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Supervisor's Names: **Prof. Niyitanga Fidèle**

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DECLARATION

I, declare that this dissertation is the result of my own work, and has not been submitted for any other degree at the University of Rwanda or any other institution. It has been passed through the anti-plagiarism system and found to be compliant and this is the approved final version of the dissertation

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ABSTRACT

This thesis examines the welfare impact of energy access in Rwandan households with a focus on Electricity and biomass access. The welfare determinants used are the education expenses, health expenses, poverty and income. This study used simple OLS to determine the impacts of electricity and biomass access on household welfare. Findings have shown that electricity access has a positive and statistically significant impact on household welfare while biomass access was found to have a negative and statistically significant impact on household welfare. This study asserts that biomass energy consumption reduction in Rwanda is an efficient policy tool for environmentally sustainable country. While electricity access should be strengthened as it helps improve household welfare.

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LIST OF ABREVIATION

CFL: Compact Fluorescent Lights

CO2: Carbon Dioxide

DFID: Department for International Development

EA: Enumeration of Areas

EARP: Electricity Access Rollout Program

EICV: Enquete integrale sur les condition de vie

EU: European Union

GDP: Gross Domestic Product

HFO: Heavy Fuel Oils

HH: Household

HPS: High Pressure Sodium

IEA: International Energy Agency

LPG: Liquefied Petroleum Gas

MININFRA: Ministry of Infrastructure

MW: Mega Watt

NISR: National institute of statistics of Rwanda

OECD: Organization for Economic Co-operation and Development

REG: Rwanda Energy Group

RES: Rural Electrification Strategy

SDG: Sustainable Development Goals

USA: United State of America

USD: United State Dollar

VUP: Village Umurenge Program

WHO: World health organization

Chapter 1: INTRODUCTION

1.1. BACKGROUND

Access to energy affects all aspects of life from the global level to household level, energy is very essential for the human living. If a country is to develop, it has to increase its level of access to energy as one of the main factors for development. The world energy consumption in 2018 was more than 550 quadrillion Btu with more than 350 quadrillion Btu in Non-OECD countries and more than 200 quadrillion Btu in OECD countries and projected to reach 736 quadrillion Btu by 2040 [1]. However, irrespective of its importance in life, some 800 million people remain without electricity globally [2] while "*ensure access to affordable, reliable, sustainable and modern energy for all*" is the seventh SDG goal [3]. By 2019,the global access rate was 87% with 43% in sub Saharan Africa and 25% in rural Africa [4] with the 15 million new connections that provide electricity for the first time to 68 million homes and businesses that year [5].

Only 42.8 % of Africans were having access to electricity by 2016, much less than any other developing region [4]. More than 600 million people [6] in Sub- Saharan Africa live without electricity, including more than 80 % of those living in rural areas [6]. Only two African countries Mauritius and the Seychelles, are close to global electricity coverage. Home power supply is 75 percent or more in only six African nations (Cabo Verde, Gabon, Ghana, Mauritius, Seychelles and South Africa). About two thirds of the countries in the region have household access rates of less than 50 percent [4].

Energy consumption has shown a remarkable contribution in the development across the globe, rural electrification has affected lives of rural people [7]between financial development, economic growth, and the use of force in OECD countries. There is a positive long run relationship between economic growth and energy use [8]. The causal results revealed that there is a Granger trend between economic growth and energy use and for the global panel both in the short and long runs. There is a positive relationship between economic growth and energy use in the top ten energy-consuming countries (China, USA, Russia, India, Japan, Canada, Germany, Brazil, France and South Korea) [9]. Therefore, energy is an important input for economic development in these countries. In a study examining the non-linear relationship between financial development, economic growth, and energy consumption in

OECD countries, [9]found an inverted U-shaped relationship between Energy consumption and economic growth. This means that energy consumption leads to economic growth at certain level and if that level exceeds, its impact on economic development declines.

In Europe, energy consumption and development have shown a positive relationship in many studies [10] and [11] with a unidirectional relationship in the short run and bidirectional relationship in the long run [11]. Therefore, energy is an essential factor for economic development as other factors in European countries [12]. In the united states of America, energy has contributed much to the growth of the country. There is a positive relationship between economic growth and energy consumption though causality has different directions (unidirectional and bidirectional depending on the variables used) [13] [14] [15]and [16]found that infant mortality rates decreased between 1930 and 1940 due to access to electricity in the United states.

In China energy consumption has shown a valuable growth in recent years. While energy saving and technology change related to economic development have shown a significant role in reducing energy consumption in China, [17],Urbanization is one of the main causes of increased energy consumption in China [18], [17]. Among different researches, it is shown that energy consumption has been one of the leading drivers of growth in China, coal consumption increased by more 2.3 billion over the past 10 years and oil consumption grew by 4.3% at the end of 2016 [1]. With 51% of the total gross output of 2015 from manufacturing, coal and oil consumption are positive contributors to economic growth in China [19]. More oil is consumed, the more the economy grows, demonstrating thus the crucial role of oil for economic growth in china [19]. [20]also confirmed the presence of long-term positive impact of the consumption and production of coal, oil, and natural gas on GDP growth in China. In India, energy consumption has shown a great contribution to economic development as in other countries. Specifically, access to electricity has shown an impact on agriculture sector by increasing the value of land and agricultural innovation [21]. In Pakistan, energy consumption has also shown a great importance in the development of the country. The use of modern fuel has improved environmental sustainability by enhancing energy efficiency and reducing deforestation [22].

In Africa, energy has shown a vital role in human services that help to improve standards of living. These include access to education and knowledge, increase of income that is used to provide

households with shelter, adequate food and other necessities, enjoying good health, long and productive life. Improvement of modern energy also leads to job creation [23]. This is evidenced in South Africa where electrification increased hours of work for both men and women and enables micro enterprises creation [24].

Energy consumption has a great benefit of poverty alleviation [25]. It helps in increment of household income by creation of new employment though the supply (generating and delivering energy) for engineers, technicians in the energy sector. It also boosts startup businesses and increase productivity of already existing businesses [26]. Energy access eases housework for women and hence women end up taking paid employment [27] and [24]. Tanzania government in 2010 set a target of over one million jobs that could be created from the 500,000 household connections from gas, hydro-power and coal that were planned in the five years' time-frame [28].

