pp. 76–82, 2012.

[45] P. Lewis, “Fuel Poverty Can Be Stopped. National Right to Fuel Campaign, Bradford,” 1982

[46] B. Boardman, “Fuel Poverty: From Cold Homes to Affordable Warmth,” 1991

[47] B. Boardman, “Liberalisation and fuel poverty. In: Rutledge, I., Wright, P. (Eds.), ,” in *UK Energy Policy and the End of Market Fundamentalism*, P. Wright, Ed., Oxford University Press, 2010.

[48] J. Hills, “Getting the measure of fuel poverty, Hills Fuel poverty review.,” 2012.

[49] J. Hills, “Fuel Poverty—The Problem and its Measurement. Interim Report of the Fuel Poverty Review. ,” 2011

[50] B. K. Sovacool, “The political economy of energy poverty: A review of key challenges,” *Energy for Sustainable Development*, vol. 16, no. 3, pp. 272–282, 2012.

[51] S. Pachauri and D. Spreng, “Measuring and monitoring energy poverty,” *Energy Policy*, vol. 39, no. 12, pp. 7439–7504, 2011.

[52] IEA, “Energy Poverty: How to Make Modern Energy Access Universal? In: World Energy Outlook 2010,” Paris, 2010.

[53] IEA, “Focus on Energy Poverty. In: World Energy Outlook, 2007,” Paris, 2007.

[54] IEA, “Energy and Development. In: World Energy Outlook 2004,” Paris, 2004.

[55] IEA, “Energy and Poverty. In: World Energy Outlook 2002,” 2002.

[56] Z. Zhang, H. Shu, H. Yi, and X. Wang, “Household multidimensional energy poverty and its impacts on physical and mental health,” *Energy Policy*, vol. 156, p. 112381, 2021.

[57] S. Oum, “Energy poverty in the Lao PDR and its impacts on education and health,” *Energy Policy*, vol. 132, pp. 247–253, 2019.

[58] C. B. Mendoza, D. Dwane, D. Cayonte, Michael. S. Leabres, and L. A. Manaligod, “Understanding multidimensional energy poverty in the Philippines,” *Energy Policy*, vol. 133, 2019.

[59] H. Phoumin and F. Kimura, “Cambodia’s energy poverty and its effects on social wellbeing: Empirical evidence and policy implications,” *Energy Policy*, vol. 132, pp. 283–289, 2019.

[60] P. , Nussbaumer, M. Bazillian, V. Modi, and K. Yumkella, “Measuring energy poverty: focusing on what matters,” *Renewable Sustainable Energy Reviews*, 2012.

[61] R. Day, G. Walker, and N. Simcock, “Conceptualizing energy use and energy poverty using a capabilities framework,” *Energy Policy*, vol. 93, pp. 255–264, 2016.

[62] B. K. Sovacool, R. V. Sidortsov, and B. R. Jones, “Deciphering energy justice and injustice. In: Sovacool, B.K., Sidortsov, R.V., Jones, B.R. (Eds.), ,” in *Energy Security, Equality and Justice*, B. K. Sovacool, R. V. Sidortsov, and B. R. Jones, Eds., Routledge, Abingdon and New York, 2014.

[63] M. C. Nussbaum, “Women and Human Development: the Capabilities Approach,” 2000

[64] M. C. Nussbaum, “Capabilities as fundamental entitlements: Sen and global justice,” *Fem Econ*, vol. 9, no. 2–3, pp. 33–59, 2003.

[65] M. C. Nussbaum, “Creating Capabilities: the Human Development Approach,” 2011

[66] A. Sen, “Capability and well-being. ,” in *The Quality of Life.*, A. Sen and M. Nussbaum, Eds., Oxford: Oxford University Press, 1993, pp. 30–53.

[67] J. Rawls, “A theory of justice,” 1971

[68] S. T. Herrero, “Energy poverty indicators: A critical review of methods,” *Indoor and Built Environment*, vol. 26, no. 7, pp. 1018–1031, 2017.

[69] European Commission, “An energy policy for consumers,” Brussels, 1407, 2010.

[70] P. Heindl, “Measuring fuel poverty: General Considerations and Application to German household Data,” Berlin, Working paper 632, 2014.

[71] J. Hills, “Getting the measure of fuel poverty. Final Report of the Fuel Poverty Review,” 2012

[72] K. Chen and C. Feng, “Linking Housing Conditions and Energy Poverty: From a Perspective of Household Energy Self-Restriction,” *International Journal of Environment Research and Public Health* , vol. 19, p. 8254, 2022.

[73] R. Moore, “Definitions of fuel poverty: Implications for policy,” *Energy Policy* , vol. 49, pp. 19–26, 2012.

[74] F. Bradford and B. Mills, “www.econstor.eu,” 2009.

[75] P. Bezerra, T. Cruz, A. Mazzone, A. F. P. Lucena, E. De Cian, and R. Schaeffer, “‘The multidimensionality of energy poverty in Brazil: A historical analysis,’” *Energy Policy*, vol. 171, 2022.

[76] M. González-Eguino, “Energy poverty: An overview,” *Renewable and Sustainable Energy Reviews*, vol. 47, pp. 377–385, 2015.

[77] S. Pachauri, “An analysis of cross-sectional variations in total household energy requirements in India using micro survey data,” *Energy Policy*, vol. 32, no. 15, pp. 1723–1735, 2004, doi: 10.1016/S0301-4215(03)00162-9.

[78] V. , Modi, S. McDade, D. Lallement, and J. Saghir, “Energy and the Millennium Development Goals; Energy Sector Management Assistance Programme,” 2005

[79] UN AGECC, “Energy for a Sustainable Future,” 2010

[80] B. Mirza and A. Szirmai, “Towards a new measurement of energy poverty: A cross community analysis of rural Pakistan,” Working Papers, No.024., 2010.

[81] IEA, “World Energy Outlook 2012,” Paris, 2012.

[82] WHO, “Health impact of low indoor temperatures: report on a WHO meeting,” Copenhagen, 1987.

[83] K. Rademaekers, J. Yearwood, and A. Ferreira, “Selecting indicators to measure energy poverty. Under the pilot project ‘Energy Poverty Assessment of the Impact of the Crisis and Review of Existing and Possible New Measures in the Member States’ Framework,” 2016.

[84] L. C. Culver, “Energy poverty: what you measure matters. In: Pre-symposium White Paper for - Reducing Energy Poverty with Natural Gas: Changing Political, Business, and Technology Paradigms,” Stanford, 2017.

[85] M. Bhatia and N. Angelou, “Beyond connections energy access redefined. Tech. Rep.,” 2015

[86] IEA, “World Energy Outlook 2014.International Atomic Agency Publications 2014.,” Paris, 2014.