Energy consumption improves standards of living through facilitating education in the family, improved technology use, affect thinking capacity, increased hours of productive work enhancing income [29]. Lack of access to energy hinder the achievement of many goals like provision of good health facilities [30], provision of information, adequate education to children, access to clean water, food, security, sanitation and income. Lack of access to energy can impact health in the way that there is no way to keep some drugs which need refrigeration, no power in the operation rooms and others. On the other hand, lack of modern and clean energy will lead to families turning to biofuels for cooking and lighting. These biofuels are very bad for human health. Biofuel is linked to tuberculosis, lung cancer, and respiratory infections. More people die from indoor air pollution than malaria, drugs, unsafe sex, alcohol, and tobacco [31].

Lack of electricity access heavily affect education [32]. Children won't be able to extend their evenings to do school work, and the schools won't be able to use technology in their service provision. Schools won't be able to use computers and hence lack of information to students. Energy consumption is linked to environmental and health problems. The characteristics of energy consumption associated with these facts may be captured in household level of electricity consumption. Based on these characteristics and their theoretical linkage to standards of living, household level consumption of energy is believed to convey important information regarding standards of living.

1.2. STATEMENT OF THE PROBLEM

According to MININFRA, Rwanda has a target of 100% electricity access by 2024. Current electricity access in Rwanda is 51% as of 2019, with (On-grid -38% & Off-grid –13%). 1,021,734 households connected to On-grid, and 350,216 households to Off-grid. Rwanda has an installed generation capacity of 221MW to serve a peak load of 140MW. However, there is still a need to increase efforts put in by the government and the many energy resources available as Rwanda still has energy crisis due to lack of enough capital to invest in the energy sector and hence a delay in development [33] . Land stress is also endangering energy due to high population growth in Rwanda [34].

Energy access has shown significant benefits in Rwanda; for example significant effects on lighting hours [35] as well as effects on income and children's home studying if regional differences are accounted for. There are business opportunities in the energy sector in Rwanda [36]. These include energy production and strengthening distribution lines and links in different energy sources like hydropower and solar energy. People in agriculture sector have an advantage of agriculture residues that are source of biomass which is the largest energy sources in Rwanda [37]. Biomass has an advantage of being renewed if you cut it and replant.

The Government's vision calls for 50% reduction in biomass consumption by 2020. Currently, there are a number of alternative fuels to biomass. The Biogas system is currently being used as a suitable cooking fuel and heat energy needed for farms and small institutions especially considering households in Rwanda that own cows and other livestock. Liquefied Petroleum Gas (LPG) and Kerosene are possible alternatives, as well as pellets and briquettes that can be used for cooking [38]. According to MININFRA quoted by [38], biogas systems installed in schools and prisons have reduced wood consumption by about 60% and 40% respectively, as well as improved hygienic conditions and cost savings. Currently, 11 out of 14 prisons use biogas for cooking. This has reduced the costs of cooking in prisons by 50% compared to using electricity.

In Rwanda, household have adopted the use of different electronic devices like telephones, radios and TV. Lighting hours have more than tripled, education has been improved as students spend studying at home during night hours due to increased hours of lighting, health sector has been improved. The

improvement in health sector is seen through the increase of the electronic appliance used in the health sector and reforms in the sector from 2009 to 2014. This led to a rise in per capita health expenses from 50 USD in 2005 to 144 USD in 2012 and household health has been improved by reducing smoke from kerosene [39]. There is also an evidence of increase in the income of household. Majority of communities didn't have business centers and had very little or no entrepreneurial activity and now they have developed small enterprises like bars, snacks shops, phone charging, hairdressers, and others [39].

Given the increase in the production of energy and access as well as consumption of energy, this study aimed at to assess the impact of energy access on households' welfare in Rwanda. In other words, is there a causality between households' welfare and energy access by households in Rwanda? What is the impact of energy access on households' welfare?

1.3. OBJECTIVES

This study aimed to examine the association between energy access and welfare in Rwandan households. Specifically, this study measured the effect of energy access by households on income, poverty reduction; and education and health improvements. It focused on the effect of electricity and biomass access on household welfare. Electricity and biomass are two types of energy are dominantly used by households in Rwanda.

1.4. HYPOTHESIS

It is clear that there is an increase in energy access amongst the households in Rwanda due to the increase in energy production and strengthening distribution lines and links in different energy sources like hydropower and solar energy. The increase in access to energy should result in the increase in welfare. Therefore, we assume that:

"*the increase in the access to energy by Rwandan households has positively impacted on Rwandan households' welfare".*

The following four specific hypothesizes have been measured for concluding on the impacts of energy access on households 'welfare:

- *The access to energy led to increase in income of Rwandan households*
- *The access to energy helped in poverty reduction in Rwandan households*
- *The access to energy resulted in quality education improvement through the increase in financing education services*
- *The access to energy helped in accessing the healthcare for Rwandan households' members through the increase in financing the health services*

1.5. ORGANIZATION OF THE STUDY OR THESIS

This thesis analyses the impact of energy access on household welfare. In addition to conclusion and recommendations; this thesis is divided into four chapters, Chapter 1 concentrates on the background of the study, objectives and the problem statement. Chapter 2 talks about the literature on welfare and energy access. It focuses on overview of energy sector in Rwanda (electricity and biomass status), productive users access, energy policy, energy types and sources in Rwanda, energy and environment, energy consumption in Rwanda, outcomes of electrification and empirical studies on energy access and welfare. Chapter 3 explains the methodology used. In this chapter, there is the source of data used, and the methodology used in the data analysis. Chapter 4 presents the results and discussion.

Chapter 2: THEORETICAL CONSIDERATION ON WELFARE AND ENERGY ACCESS.

2.1. Overview of energy sector in Rwanda

2.1.1. Electricity Subsector Status

Electricity is an important driver of modern technology, social and economic development. Electricity empowers small appliances, like lamps and mobile phones that improve the wellbeing of citizens and industrial processing activities, contributing to economic products that need value addition and job creation. Considering the importance of energy, the Government of Rwanda decided to raise its energy production capacity and the energy produced. According to [36] installed energy capacity is 218 MW in Rwanda, with 212.5 MW grid connections and 5.5 MW import option. The technology mix is also varied. Hydro accounts for 45% of installed energy capacity, Diesel & HFO make up 27%, methane gas 14%, peat 7% and 6% for solar.