[87] P. Nussbaumer, F. F. Nerini, I. Onyeji, and M. Howells, “Global insights based on the multidimensional energy poverty index (MEPI),” *Sustainability*, vol. 5, no. 5, 2013.

[88] I. Iddrisu and S. C. Bhattacharyya, “Sustainable Energy Development Index: A multi-dimensional indicator for measuring sustainable energy development,” *Renewable and Sustainable Energy Reviews*, vol. 50, pp. 513–530, 2015.

[89] A. Khizar, L. Shixiang, X. Deyi, B. Khan, and R. et al. Aigerim, “Do socioeconomic factors determine household multidimensional energy poverty? Empirical evidence from South Asia,” *Energy Policy* , vol. 146, 2020.

[90] B. Legendre and O. Ricci, “Measuring fuel poverty in France: Which households are the most fuel vulnerable?,” *Energy Econ*, vol. 49, pp. 620–628, 2015.

[91] Q. Lin, C. Weida, and S. Licheng, “Impact of energy poverty on household quality of life -- based on Chinese household survey panel data,” *J Clean Prod*, vol. 366, 2022, doi: https://doi.org/10.1016/j.jclepro.2022.132943.

[92] Clemente, “Remembering Stockholm: The Environment is People and their necessity for more Energy,” 2014

[93] G. H. Boyce, “Fuelling the future with 21st Century Coal,” 2016,” 2016

[94] A. C. Langat, “Barriers hindering Implementation, Innovation and Adoption of ICT in Primary Schools in Kenya,” *International Journal of Innovative Research and Development*, vol. 4, no. 2, pp. 1–11, 2015.

[95] M. Mapako, “Energy, the Millennium Development Goals and the key Emerging issues,” 2010

[96] B. Bridge, “Individual and household-level effects of energy poverty on human development,” PhD Thesis, University of New Mexico, Albuquerque. New Mexico, 2016.

[97] F. Birol, “Energy economics: a place for energy poverty in the Agenda? ,” *Energy* , vol. 28, no. 3, pp. 1–6, 2007.

[98] WHO, “Household Air Pollution and Health,” WHO Factsheet No. 292, 2018

[99] IEA, IRENA, UNSD, World Bank, and WHO, “Tracking SDG 7: The Energy Progress Report,” Washington, DC, USA, 2021.

[100] E. R. Schislyaeva and O. A. Saychenko, “Evaluation of post COVID-19 energy poverty and global trading impact on energy affordability,” *Front Energy Res*, Sep. 2022.

[101] B. Tarekegne, “Just electrification: Imagining the justice dimensions of energy access and addressing energy poverty,” *Energy Research for Social Sciences*, vol. 70, p. 101639, 2020.

[102] NASIR, “Rwandan Integrated Household Living Conditions Survey – 2016/17,” Kigali, 2018.

[103] NASIR, “EICV5_Environment and Natural Resources Thematic Report,” Kigali, Dec. 2018.

[104] NSO, “Malawi Integrated Household Survey 2016-2017. Household Socioeconomic Characteristics report,” Zomba, 2018.

[105] S. Gupta, E. Gupta, and G. K. Sarangi, “ Household energy poverty index for India: an analysis of inter-state differences,” *Energy Policy*, vol. 144, 2020.

[106] E. Gupta, “Oil vulnerability index of oil-importing countries,” *Energy Policy* , vol. 36, pp. 1195–1211, 2008.

[107] P. J. Gertler, O. Shelef, C. D. Wolfram, and A. et al. , Fuchs, “The demand for energy using assets among the world’s rising middle classes,” *American Economic Review*, vol. 106, no. 6, pp. 1366–1401, 2016.

[108] A. C. Sadath and R. H. Acharya, “Assessing the extent and intensity of energy poverty using Multidimensional Energy Poverty Index: empirical evidence from households in India,” *Energy Policy*, vol. 102, pp. 540–548, 2017.

[109] B. Lin and H. Zhao, “ Does off-farm work reduce energy poverty? Evidence from rural China,” *Sustainable Production Consumption* , vol. 27, pp. 1822–1829, 2021.

[110] B. Lin and H. Zhao, “Does off-farm work reduce energy poverty? Evidence from rural China,” *Sustain Prod Consum*, vol. 27, pp. 1822–1829, Jul. 2021.

[111] G. Y. Obeng, E. Hans-Dieter, A. Braimah, and et al. Brew-Hammond, “Solar photovoltaic electrification and rural energy-poverty in Ghana,” *Energy Sustainable Development*, vol. 12, no. 1, pp. 43–54, 2008.

[112] M. Salari and R. J. , et al. Javid, “Modeling household energy expenditure in the United States,” *Renewable Sustainable Energy Review*, vol. 69, pp. 822–832, 2017.

[113] H. Phoumin and F. Kimura, “Cambodia’s energy poverty and its effects on social well-being; Empirical evidence and policy implications,” *Energy policy* , vol. 132, pp. 283–289, 2019.

[114] A. N. Mulaga, M. S. Kamndaya, and S. J. Masangwi, “Examining the incidence of catastrophic health expenditures and its determinants using multilevel logistic regression in Malawi,” *PLoS One*, vol. 16, p. e0248752., 2021.

[115] H. M. Crowson, “Multilevel Binary Logistic Regression Using Stata . (Drop-down Menus) [Powerpoint Slides].”

[116] N. Sommet and D. Morselli, “Keep calm and learn multilevel logistic modeling: a simplified three-step procedure using Stata, R, mplus, and SPSS,” *International Review of Social Psychology* , vol. 30, no. 1, pp. 203–218, 2017.

[117] D. W. Gafa and Y. G. A. Egbendewe, “Energy Poverty in rural West Africa and its determinants: Evidence from Senegal and Togo,” *Energy Policy* , vol. 156, p. 112476, 2021.

[118] K. Kaygusuz, “Energy services and energy poverty for sustainable rural development,” *Renewable Sustainable Energy Review*, vol. 15, no. 2, pp. 936–947, 2011.

[119] Trung Thanh Nguyen, Thanh-Tung Nguyen, Viet-NguHoang, Clevo Wilson, and Shunsuke Managi, “Energy transition, poverty and inequality in Vietnam,” *Energy Policy*, vol. 132, pp. 536–548, 2019, doi: https://doi.org/10.1016/j.enpol.2019.06.001.

[120] S. Khandker, D. Barnes, and A. S. Hussain, “Are the energy poor also income poor? Evidence from India,” *Energy policy* , vol. 47, pp. 1–12, 2012.

[121] R. Castano-Rosa and S. Okushima, “Prevalence of energy poverty in Japan: a comprehensive analysis of energy poverty vulnerabilities,” *Renewable Sustainable Energy Reviews* , vol. 145, p. 111006, 2021.