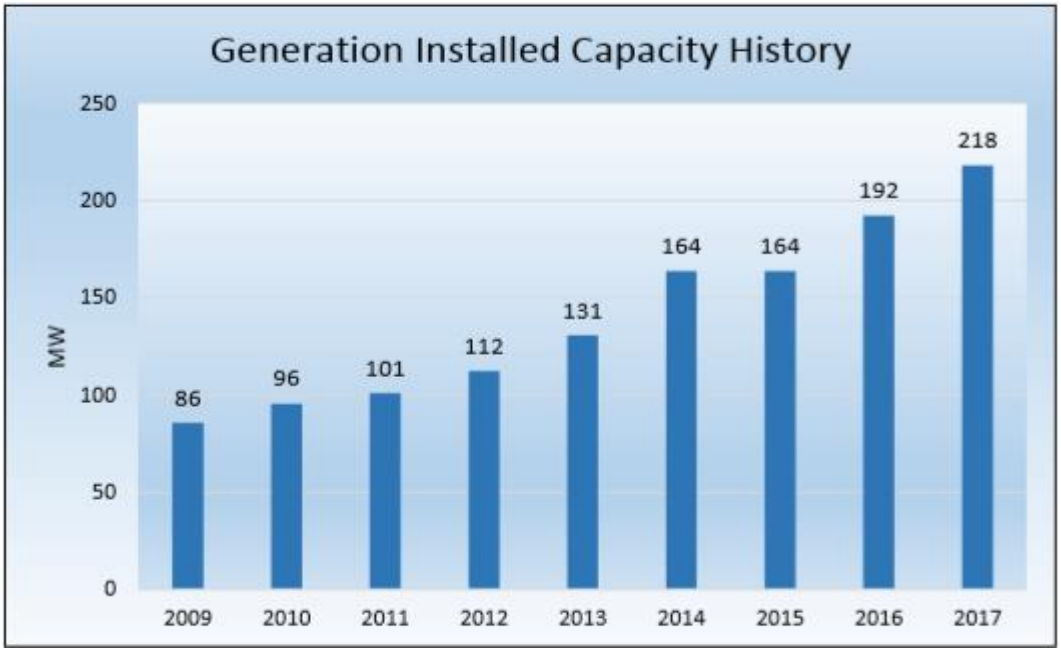

Figure 1: The evolution of installed electricity generation capacity of Rwanda

Source: [40]

Rwanda's energy is from many sources and those sources have different capacities. Some resources are not exploited enough compared to their potentials while others have not been measured yet. Here below are the detailed potentials of different energy sources in Rwanda

Table 1: Power supply sources and their potentials.

Energy resource	Installed capacity(MW 2017)	Total Resource potential
Hydro power	100.34	313
Methane	30.001	480
Solar	12.80	N/A
Thermal	57.80	N/A
Peat	15.00	300
Geothermal	N/A	520
Biomass	0.07	N/A

Source: [36]

According to [40], Rwanda's electricity access has been improving. Grid connection extended to 32.7% as a result of removing the around 50$ connection requirement. This has been done through the EARP program launched in 2009 by the Government of Rwanda and its development partners. The availability of off-grid in Rwanda has improved from nearly 0% to more than 10.7%, which is equal to 258,670 households in 2017 [40]. A big part of this has been achieved through Solar Home programs. A key factor in the growth has been the publication of the 2016 Rural Electrification Strategy (RES). The RES has also redesigned accessibility targets to focus on off-grid and established programs to give out these systems to low-income homes and support private sector development [40]. While there are many achievements with in the Rwandan electricity sector, there are also challenges in the sector. These include: balancing supply and demand sides of electricity, ensuring timely servicing and maintenance of the infrastructure, making sure transmission is aligned with new generation, difficulty in funding infrastructure investments, expanding access to remote areas, making sure that on- and off-grid access is aligned, poor maintenance off-grid solutions and lack of access to consumer finance.

2.1.2. Biomass achievements

Biomass Energy Strategy was published in 2017. There is a shortage of biomass (more wood is being used than planted), as well as concerns about the health and well-being of citizens, which highlight the need for change. Majority of Rwandans use wood resources as they are the most affordable energy source in the country. Wood is also mentioned among the rural development engines and an important source of income in Rwanda. Kigali consumes 20.7% of wood (either as wood or charcoal) of the national supply [33]. There are also methane gas,peat, biogas installations mainly in prisons and some schools as mentiones above.

Despite the achievements in the sector, the sector has faced some challenges. Sustaining wood supplies in the medium term is one of the biggest challenges in the sector. During the reduction of biomass consumption in the country, identifying and promoting alternatives that can be economically and culturally accepted has become a strong issue. There are also competing uses of biomass.

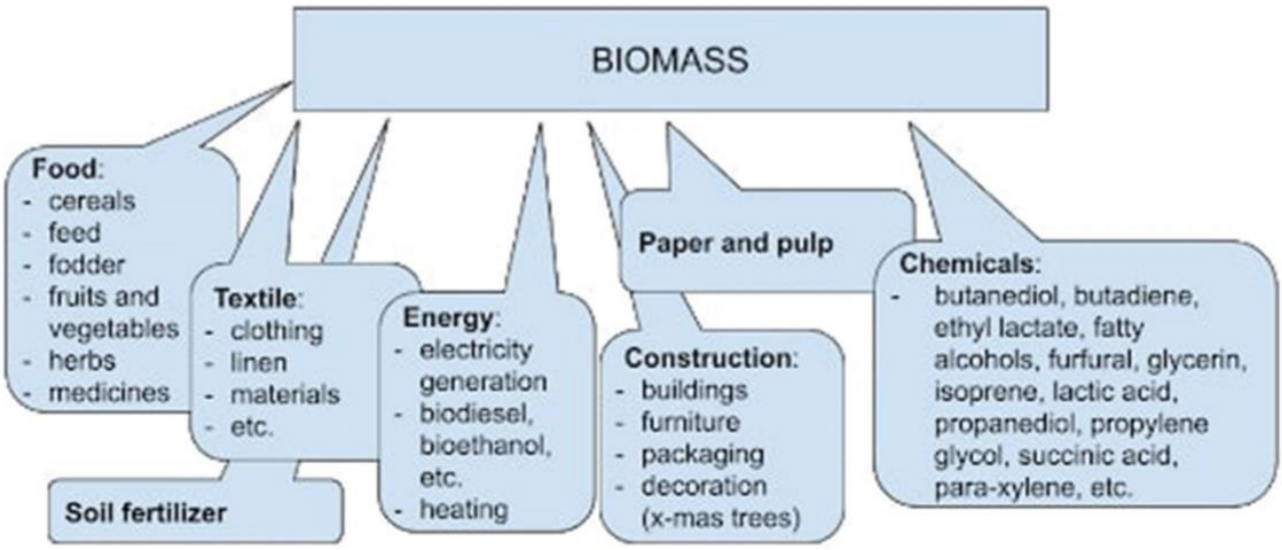

Figure 2: Competing uses of biomass

Source: [41]

2.2. Productive user access

The productive use of electricity involves the use of electricity as an input in activities that promote economic and social well-being. It's also an advantage to connect productive users because it helps to raise the financial stability of the sector since they operate in off peak hours which helps to cover more

than their connection cost. According to REG, among the 8,855 productive users that have been identified, 2,733 (31%) are not connected to electricity. Of the 69% who are connected, 6,100 have on-grid connections and only 22 have off-grid connections. These productive users are in different categories including schools, health facilities, markets, administrative offices like province, district cells and sectors, mining and quarry areas, big industries (beverages, cement, chemicals, furniture and printing, tea factories, textiles and industrial perks) and small industries (food processing, milk collection centers, coffee washing stations, integrated craft production and public infrastructure which include airport and aerodrome, water pumping station.

2.3. Energy policy

The overall goal of the Rwanda energy policy is to ensure that all residents and industries can access energy products and services that are sufficient, reliable, affordable, and sustainable. Rwanda energy policy has the following specific objectives:

1. "To make sure sufficient, reliable and affordable energy supplies are available to the whole population of Rwanda
2. set up and promote an enabling environment for increased private sector participation in energy supply and service provision
3. Encouraging and incentivizing more rational, efficient use of energy in public institutions, and amongst industrial and household end-users
4. Ensuring the sustainability of energy exploration, extraction, supply, and consumption so as to prevent damage to the environment and habitats.
5. Promoting safe, efficient, and competitive production, procurement, transportation, and distribution of energy.
6. Developing the requisite institutional, organizational, and human capacity to increase accountability, transparency, national ownership and decentralized implementation capacity for sustainable energy service delivery."

2.4. The energy types and sources in Rwanda

Rwanda's energy resources include biomass and fossil fuels. Rwanda's energy system is made up of a large proportion of 47% and 27% diesel power and 27% respectively of all energy systems [42]. Biomass resources in Rwanda are biogas, peat, wood, methane gas, and other organic waste. They

account for nearly 85% of energy consumed by the whole nation and contribute 5 percent to GDP [33].Wood is still the mainly used and most inexpensive energy source for domestic activities for example cooking and heating in Rwanda. Kigali has a population of about 8% of the country's population and accounts for more than 20% of the fuel wood used in the year [33].

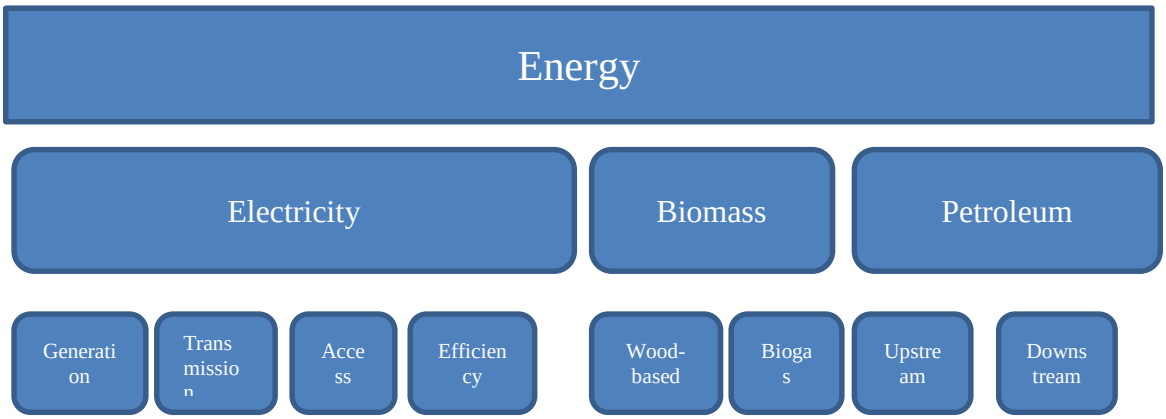

Figure 3:The energy sector is made up of three subsectors: electricity, biomass and petroleum

Source: [40]

Rwanda's peat to power sector is a matter of urgency to achieve the development goal and to make sure that all people will be connected to electricity by 2025. Many peat deposits in Rwanda can be used to generate energy based on the calorific values of the samples. Akanyaru, Mukindo, Gishoma, Mashya, Kaguhu, Mukindo and Nyirabirande are the most promising sites for peat mining to generate energy. Nationwide, quantitative deposits assessment in Rwanda is approximately 155 million tons of peat on a dry basis [43].

In the rural areas, wood is the widely used sources of energy and this has forced the Rwandan Government and its partners to start building peat to power plants. These peats to power plants are expected to generate 20.6% of all Rwandan energy resources. The efforts to use peat as a source of energy and other activity, will boost the country's growth. Using peat as a source of energy, would be good for the country to build an effective pollution control system because burning coal contributes to environmental pollutants and hence climate change. The Rwandan government is taking actions to promote energy production from peat taking into account the impact it has on the environment [43].

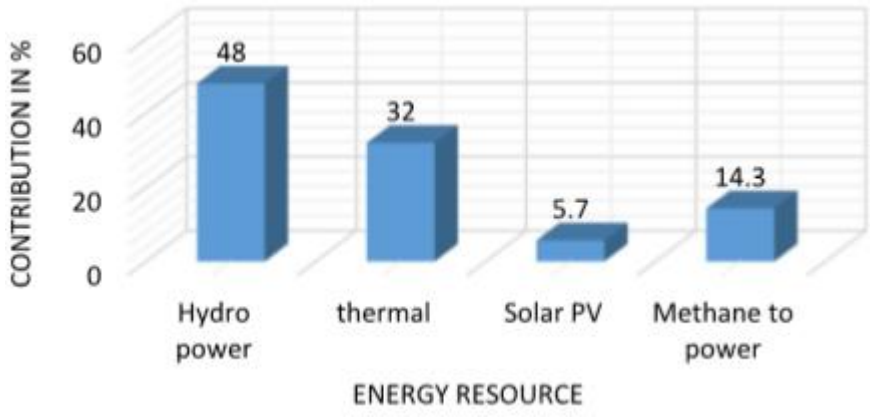

Figure 4: Energy sources in Rwanda

Source: [44]

Renewable energy sources such as solar, wind, hydroelectric energy and geothermal power are available in Rwanda. When fully exploited, these sources of energy can contribute to economic development. Lack of awareness on energy sources potentials in the region makes them under used. [45]. According to [36], solar and hydropower are the leading renewable energy resources in the country. The largest power percentage originates from hydropower plant across many waterfalls and rivers in Rwanda.