[122] W. M. Ashagidigbi, B. A. Babatunde, A. I. Ogunniyi, K. O. Olagunju, and A. O. Omotayo, “Estimation and Determinants of Multidimensional Energy Poverty Among Households in Nigeria,” *Sustainability* , vol. 12, p. 7332, 2020.

[123] S. Bouzarovski, “Energy Poverty: (Dis)Assembling Europe’s Infrastructural Divide.” Palgrave Macmillan, Switzerland, p. 2018, 2018.

[124] F. Ogwumike and U. Ozughalu, “Analysis of energy poverty and its implications for sustainable development in Nigeria,” *Environmental Development Economics* , vol. 21, no. 3, pp. 273–290, 2016.

[125] S. Bouzarovski and S. Petrova, “A global perspective on domestic energy deprivation: overcoming the energy poverty-fuel poverty binary,” *Energy Research Social Science* , vol. 10, pp. 31–40, 2015.

[126] K. Finnoff, “Decomposing inequality and poverty in post-war Rwanda: The roles of gender, education, wealth and location,” *Development in Southern Africa* , vol. 32, no. 2, 2015.

[127] R. Anker and M. Anker, “Living Wage Report Kenya,” 2017.

[128] J. , Sokolowski, P. Lewandowski, A. Kielczewska, and S. Bouzarovski, “A multidimensional index to measure energy poverty: The Polish case,” *Energy Sources Part B Energy Economic Planning* , vol. 15, no. 2, pp. 92–112, 2020.

[129] K. Rutkowski, A. Salach, and Z. Szpor Ziolkowska, “How to Reduce Energy Poverty in Poland?,” IBS Policy Paper 01/2018, 2018.

[130] R. H. Heck, S. L. Thomas, and L. N. Tabata, *Multilevel Modeling of Categorical Outcomes Using IBM SPSS*, Second ed. Routledge. New York, 2014.

[131] F. K. Mkomba, A. K. Saha, and U. G. Wali, “Household-Level Effects of Energy Insecurity on Welfare in Southern Africa: A Malawian Case Study,” *International Journal of Renewable Energy Development*, vol. 1, pp. 105-118., 2021.

[132] H. Phoumin and F. Kimura, “The impacts of energy insecurity on household welfare in Cambodia: Empirical evidence and policy implications,” *Econ Model*, 2019.

[133] D. Hernandez, Y. Jiang, D. Carrion, D. Phillips, and Y. Aratani, “Housing hardship and energy insecurity among native-born and immigrant low-income families with children in the United States,” *J Child Poverty*, 2016.

[134] D. Hernández, Y. Aratani, and Y. Jiang, “Energy Insecurity among families with children,” New York, 2014.

[135] V. Foster, J.-P. tre, and Q. Wodon, “Energy Prices, Energy Efficiency, and Fuel Poverty Latin America and Caribbean Regional Studies Programme. ,” 2000

[136] UNDP, “The Sustainable Development Goals Report,” New York, 2017.

[137] D. F. Barnes, S. R. Khandker, and H. A. Samad, “Energy Access, Efficiency, and Poverty: How many are energy poor in Bangladesh? ,” 5332, Jun. 2010.

[138] R. D. Colton, “Home Energy Affordability in New York: The Affordability gap (2008-2010),” 2011

[139] J. Cook and M. Shah, “Reducing Energy Burden with Solar: Colorado’s Strategy and Roadmap for States.,” 2018

[140] A. Drehobl and L. Ross, “Lifting the High Energy Burden in America’s Largest Cities: How Energy Efficiency can improve Low Income and Undeserved Communities.,” 2016.

[141] C. Berry, C. Hronis, and M. Wood ward, “Who ‘s Energy Insecure? You Might be Surprised.” 2018 ACEEE Summer study on Energy Efficiency in Buildings: Making Efficiency Easy and Enticing,” 2018, p. 393.

[142] A. Elnakat, J. D. Gomez, and N. Booth, “A zip code study of socioeconomic, demographic, and household gendered influence on the residential energy sector,” *Energy Reports* , vol. 2, pp. 21–27, 2016.

[143] A. Drehobl and L. Ross, “Lifting the High Energy Burden in America’s Largest Cities: How Energy Efficiency Can Improve Low-Income and Underserved Communities,” 2016

[144] C. Ayoo, *Towards Energy Security for the Twenty-First Century, Energy Policy*. 2020.

[145] B. K. Sovacool, “Defining, measuring and tackling energy poverty. Book chapter. In: Energy Poverty: Global Challenges & Local Solutions,” Oxford University Press, 2014, pp. 21-53.

[146] S. Oum, “Energy poverty in the Lao PDR and its impacts on education and health,” *Energy Policy*, vol. 132, pp. 247-253, 2019.

[147] J. Gubbels, C. Put, and M. Assink, “Risk Factors for School Absenteeism and Dropout: A Meta-Analytic Review,” *J Youth Adolesc*, 2019.

[148] T. Belachew, C. Hadley, and D. et al. Lindstrom, “Food insecurity, school absenteeism and educational attainment of adolescents in Jimma Zone Southwest Ethiopia: a longitudinal study,” *Nutritional Journal*, vol. 10, 2011.

[149] C. A. Kearney and A. Bensaheb, “School Absenteeism and School Refusal Behavior: A Review and Suggestions for School-Based Health Professionals,” *Journal of School Health*, vol. 76, no. 1, pp. 3–7, Feb. 2006.

[150] UNCTAD, “TRADE AND DEVELOPMENT REPORT 2018: POWER, PLATFORMS AND THE FREE TRADE DELUSION,” Geneva, 2018.

[151] M. J. Castro-Sitiriche and J. Ozik, “Rural Electrification Pathways to Well-being,” in *6th International Conference on Appropriate Technology. Kenyatta University Conference Center*, Nairobi: Kenyatta University Conference Center, Nov. 2014.

[152] L. Ross, A. Drehobl, and B. Stickles, “The High Cost of Energy in Rural America: Household Energy Burdens and Opportunities for Energy Efficiency,” 2018.

[153] W. Greene, *Econometrics Analysis*. New York : Pearson, 2012.

[154] S. Di Falco, M. Veronesi, and M. Yesuf, “Does adaptation to climate change provide food security? A micro-perspective from Ethiopia ,” *Am J Agric Econ*, vol. 93, no. 3, pp. 829–846, 2011.

[155] E. Martey, P. M. Etwire, and J. Mockshell, “Climate-smart cowpea adoption and welfare effects of comprehensive agricultural training programs,” *Technology in society* , vol. 64, p. 101468, 2021.

[156] P. R. Rosenbaum and D. B. Rubin, “ The Central Role of the Propensity Score in Observational Studies for Causal Effects. ,” *Biometrika*, vol. 70, no. 1, pp. 41–55, 1983.

[157] M. A. Hernan and J. M. Robins, *Causal Inference: What If*. Boca Raton: Chapman & Hall/CRC., 2020.

[158] E. Martey, P. M. Etwire, and I. Koomson, “Parental Time Poverty, Child Work and School Attendance in Ghana,” *Child Indicators Research* , vol. 15, pp. 1489–1515, 2022.

[159] S. Trace, “Measuring access for different needs implications,” in *L. Guruswamy (Ed.), International Energy and Poverty: the Emerging Contours, Routledge, New York (2016)*, New York: Routledge, 2016, pp. 160–178.

[160] B. Sovacool and I. M. Drupady, *Energy access, poverty, and development: The governance of small-scale renewable energy in developing Asia. Energy Access, Poverty, and Development: The Governance of Small-Scale Renewable Energy in Developing Asia*. 2012.

[161] R. Moore, “Definitions of Fuel poverty: Implications for Policy,” *Energy Policy* , vol. 49, pp. 19–26, 2012.

[162] S. Jesse, S. Sawyer, and D. Hernandez, “Energy, Poverty, and Health in Climate Change: A Comprehensive Review of an Emerging Literature.,” *Frontiers of Public Health* , vol. 7, p. 357, 2019.

[163] Heltberg R, “ Factors determining household fuel choice in Guatemala,” *Environment and Development Economics* , vol. 10, pp. 337–361, 2005.

[164] O. R. Masera, B. D. Saatkamp, and D. M. Kammen, “From linear fuel switching to multiple strategies: a critique and alternative to the energy ladder model,” *World Development* , vol. 28, pp. 2083–2103, 2000.

[165] A. Mekonnen and G. Kohlin, “Determinants of household fuel choice in major cities in Ethiopia. ,” No. 399, 2009.

[166] S. Pachauri and D. Spreng, “Energy use and energy access in relation to poverty,” *Econ Polit Wkly*, vol. 39, pp. 271–278, 2004.

[167] E. Martey, “Tenancy and energy choice for lighting and cooking: Evidence from Ghana,” *Energy Economics* , vol. 80, pp. 570–581, 2019.

[168] M. D. Cattaneo, R. K. Crump, M. H. Farrell, and Y. Feng, “Binscatter Regressions,” in preparation for the Stata Journal,” 2019

[169] R. Toole, “The Energy Ladder: A Valid Model for Household Fuel Transitions in Sub-Saharan Africa?,” Master’s thesis, Tufts University, 2015.

[170] A. K. Banash, D. H. Holben, and T. Basta, “Food insecurity is associated with household utility insecurity among individuals living with HIV/AIDS in rural Appalachia,” *J Hunger Environ Nutr*, vol. 8, pp. 242–255, Jun. 2013.

[171] M. E. Webber, “Thirst for Power: Energy, Water, and Human Survival,” 2016

[172] D. Hernandez, “Energy insecurity: A framework for understanding energy, the built environment, and health among the vulnerable populations in the context of climate change,” *Am J Public Health*, pp. e32-4, 2013.

[173] C. Farbotko and G. Waitt, “Residential air conditioning and climate change: voices of the vulnerable,” *Health Promotion Journal of Australia*, vol. 22, pp. 13–5, 2011.

[174] M. Gonzalez-Eguino, “Energy poverty: an overview,” *Renewable Sustainable Energy Review* , vol. 47, pp. 377–385, 2015.

[175] D. J. Bednar, T. G. Reames, and G. A. Keoleaian, “The intersection of energy and justice: modelling the spatial, racial/ethnic and socioeconomic patterns of urban residential heating consumption and efficiency in Detroit, Michigan,” *Energy Building*, vol. 143, pp. 25–34, 2017.

[176] D. Y. Bisu, A. Kuhe, and H. A. Lortyer, “Urban household cooking energy choice: an example of Bauchi metropolis, Nigeria,” *Energy, Sustainability and Society* , vol. 6, p. 15, 2016.

[177] S. Bird and D. Hernandez, “Policy options for the split incentive: Increasing energy efficiency for low income renters.,” *Energy Policy*, vol. 48, pp. 506–514, 2012.

[178] J. Lay, J. Ondraczek, and J. Stoever, “Renewables in theenergy transition: Evidence on solar home systems and lighting fuel choice in Kenya. ,” *Energy Econ*, vol. 40, pp. 350–359, 2013.

[179] Laterite, “Factors and drivers of dropout and repetitioning Rwandan schools,” Laterite Policy Brief no.07/2019, 2019

[180] B. Shiferaw, M. Kassie, M. Jaleta, and C. Yirga, “Adoption of improved wheat varieties and impacts on household food security in Ethiopia,” *Food Policy*, vol. 44, pp. 272–284, 2014.

[181] Practical Action, “Final Quantitative Report on the Cost and Efficiency of Cooking Fuels in Malawi,” Lilongwe, 2017.

[182] M. A. Maganga, B. B. Maonga, and G. G. Gebremariam, “Non-price determinants of household’s choice of cooking energy in Malawi.,” *International Journal of Development and Sustainability*, vol. 4, pp. 18–28, 2015.

[183] F. Khundi-Mkomba, “Are urban Rwandan households using modern energy sources? An exploration of cooking fuel choices ,” *International Journal of Energy Economics and Policy*, vol. 11, 2021.

[184] F. Khundi-Mkomba, U. G. Wali, E. Ntagwirumugara, and A. K. Saha, “ Determinants of Home Lighting Fuel Choices in Rwanda: A Discrete Choice Analysis,” *Journal of Energy and Power Engineering*, 2020.

[185] IRENA, “Renewable Energy: A Gender Perspective,” Abu Dhabi, 2019.

[186] Falak Sher, Akhtar Abbas, and Rehmat Ullah Awan, “An Investigation of Multidimensional Energy Poverty in Pakistan: A Province level Analysis,” *International Journal of Energy Economics and Policy*, vol. 2, pp. 65–75, 2014.

[187] Buba Abdullahi, Abdu Musa, Adamu Idi, Jibir Adamu, and Usman Y I, “Socio-economic determinants of households fuel consumption in Nigeria,” *International Journal of Research- Granthaalayah*, vol. 5, pp. 348–360, 2017.

[188] IEA, “World Energy Outlook,” Paris, 2006.

[189] Morrissey J, “The energy challenge in sub-Saharan Africa: A guide for advocates and policy makers: Part 2: Addressing energy poverty,” 2017.

[190] Bhattacharyya S C, “Energy access programmes and sustainable development: A critical review and analysis,” *Energy for Sustainable Development* , vol. 16, pp. 260–271, 2012.