Biogas has been revealed as an encouraging renewable technology which can provide inexpensive, clean and safe energy to rural people. In Rwanda, domestic biogas was launched as a partial solution to energy security issues in rural areas. It was targeting 15,000 installed biogas plants by 2012 [46]. Biogas and solar energy resources have the potential of creating jobs and providing a way of fighting deforestation, droughts, harsh health issues and soil erosion. As Rwanda strives to be one of the most clean places in the worldwide, an investment in solar and biogas is very important [47].

There is a great interest in controlling and making use of wind as a new source of power in Rwanda [48]. Development of wind power needs detailed and dependable information on wind regimes and potential installation sites that have not been mapped out in Rwanda so far. However, in Rwanda, energy consumption has shown a steady increase in growth. The energy sector should explore new energy resources including the wind power as much as possible. Previous research indicates that wind turbines in Rwanda require policy makers and in-depth research based on a detailed and systematic

analysis of wind speed patterns. In addition, the average annual wind speed in some parts of the country including Kigali City can be used to generate electricity during windy seasons [49].

2.5. Energy and environment

Rwanda has many energy resources and has developed clean energy generation projects with the intention of boosting energy supply while alleviating socio-environmental impacts related to energy production [33] deforestation leads to ecological imbalance and hence environmental degredation [50]. In Rwanda, some diesel-powered generators are connected to slow-moving buses and vary their corresponding generation capacities following variations in power demand aimed at keeping the frequency at an acceptable level; as a result, they do not always work close to their self-reported energy levels. This increases fuel consumption and emissions of CO2 into the atmosphere [51]. To improve environmental quality, governments must continue to improve their monetary resources and reduce urban growth through new local urban development strategies and hence reducing greenhouse gas emissions (CO_2, NO_x and others). Given the positive role played by trade openness and institutional quality over the global economy, these factors can support the adoption of clean technology, and governments should increase community efforts in environmental protection [52].

2.6. Energy consumption in Rwanda.

Energy is consumed in different types and by different users in Rwanda like other developing countries. Of the total energy consumption in Rwanda, biomass accounts for 85.0%, petroleum 13.0% , and electricity accounts for 2.0%. While energy consumption looking at user categories is led by households which accounts for 82.0%, 8.0%, for transport, 6.0% for industries and others at and others take the remaining 4.0%.

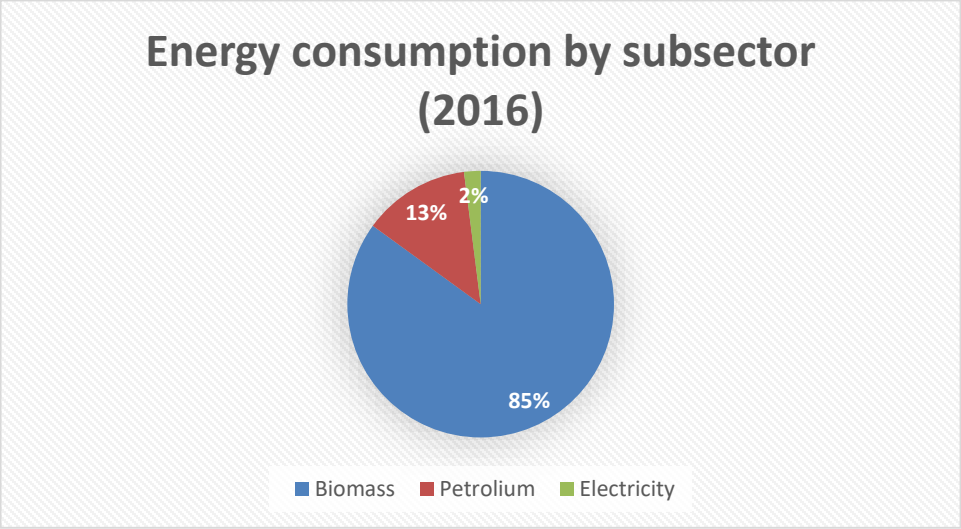

Figure 5: Energy consumption in Rwanda by subsector

Source: [40]

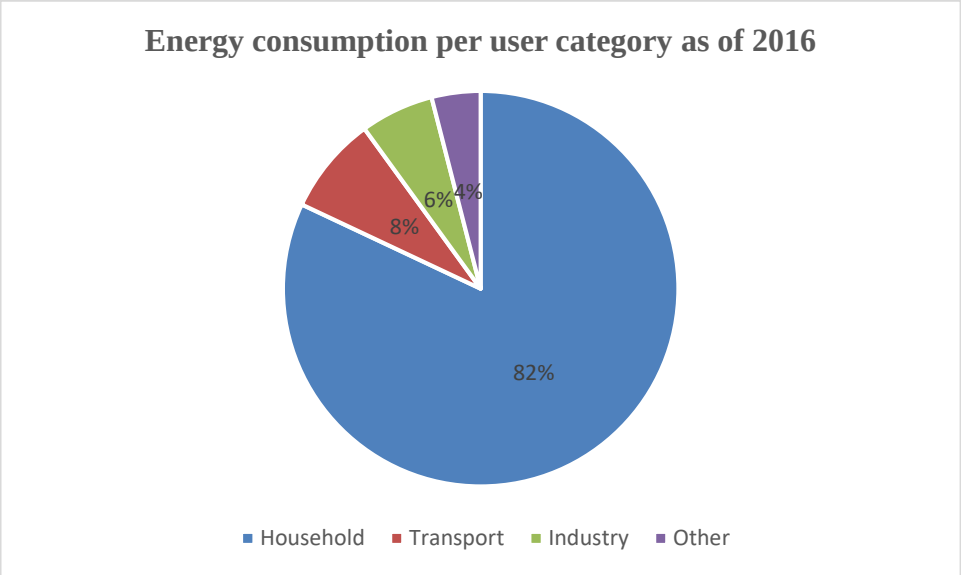

Figure 6: Energy consumption in Rwanda per user category (%)

Source: [40]