[191] Frans Berkhout, Peter Marcotullio, and Tatsuya Hanaoka, “Understanding energy transitions,” *Sustain Sci*, vol. 7, pp. 109–111, 2012.

[192] IRENA, “International Renewable Energy Agency, ‘Energy Transition’ (2018) .” 2018.

[193] NASIR, “The EICV 5 Rwanda Poverty Panel Thematic Report -2016/2017,” Kigali, Dec. 2018.

[194] A. Tashobya, “Rwanda launches green growth campaign ,” Jan. 05, 2017.

[195] Lighting Africa, “Lighting Africa ,” Apr. 17, 2020

[196] MININFRA, “Rural Electrification Strategy,” Kigali, 2016.

[197] Republic of Rwanda, “National Urbanisation Policy,” Kigali, Dec. 2015.

[198] NASIR, “Fourth Population and Housing Census of Rwanda 2012,” Kigali, 2012.

[199] Republic of Rwanda, “Law No10/ 2012 of 02/05/2012 governing urban planning and building in Rwanda,” Kigali, 2012.

[200] MEHDI FARSI, MASSIMO FILIPPINI, and SHONALI PACHAURI, “Fuel choices in urban Indian households ,” *Environment and Development Economics* , vol. 12, pp. 754–774, 2007.

[201] Smith Michael G. and Urpelainen Johannes, “Early Adopters of Solar Panels in Developing Countries: Evidence from Tanzania,” *Review of Policy Research*, vol. 31, pp. 17–37, Jan. 2014.

[202] Pachauri S and Jiang L.W, “The household energy transition in India and China,” *Energy Policy* , vol. 36, pp. 4022–4035, 2008.

[203] Government of Malawi, “National Energy Policy,” Lilongwe, 2018.

[204] M. A. Z. Manda, “Situation of Urbanization in Malawi Report,” 2013.

[205] Daioglou V, Van Ruijven BJ, and Van Vuuren DP, “Model projections for household energy use in developing countries,” *Energy*, vol. 37, pp. 601–615, 2012.

[206] Van Ruijven BJ, Van Vuuren DP, de Vries BJM, Isaac M, and van der Sluijs JP, “Model projections for household energy use in India.,” *Energy Policy*, vol. 39, pp. 7747–7761, 2011.

[207] Pachauri S, Van Rjuvien B, Nagai Y, Riahi K, and Van Vuuren DP, “Pathways to achieve universal household access to modern energy by 2030,” *Environmental Research Letters* , vol. 8, 2013.

[208] Ekholm T, Krey V, Pachauri S, and Riahi K, “Determinants of household energy consumption in India,” *Energy Policy*, vol. 38, pp. 5696–5707, 2010.

[209] S. Pachauri, N. Rao, and C. Cameron, “Outlook for modern cooking energy access in Central America,” *PLoS ONE* , 2018.

[210] C. Cameron, S. Pachauri, N. Rao, D. McCollum, and J. Rogelj, “Policy trade-offs between climate mitigation and clean cook-stove access in South Asia,” *Nature Energy* , vol. 1, 2016.

[211] T. Makonese, A. P. Ifegbesan, and I. T. Rampedi, “Household cooking fuel use patterns and determinants across southern Africa: Evidence from the demographic and health survey data. ,” *Energy & Environment* , vol. 29, pp. 29–48, 2018.

[212] G. Hiemstra-van der Horst and A. J. Hovorka, “Reassessing the ‘energy ladder’: household energy use in Maun, Botswana,” *Energy Policy* , vol. 36, pp. 3333–3344, 2008.

[213] M. Madubansi and C. M. Shackleton, “Changes in fuelwood use and selection following electrification in the Bushbuckridge lowveld, South Africa,” *Journal of Environment Management*, vol. 83, pp. 416–426, 2007.

[214] M. Arnold, G. Kohlin, and R. Persson, “Wood fuels, livelihoods and policy interventions: changing perspectives,” *World development* , vol. 34, pp. 596–611, 2006.

[215] NASIR, “Rwandan Integrated Household Living Conditions Survey – 2013/14,” Kigali, 2014.

[216] World Population Review, “Rwanda Population.” 2020.

[217] NSO, “Malawi Fifth Integrated Household Survey (IHS 5) 2019-2020. National Statistics Office. Zomba. Malawi.,” Zomba, 2020.

[218] NSO, “Malawi-Fourth Integrated Household Survey 2016-2017,” Zomba, 2020.

[219] R. Mussa, “Spatial Comparisons of Poverty and Inequality in living standards in Malawi,” *South African Journal of Economics* , vol. 81, 2013.

[220] S. Murkhejee and T. Benson, “The determinants of poverty in Malawi. ,” *World Dev*, vol. 31, pp. 339–358, 2003.

[221] J. Haughton and S. R. Khandker, *Handbook on Poverty and Inequality*. Washington, DC: The World Bank, 2009.

[222] A. Wagstaff, P. Pierella, and E. Van doorslaer, “On the measurement of inequalities in health.,” *Social Science and Medicine*, vol. 33, pp. 545–557, 1991.

[223] A. Jacobson, A. D. Milman, and D. M. Kammen, “Letting the (energy) Gini out of the bottle: Lorenz curves of cumulative electricity consumption and Gini coefficients as metrics of energy distribution and equity,” *Energy Policy* , vol. 33, pp. 1825–1832, 2005.

[224] S. Wu, X. Zheng, and C. Wei, “Measurement of inequality using household energy consumption data in rural China,” *Nat Energy*, vol. 2, pp. 795–803, 2017.

[225] A. Pallegedara, K. A. Mottaleb, and D. B. Rahut, “Exploring choice and expenditure on energy for domestic works by the Sri Lankan households: Implications for policy,” *Energy*, vol. 222, 2021.

[226] C. B. . L. Jumbe and A. Angelsen, “Household’s choice of fuelwood source in Malawi: A multinomial probit analysis,” in *International Association of Agricultural Economists Conference*, Gold Coast , Aug. 2006.

[227] J. . H. Nlom and A. . A. Karimov, “Modeling Fuel Choice among Households in Northen Cameroon,” *Sustainability* , vol. 7, pp. 9989–9999, 2015.

[228] J. T. Mensah and G. Adu, “An empirical analysis of household energy choice in Ghana,” *Renewable Sustainable Energy Review*, vol. 51, 2015.

[229] A. Karimu, “Cooking fuel preferences among Ghanaian Households: An Empirical analysis,” *Energy for Sustainable Development* , vol. 17, pp. 10–17, 2015.

[230] D. B. Rahut, A. Ali, and K. A. Mottaleb, “Understanding the determinants of alternate energy options for cooking in the Himalayas: Empirical evidence from the Himalayan region of Pakistan,” *Journal of Clean Production*, 2017.

[231] Y. Alem, A. D. Beyene, G. Köhlin, and A. Mekonnen, “Modeling household cooking fuel choice: A panel multinomial logit approach,” *Energy Econ*, vol. 39, pp. 129–137, 2016.

[232] Z. Jingchao, K. Kotani, and T. Saijo, “Low-quality or high-quality coal? Household energy choice in rural Beijing,” *Energy Econ*, vol. 78, pp. 81–90, 2019.

[233] D. Bahadur, B. Behera, and A. Ali, “Household energy choice and consumption intensity : Empirical evidence from Bhutan,” *Renewable Sustainable Energy Review* , vol. 53, pp. 993–1009, 2016.

[234] W. Akpalu, I. Dasmani, and P. B. Aglobitse, “Demand for cooking fuels in a developing country: To what extent do taste and preferences matter? ,” *Energy Policy*, vol. 39, pp. 6525–6531, 2011.

[235] U. Paudel, U. Khatri, and P. P. Krishna, “Understanding the Determinants of Household Cooking Fuel Choice in Afghanistan: A Multinomial Logit Estimation,” *Energy*, 2018.

APPENDICES

Appendix 1: Table 28. Disaggregated energy transitions by rurality, income poverty and gender in Rwanda

	2013		2017		Δ 2013–2017	
Rural vs Urban	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
Share of wood users (%)	24.87	25.46	18.17	26.23	-6.70	0.77
Share of kerosene users (%)	21.67	29.90	8.19	9.74	-13.48	-20.16
Share of charcoal users (%)	78.90	11.90	74.54	13.32	-4.36	1.40
Share of electricity users (%)	65.85	6.92	68.92	13.55	3.07	6.63
Wood expenditure/capita (RWF)	797.40	682.28	641.52	868.05	-155.88	185.77
Kerosene expenditure/capita (RWF)	257.24	315.21	93.99	146.37	-163.25	-168.84
Charcoal expenditure/capita (RWF)	11710.77	754.95	12155.57	995.86	444.80	240.91
Electricity expenditure/capita (RWF)	5828.74	469.03	5917.77	590.34	89.03	121.31
Proportion of wood in energy expenses (%)	7.38	15.75	6.48	18.50	-0.90	2.75
Proportion of kerosene in energy expenses (%)	6.85	20.46	2.40	6.34	-4.45	-14.12
Proportion of charcoal in energy expenses (%)	48.30	5.83	47.02	7.66	-1.28	1.83
Proportion of electricity in energy expenses (%)	26.83	4.50	28.93	9.05	2.10	4.55
Energy expenditure per capita (RWF)	19240.76	2400.02	20023.52	2802.13	782.76	402.11
Total consumption per capita (RWF)	665180.30	215621.70	645232.50	217150.70	-19947.80	1529.00
Monetary poverty	**nonpoor**	**poor**	**nonpoor**	**Poor**	**nonpoor**	**poor**
Share of wood users (%)	29.72	17.24	28.11	18.23	-1.61	0.99
Share of kerosene users (%)	30.64	24.77	9.55	9.32	-21.09	-15.45

Share of charcoal users (%)	30.92	6.79	32.09	7.48	1.17	0.69
Share of electricity users (%)	23.37	2.95	31.60	6.10	8.23	3.15
Wood expenditure/capita (RWF)	977.61	182.43	1125.77	230.64	148.16	48.21
Kerosene expenditure/capita (RWF)	385.24	157.92	162.16	87.19	-223.08	-70.73
Charcoal expenditure/capita (RWF)	3723.42	186.20	4275.05	218.56	551.63	32.36
Electricity expenditure/capita (RWF)	1979.82	81.25	2203.08	123.98	223.26	42.73
Proportion of wood in energy expenses (%)	15.57	12.29	17.65	13.93	2.08	1.64
Proportion of kerosene in energy expenses (%)	18.16	18.57	5.22	6.54	-12.94	-12.03
Proportion of charcoal in energy expenses (%)	17.23	3.83	19.23	4.91	2.00	1.08
Proportion of electricity in energy expenses (%)	11.30	1.93	16.41	4.59	5.11	2.66
Energy expenditure per capita (RWF)	7406.43	696.65	8277.60	766.50	871.17	69.85
Total consumption per capita (RWF)	386335.80	100838.70	385839.00	100922.7	-496.80	84.00
Gender disparity (Male-headed vs female-headed)	**mhh**	**fhh**	**mhh**	**fhh**	**mhh**	**fhh**
Share of wood users (%)	27.36	19.62	26.61	19.66	-0.75	0.04
Share of kerosene users (%)	28.46	28.99	9.50	9.40	-18.96	-19.59
Share of charcoal users (%)	23.98	18.28	25.67	18.85	1.69	0.57
Share of electricity users (%)	17.50	12.68	25.47	16.35	7.97	3.67
Wood expenditure/capita (RWF)	719.37	646.23	860.82	735.48	141.45	89.25
Kerosene expenditure/capita (RWF)	280.09	380.72	123.50	177.49	-156.59	-203.23
Charcoal expenditure/capita (RWF)	2629.72	2090.91	3096.97	2440.45	467.25	349.54
Electricity expenditure/capita (RWF)	1415.66	1037.69	1617.66	1209.18	202.00	171.49

Proportion of wood in energy expenses (%)	15.63	10.96	17.23	14.05	1.60	3.09
Proportion of kerosene in energy expenses (%)	17.60	20.32	5.46	6.24	-12.14	-14.08
Proportion of charcoal in energy expenses (%)	13.32	10.39	15.40	11.80	2.08	1.41
Proportion of electricity in energy expenses (%)	8.66	6.24	13.76	8.78	5.10	2.54
Energy expenditure per capita (RWF)	5307.41	4379.87	6086.12	4910.12	778.71	530.25
Total consumption per capita (RWF)	297324.90	256689.80	297591.4	273023.70	266.50	16333.90

Appendix 2: Table 29. Disaggregated energy transitions by rurality, income poverty and gender in Malawi

	2016		**2020**		**Δ 2016–2020**	
Rural vs Urban	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
Share of wood users (%)	46.08	94.25	36.07	91.87	-10.01	-2.38
Share of kerosene users (%)	1.67	1.77	0.29	0.41	-1.38	-1.36
Share of charcoal users (%)	65.89	7.81	69.07	12.12	3.18	4.31
Share of electricity users (%)	41.81	3.21	42.22	4.24	0.41	1.03
Wood expenditure/capita (MK)	8182.37	21146.81	7942.28	25829.34	-240.09	4682.53
Kerosene expenditure/capita (MK)	61.45	84.21	25.60	11.59	-35.85	-72.62
Charcoal expenditure/capita (MK)	14788.80	1546.24	18420.85	2641.67	3632.05	1095.43
Electricity expenditure/capita (MK)	9290.59	481.17	9965.78	710.91	675.19	229.74
Proportion of wood in energy expenses (%)	28.33	90.31	20.39	84.48	-7.94	-5.83
Proportion of kerosene in energy expenses (%)	0 .34	0.39	0.08	0.06	-0.26	-0.33
Proportion of charcoal in energy expenses (%)	39.55	4.17	46.71	6.44	7.16	2.27