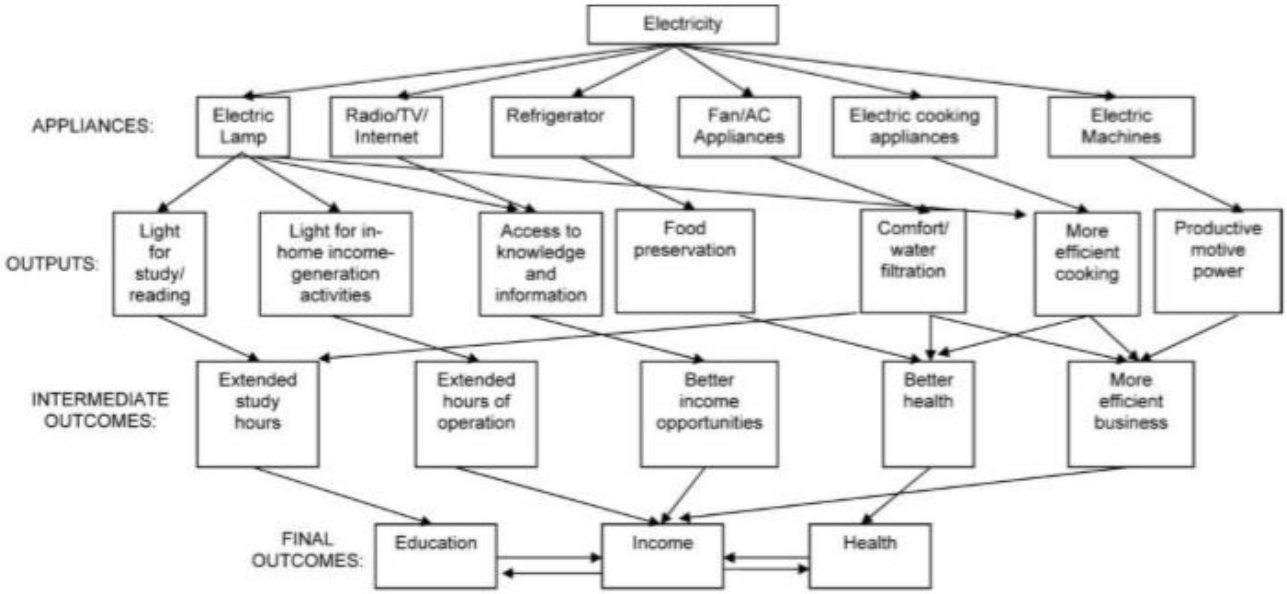

Figure 7:Possible inter related outcomes of household electrification (health, income, education) **source** [53]

2.7. Empirical studies on energy access and welfare

Many studies have been made at the macro level to see the relationship between energy access and income, and many have been particularly looking at electricity as a source of energy. Here are some examples of the research done so far: Energy poverty and its implications on the standards of living in kirinyaga Kenya [54]. The findings of this study show that energy poverty in that region has a negative effect on the standards of living indicators studied, calorific intake, life expectancy and literacy levels. [55] studied the causality relationship between energy consumption and the GDP in 18 developing countries. He found that in both long and short run periods, causality was unidirectional (from energy consumption to GDP), [56] in their study of the association between income level and electrification rates in a global analysis of progress in household electrification. They found a rapid progress in Household electrification and a strong association between per capita income and electrification.

However, little has been done on the microeconomic level of energy consumption, and the most studies done look much on the electricity access not energy in general. [57] analyzed the effect of electricity on income in Nepal. They used the two stage probit least squares model with Nepal living standards survey data for 2010-2011. They found the causality running both ways. [58] used the panel data for

Vietnam to estimate the impact of rural electrification on the welfare. They found that electrification increases income by 28% and expenditure by 23% and school attendance by 9 % points for girls6.3 % points for boys and [59] also estimated the effect of electricity on the welfare in Bangladesh using cross sectional data with the instrumental variable approach. They realized that grid connection has a positive and statistically significant estimates of 21% rise in income,1.5% point reduction in poverty every year and expenditure rises by 11% [60] used Engel curves to understand how the pattern of energy use changes with income in Bangladesh at the household level and found a U-shaped relationship between energy use and household expenditure.

In particular for Rwanda, [61] investigated the impact of electricity on different indicators and estimated the probability to be connected for household in all villages (electrified and non-electrified villages). They found effects on income and children's home studying insignificant if regional differences are taken into consideration while other factors showed a positive impact.

[33]wrote about the available energy potentials, production opportunities, demand picture, as well as the country's ambitions to produce pollution-free energy to all inhabitants by 2020 They found that Rwanda has several energy resources which include biodegradable wastes had a potential of 1MW, Solar energy (4.3-5.2)×10-3MW/m2 ×day, peat 700 MW, geothermal 170-320 MW, methane gas 750 MW hydropower 313-400 MW, while biodiesel, wind and wood sources did not have estimated potentials. They also found that the energy supply policy is constrained by three challenges which include not enough energy sources and production, consumption while keeping the environment clean, lack of potential to provide clean energy to all residents.

[62] analyzed the drivers and associations of early adoption of a household energy intervention marketed by a private sector firm. Their findings showed that households with married household heads and female cooks were significantly more likely to adopt. [63]studied about energy poverty in an off grid village and constructed an asset- and income-based index to disaggregate their results by socio-economic status. Their findings suggest that efforts aimed at eradicating energy poverty and helping to improve rural development should recognize potential policy implications for diverse socio-economic families, address energy stacking behavior, focus entirely on rural development, and ensure that households have access to modern energy through flexible payment schemes and practices.

Chapter 3: METHODOLOGY

3.1. Data types and source

This study used the EICV5 survey data (integrated household living conditions survey-5) that was done over a 12-month cycle from October 2016 to October 2017. The collection of data was divided into 10 cycles in order to represent recurring periodic change in the income and consumption data. These data are divided into cross-sectional data, panel data and a VUP sample survey data. Consequently, this research used the cross sectional data.

The mode of data collection was questionnaire administering and the main data collection began in October 2016 and finished in October 2017. In 27 mainly rural districts, the 12-month study calendar was divided into 10 cycles, with each cycle divided into 2 sub-cycles, for 20 periods of enumeration of 16 days each. Each data collector visited a group of three sampled homes daily. A team of data collectors covered two sample enumeration areas in each sub-cycle, or 4 enumeration areas during a full cycle. That is to say that each sample household living in a rural district was visited 8 times throughout a 16- days period.

In 3 mainly urban districts of Kigali, data collection for each EA sample was performed over a period of 33 days (one cycle). The 9 homes in each EA sampled were divided into 3 groups of 3 households each. Each enumerator visited one group of 3 sample homes daily, so each sample household was visited every three days. Five EAs are combined in each cycle. This means that each sample household in Kigali was visited 11 times in a 33-days period.

3.2. Sampling

The survey covered a wide geographical area of the country. At the national level, there were 1,260 sample villages and 14,580 sample households. In the urban strata there are 245 sample villages and 2,526 sample households and in the rural strata there are 1,015 sample villages and 12,054 sample households. This sampling frame of cross-sectional survey was based on the NISR master sample data which was got from the 2012 national census. This master sample was selected to be used for the different national household surveys in Rwanda.