Proportion of electricity in energy expenses (%)	20.54	1.39	18.62	1.63	-1.92	0.24
Energy expenditure per capita (MK)	34670.39	23564.22	39133.90	30140.37	4463.51	6576.15
Total consumption per capita (MK)	447300.60	169866.70	517340.20	230077.10	70039.60	60,210.40
Monetary poverty	**nonpoor**	**poor**	**nonpoor**	**poor**	**nonpoor**	**poor**
Share of wood users (%)	77.60	95.17	75.40	91.35	-2.20	-3.82
Share of kerosene users (%)	1.99	1.46	0.40	0.36	-1.59	-1.1
Share of charcoal users (%)	29.89	4.22	32.22	7.50	2.33	3.28
Share of electricity users (%)	17.88	0.84	17.64	1.17	-0.24	0.33
Wood expenditure/capita (MK)	21319.86	15639.89	26850.12	15824.93	5530.26	185.04
Kerosene expenditure/capita (MK)	111.45	41.23	17.95	8.24	-93.50	-32.99
Charcoal expenditure/capita (MK)	6910.64	319.75	8620.78	723.57	1710.14	403.82
Electricity expenditure/capita (MK)	3742.57	45.10	3908.49	68.93	165.92	23.83
Proportion of wood in energy expenses (%)	67.71	92.96	64.40	85.71	-3.31	-7.25
Proportion of kerosene in energy expenses (%)	0.40	0.36	0.06	0.08	-0.34	-0.28
Proportion of charcoal in energy expenses (%)	17.45	2.19	19.90	4.36	2.45	2.17
Energy expenditure per capita (MK)	33208.5	16173.55	41039.61	17348.19	7831.11	1174.64
Total consumption per capita (MK)	322307.00	94644.52	391002.60	113835.4	68695.60	19190.88
Gender disparity (male-headed vs female-headed)	**mhh**	**fhh**	**mhh**	**fhh**	**mhh**	**fhh**
Share of wood users (%)	84.44	87.99	79.70	86.20	-4.74	-1.79
Share of kerosene users (%)	1.54	2.27	0.33	0.54	-1.21	-1.73
Share of charcoal users (%)	20.16	14.08	25.20	16.33	5.04	2.25
Share of electricity users (%)	11.27	7.75	12.58	7.97	1.31	0.22
Wood expenditure/capita (MK)	17852.31	21084.37	21021.86	26164.75	3169.55	5080.38

Kerosene expenditure/capita (MK)	67.25	111.85	13.81	14.99	-53.44	-96.86
Charcoal expenditure/capita (MK)	4139.57	3526.78	6014.39	4406.85	1874.82	880.07
Electricity expenditure/capita (MK)	2151.27	1935.47	2641.19	1859.95	489.92	-75.52
Proportion of wood in energy expenses (%)	77.62	82.43	70.25	78.59	-7.37	-3.84
Proportion of kerosene in energy expenses (%)	0.29	0.61	0.06	0.08	-0.23	-0.53
Proportion of charcoal in energy expenses (%)	11.74	7.88	15.77	9.23	4.03	1.35
Proportion of electricity in energy expenses (%)	5.38	3.66	5.25	3.55	-0.13	-0.11
Energy expenditure per capita (MK)	24886.92	27341.67	30981.89	33712.16	6094.97	6370.49
Total consumption per capita (MK)	230826.40	194897.40	292606.00	259535.30	61779.60	64637.90

Appendix 3: Table 30. Estimates from Multivariate probit model for Rwanda (Factors that drive fuel choice/ consumption expenditures)

Regressors	Dependent variables (Household spent on specific fuel in binary form, yes=1)			
	Firewood	Charcoal	Kerosene	Electricity
Family asset value (RWF) (ln logarithm)	0.0576** (0.0026)	0.1063 ** (0.0035)	0.0162** (0.0027)	0.2038**(0.0050)
Rural dummy (Yes=1)	-0.0305 (0.0270)	-1.2317** (0.0272)	-0.0267 (0.0304)	-1.0579** (0.0286)
Age of family head (years)	-0.0048** (0.0006)	-0.0129** (0.0008)	0.0024** (0.0007)	-0.0018* (0.0009)
Family size (number of persons)	0.00448 (0.0044)	-0.0411** (0.0057)	0.0007 (0.0048)	0.0183** (0.0059)
Family head only with primary school level	0.1073** (0.0212)	0.1842** (0.0281)	0.0763** (0.0225)	0.2756** (0.0319)
Family head with secondary school level	0.1064** (0.0371)	0.6654** (0.0421)	-0.1164** (0.0427)	0.6345** (0.0451)
Family head with tertiary school level	-0.1132* (0.0544)	0.6668** (0.0612)	-0.2899** (0.0657)	0.8859** (0.0655)
Proportion of the dependents in HH size (%)	0.0026** (0.0004)	0.0013** (0.0005)	0.0022** (0.0004)	0.0002 (0.0005)
Male-headed (1=yes)	0.0493* (0.0222)	-0.1838** (0.0277)	0.0047 0.0236)	-0.1270** (0.0304)
Off-farm work (1=yes)	0.0499** (0.0187)	0.1798** (0.0222)	-0.0070 (0.0208)	0.0911** (0.0242)

Kigali city	-0.8940** (0.0405)	0.8477** (0.0391)	-0.7269** (0.0419)	0.8599** (0.0402)
Southern	-0.1115** (0.0234)	-0.1541** (0.0298)	-0.3127** (0.0240)	-0.0992** (0.0322)
Northern	0.0877 **(0.0256)	-0.0059 (0.0321)	-0.7166** (0.0300)	0.0368 (0.0350)
Western	0.1527** (0.0235)	0.2812** (0.0286)	-0.4371** (0.0255)	0.2313** (0.0315)
The year 2016/ 2017 (1=yes)	0.0056 (0.0164)	0.0236 (0.0201)	-0.7593** (0.0186)	0.3842 **(0.0220)
Constant	-1.0257** (0.0538)	-0.1477* (0.0646)	-0.5351** (0.0576)	-2.2235** (0.0771)
Atrho (Firewood & charcoal)	0.2624 (0.0124)			
Atrho (Firewood & Kerosene)	0.0876 (0.0113)			
Atrho (Firewood & Electricity	0.1613 (0.0134)			
Atrho (Charcoal & Kerosene)	0.0724 (0.0128)			
Atrho (Charcoal & Electricity)	0.3642 (0.0147)			
Atrho (Kerosene & Electricity)	-0.2118 (0.0150)			
No. observations	28995			
Log pseudo-likelihood	-45404.97			
Wald Chi2 (84)	17152.00			
Prob > Chi2	0.00			

*Significant at the 5% level. **Significant at the 1% level. Source: Authors' computation using EICV4 & EICV5. Standard errors are in brackets.

Appendix 4: Table 31. Estimates from SUR model depicting household fuel consumption intensity in Rwanda

Regressors	Dependent variables (Proportion: Specific fuel costs/total fuel expenses)			
	Firewood	Charcoal	Kerosene	Electricity
Family asset value (RWF) (ln logarithm)	0.6548** (0.0579)	0.7979** (0.0412)	-0.0612 (0.0518)	1.4250** (0.0413)

Rural dummy (Yes=1)	5.4696** (0.6395)	-24.4893** (0.4546)	3.1533** (0.5719)	-11.3835** (0.4561)
Age of family head (years)	-0.0843** (0.0143)	-0.1564** (0.0102)	0.0734** (0.0128)	0.0303** (0.0102)
Family size (number of persons)	-0.2449* (0.1010)	-0.8505 ** (0.0718)	0.1744 (0.0904)	0.0919 (0.0721)
Family head only with primary school level	1.0429* (0.4793)	1.4534** (0.3407)	0.8691* (0.4287)	2.1527** (0.3419)
Family head with secondary school level	-0.6462 (0.8627)	9.8908** (0.6132)	-2.8872** (0.7715)	8.3910** (0.6153)
Family head with tertiary school level	-5.6630** (1.2135)	3.8861** (0.8627)	-3.9119** (1.0854)	17.6511** (0.8656)
Proportion of the dependent in HH size (%)	0.0417** (0.0084)	0.0194** (0.0059)	0.0256** (0.0075)	-0.0246** (0.0060)
Male-headed (1=yes)	2.2363** (0.4970)	-1.3193** (0.3533)	-0.1600 (0.4445)	-0.5405 (0.3545)
Off-farm work (1=yes)	0.1029 (0.4357)	2.2023** (0.3097)	-1.2298** (0.3897)	0.3098 (0.3108**)**
Kigali city	-12.2667** (0.8295)	24.4252** (0.5897)	-14.8031** (0.7419)	3.5147** (0.5916)
Southern	-1.7716** (0.5415)	-1.1919** (0.3849)	-7.5836** (0.4843)	-0.7987* (0.3862)
Northern	3.3945** (0.6081)	0.6199 (0.4323)	-16.1852** (0.5439)	0.7358 (0.4338)
Western	4.3467** (0.5601)	4.1895** (0.3982)	-13.8204** (0.5009)	1.1059 ** (0.3995)
The year 2017 (1=yes)	2.4565** (0.3779)	1.0331** (0.2687)	-12.3805** (0.3380)	4.1118** (0.2696)
Constant	6.6151** (1.2261)	33.4859** (0.8716)	20.5569** (1.0966)	5.2033 ** (0.8745)
No. observations	28,995	28,995	28,995	28,995
R squared,	0.0397	0.3727	0.0997	0.1850
F (15, 28995)				
Chi2	1199.28	17229.04	3210.88	6582.40
Prob > Chi2	0.0000	0.0000	0.0000	0.0000

*Significant at the 5% level. **Significant at the 1% level Source: Authors' computation using EICV4 & EICV5. Standard errors are in brackets.

Appendix 5: Table 32. Estimates from Multivariate probit model for Malawi (Factors that drive fuel choice/ consumption expenditures)

Regressors	Dependent variables (Household spent on specific fuel in binary form, yes=1)			
	Firewood	Charcoal	Kerosene	Electricity
Family asset value (MK) (logarithm)	-0.0000** (0.0000)	-0.0000* (0.0000)	-0.0006 (0.0007)	0.0001** (0.0000)
Rural dummy (Yes=1)	1.5741** (0.0255)	-1.6269** (0.0248)	-0.0782 (0.0712)	-1.4183** (0.0277)
Age of family head (years)	0.0031** (0.0008)	-0.0062** (0.0008)	0.0052** (0.0017)	0.0093** (0.0010))
Family size (number of persons)	0.0507** (0.0065)	0.0241** (0.0060)	0.0021 (0.0136)	0.0842** (0.0069)
Family head only with primary school level	0.0004* (0.0491)	0.1835* (0.0448)	0.1945 (0.1129)	0.1592** (0.0529)
Family head with secondary school level	-0.4415** (0.0379)	0.3700** (0.0370)	0.0166 (0.1073)	0.7342** (0.0387)
Family head with tertiary school level	-0.8023** (0.0682)	0.1519 (0.0632)	-0.6392 (0.3496)	1.1577** (0.0660)
Proportion of the dependents in HH size (%)	0.0046** (0.0005)	-0.0043** (0.0005)	-0.0005 (0.0011)	-0.0088** (0.0006)
Male-headed (1=yes)	-0.1139** (0.0276)	0.1583** (0.0259)	-0.0703 (0.0562)	0.1502** (0.0324)
Off-farm work (1=yes)	-0.0973** (0.0266)	0.3521** (0.0241)	-0.0080 (0.0650)	0.1980** (0.0296)
Southern	-0.0745 (0.0261)	0.1005* (0.0243)	0.7507** (0.0761)	0.3608** (0.0322)
Northern	0.1352** (0.0332)	-0.1125** (0.0309)	-0.1158 (0.1252)	0.3959 ** (0.0364)
The year 2020 (1=yes)	-0.2244** (0.0230)	0.1751** (0.0214)	-0.5922** (0.0611)	0.0846** (0.0263)
Constant	-0.3836** (0.0552)	0.3561** (0.0522)	-2.6941** (0.1388)	-1.3007** (0.0647)
Atrho (Firewood & charcoal)	-0.4361 (0.0151)			
Atrho (Firewood & Kerosene)	0.0003 (0.0353)			
Atrho (Firewood & Electricity	-0.4609 (0.0176)			

Atrho (Charcoal & Kerosene)	0.0619 (0.0358)			
Atrho (Charcoal & Electricity)	0.3573 (0.0169)			
Atrho (Kerosene & Electricity)	-0.4104 (0.0125)			
No. observations	23789			
Log pseudo-likelihood	-21788.11			
Wald Chi2 (84)	12113.41			
Prob > Chi2	0.0000			

*Significant at the 5% level. **Significant at the 1% level. Source: Authors' computation using IHS4 & IHS5. Standard errors are in brackets.

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