3.3. Data analysis

Simple OLS model was used for estimating the effect of energy on household welfare.

The Welfare equation is specified as follows:

$Y = \alpha_0 + \alpha_1 E + \alpha_2 X + \varepsilon$

Where

Y is the household welfare

E is energy access

X is other controls

ε is the error term

α are the parameters to estimate

In order to measure the change in household welfare due to electricity and biomass access by household, we focused on four dependent variables (income, poverty, education and health) and estimated the following four specified equations:

$Y_1 = \alpha_0 + \alpha_1 E + \alpha_2 X + \varepsilon$ (1)

$Y_2 = \alpha_0 + \alpha_1 E + \alpha_2 X + \varepsilon$ (2)

$Y_3 = \alpha_0 + \alpha_1 E + \alpha_2 X + \varepsilon$ (3)

$Y_4 = \alpha_0 + \alpha_1 E + \alpha_2 X + \varepsilon$ (4)

Where

$Y_1 - ln\ income$

$Y_2 - poverty$

$Y_3 - \ln education\ expenses$

$Y_4 - \ln health\ expenses$

$E - represents\ energy\ acess\ either\ electricity\ or\ biomass$

Chapter 4: ANALYSIS OF THE IMPACT OF ELECTRICITY AND BIOMASS ACCESS BY HOUSEHOLD ON HOUSEHOLD WELFARE

4.1. Demographic and socio-economic characteristics of households

The following Table 2 shows the demographic and social-economic characteristics of households used in data analysis. Among the 14580 households used, 12,049 (82.64%) had access on biomass and only 3,581 (24.56%) had access to electricity.74.46% were male headed households and the remaining 25.54% were households headed by females. The highest percentage of the sample lived in Rural areas (80.08%), household heads with no education level were 64.61%, household heads with primary education were 22.73%, household heads secondary education were 9.79% and only 2.87% had studied university. Household spouses with no education added up to 42.59%, household spouses with primary education were 15.86%, household spouses with secondary was 6.02%, and those with university level were 1.62%. Among the household heads, only 18.92% were between 14 &30 years,55.44% were between 31 & 55 years of age and 25.64% were above 56 years.

Table 2:Socio-economic characteristic of households

Variable	Category	Frequency	Percentage
Gender	Male	10,856	74.46
	Female	3,724	25.54
HH lives in urban area	Urban	2,904	19.92
	Rural	11,676	80.08
Education	Household head with no education	9,420	64.61
	spouse with no education	6,210	42.59
	Household head with Primary	3,314	22.73
	spouse with primary	2,312	15.86
	Household head with Secondary	1,427	9.79
	spouse with Secondary	878	6.02
	Household head with university	419	2.87
	spouse with University	236	1.62
Age	14-30	2759	18.92
	31-55	8082	55.44
	56>	3739	25.64
Energy access	Households with access to Biomass	12,049	82.64
	Households with access to Electricity	3,581	24.56

Source: Results computed by author based on EICV5 dataset from NISR

Table 3 presents the variables used, their description and their corresponding descriptive statistics. To measure welfare, this study has considered four different dependent variables i.e. income, education expenses, healthy expenses and poverty. All variables are continuous variables while poor is a dummy variable. It is represented by 1 if a household is poor and 0 other wise.

Table 3:**Descriptive Statistics**

Variable	Obs	Mean	Std. Dev.	Min	Max
ln hh income	14580	13.08	1.155	7.313	19.752
Poor	14580	.332	.471	0	1
ln education expenses	14580	6.311	4.78	0	16.275
ln healthy expenses	14580	7.047	3.817	0	13.852
electricity access	14580	.246	.43	0	1
HH head age	14580	45.157	15.641	14	109
Household size	14580	4.411	2.118	1	22
HH head is a female	14580	.255	.436	0	1
Household lives in urban area	14580	.199	.399	0	1
Household has a wage salary	14580	.522	.5	0	1
Non-farm	14580	.519	.5	0	1
Dependence in HH	14580	2.072	1.506	0	9
HH head with primary	14580	.227	.419	0	1
Spouse with primary	14580	.159	.365	0	1
HH head with secondary	14580	.098	.297	0	1
Spouse with secondary	14580	.06	.238	0	1
HH head with university	14580	.029	.167	0	1
spouse with university	14580	.016	.126	0	1

Source: Results computed by author based on EICV5 dataset from NISR

This study defines a household as having access to electricity if the source of light or cooking energy for that household is electricity. It is defined as 1 for a household with access to electricity and 0 for the household without access to electricity. As well as biomass access, we considered access to fire wood and charcoal as they are the main sources of biomass in Rwanda [40]. So it is named 1 for households with access to any of these and 0 for households without access to any of these two biomass types. Household characteristics are determinants of household welfare [64] and [65].

This research therefore has considered household characteristics as control variables; household size representing the number of people living in the household, HH head age, whether the HH head is a female (a dichotomous variable that takes the value 1 if a household is headed by a female and 0

otherwise), if the household lives in urban area (a dichotomous variable that takes the value 1 if a household lives in the urban area and 0 otherwise), Household has a wage salary (a continuous variable), if a household owns a non-farm business (dichotomous variable that takes the value 1 if a household owns a non-farm business and 0 otherwise), number of dependents in HH (a continuous variable), education level of the household head and the spouse defined as: HH head with primary, Spouse with primary, HH head with secondary, Spouse with secondary, HH head with university and spouse with university(a dichotomous variable represented by 1 if yes for both household head and spouse and 0 otherwise).This has been applied to all levels of education.

4.2. Impact of electricity access on household welfare

The following table points out the estimation results on the association between electricity access and income, poverty, education and health in Rwanda.

Table 4: Association between electricity access & welfare changes in Rwanda

Variables	(1)	(2)	(3)	(4)
Electricity access	0.351***	-0.145***	0.659***	0.800***
	(0.029)	(0.010)	(0.095)	(0.087)
Age of household head	0.007***	-0.002***	0.022***	-0.017***
	(0.001)	(0.000)	(0.002)	(0.002)
Household size	0.195***	0.024***	1.374***	0.538***
	(0.007)	(0.003)	(0.028)	(0.026)
Household head is female	-0.085***	0.037***	1.474***	-0.563***
	(0.019)	(0.009)	(0.082)	(0.084)
Household located in urban area	0.039	0.002	0.039	-0.474***
	(0.036)	(0.011)	(0.105)	(0.102)
Household has a wage salary	-0.234***	0.253***	-0.642***	-1.054***
	(0.018)	(0.009)	(0.069)	(0.067)
Non-farm business	0.439***	-0.001	-0.401***	-0.198***
	(0.018)	(0.008)	(0.064)	(0.066)
Dependence in HH	-0.159***	0.061***	0.161***	-0.260***
	(0.008)	(0.004)	(0.036)	(0.034)
HH head with primary	0.203***	-0.067***	0.585***	0.230***
	(0.018)	(0.009)	(0.071)	(0.077)
Spouse with primary	0.090***	-0.072***	0.128	0.409***
	(0.021)	(0.010)	(0.081)	(0.080)
HH head with secondary	0.712***	-0.085***	1.308***	-0.171
	(0.036)	(0.011)	(0.137)	(0.117)
Spouse with secondary	0.410***	-0.096***	0.374**	0.250**
	(0.043)	(0.012)	(0.158)	(0.126)
HH head with university	1.758***	-0.068***	1.793***	-0.435*
	(0.070)	(0.014)	(0.292)	(0.233)
Spouse with university	0.967***	-0.085***	0.606*	-0.046
	(0.087)	(0.018)	(0.313)	(0.277)
Constant	11.819***	0.131***	-1.434***	6.584***
	(0.038)	(0.016)	(0.140)	(0.137)
Observations	14,580	14,580	14,580	14,580
R-squared	0.451	0.259	0.434	0.107

Source: Results computed by author based on EICV5 dataset from NISR.
Note: We used robust standard errors that are reported in parentheses. The coefficients valued are statistically significant at *** p<0.01, ** p<0.05, * p<0.1 respectively.

The variable of interest in this table is Electricity access regressed on different welfare determinants. ln income, poverty, education expenses and health expenses. A1 unit change in the electricity access is associated with 35% increase in HH income, 14.5% decrease in poverty, 65.9% increase in education expenditure and 80% increase in health expenditure. All the estimates are statistically significant at both 1%, 5 % and 10% levels of significance. Nearly all the variables are statistically

significant.

Looking at the income equation, electricity access has shown a positive and statistically significant estimate. A 1-unit increase in electricity access shows a 35% increase in the income earned by the household. This is in line with 21% effect of rural electrification in Bangladesh by [59]. [57] also found a very large effect of electricity on income in their study of Household-level effects of electricity on income in Nepal. They used a Two Stage Probit Least Squares method in their research and found that an increase in per capita household consumption by 1% increased the probability of having electricity by 0.7%. while if a household without electricity got connected, then consumption for that household was expected to increase by 15.7%. An increase of the age of the household head by 1increases income by only 0.7%, the household size increases income by 19.5% and households located in urban areas have a 3.9% more income than a household located in rural area.

Households with a non-farm business have a 43.9% income more than those that don't have a non-farm business. Education levels of both the household head and the spouse have a statistically significant effect on income. Households which have a head with primary, secondary, university education earns 20% ,71.2%,175% respectively more income than the households which have head with no education. While households with spouse who have primary, secondary, university education earns 9%,41%,96.7% respectively more income than the household with spouses who don't have any level of education. These estimates have a positive impact on income.

Dependence in the household has shown a negative impact of 15.9% as expected because dependents don't work and therefore contribute nothing to the household income. And sometimes in most cases they need attendance and hence reducing hours of work for the elders in the household which automatically affects the household income negatively. Female headed households also have 8.5% less income compared to male headed households and households with a wage salary have a 23.4% income lower than the households with no wage salary.

Looking at equation 2, 1 additional unit of household access to electricity reduces poverty by 14.5% point. [66] found the same results in their study to see if households that are energy poor are also income poor in India. According to them, most of the urban households that are energy poor are also

income poor. They also found that electricity access reduces poverty in different ways as new business may be set, increased hours of work and others as discussed above.

Education levels of household head and spouse have also shown a significant effect on reducing poverty in Rwandan households. Household head primary, secondary, and university education levels probably reduce poverty by 6.7%,8.5%,6.8% point respectively while spouse primary, secondary, and university education levels reduce poverty by 7.2%,9.6%,8.5% point respectively compared to households with non-educated head and spouse.

Having a 1 more dependent in a household increases the probability of being poor by 6.7 percentage point. Increase of the household size by 1 also increases the probability of being by 2.4% point. These results confirm the government's strategy of family planning to reduce the number of children per family and hence reduce poverty. Female headed household have a 3.7 percentage point probability of being poor compared to male headed household and households located in urban areas have a probability of 0.2% point of being poor compared to those located in rural areas. It is surprising that households with a wage salary have a 25.3% point probability of being poor and this estimate is statistically significant. One additional year of age reduces poverty by 0.2% point while owning a non-farm business gives a 0.1 percentage point probability of not becoming poor. Only the coefficient on urban location of the household is not statistically significant, all other estimates are statistically significant ant both 1 and 5 percentage levels of significance.

Education expenses increase by 65.9% due to electricity access. This value is statistically significant and positive; probably this is because children that are able to increase their reading time have high chances of joining higher learning institutions which are expensive. [67] also found that electricity causes education expenditure in some of the eastern Chinese cities. According to them, for cities in Middle China a reverse relationship was observed, while for western cities a bi-directional causal relationship was found.

Female headed households spent more than 100% on education than men headed households while households with wage salary spent 64.5% less than households with no wage salary.1-unit increase in the household size leads to an increases of more than 100% education expenses while age of the

household head has an effect of 2.25%. Owning a non-farm business has a negative and statistically significant effect on education expenses in Rwanda equal to 40%.

Education of the household head and spouse also have a significant positive effect on education expenses of the household. For household with a head that has studied primary, secondary and university spend 58.5%,130%,179.3% more than those with heads who have not studied at all. unit increase in Dependence also increases household education expenses by 16.1%

Looking at the health expenses equation, electricity access has shown a positive and statistically significant estimate. A 1unit increase in electricity access shows a 80%increase in the health expenses. [68] found the same result in their study on Conceptualising the effect of access to electricity on health in low- and middle-income countries. They showed that electrification is associated with positive health outcomes. They included lower rates of disease, reduced mortality rate, and improved quality and access to care, one year plus of the age of the household head by decreases health expenses by 1.7%, the household size by 1 household member increases health expenses by 53.8% and households located in urban areas have a 47.4% less health expenses than a household located in rural area.

Dependence in the household has shown a negative and statistically significant impact of 26% on HH health expenses. Female headed households also have 56.3% less health expenditures compared to male headed households. Females tend to take care of all possible cases that might cause sickness at home like hygiene, possible sources of accidents at home and others and hence reducing the risks of people getting sick in female headed households. Households with a wage salary have a 105% health expenditure lower than the households with no wage salary. This might be because people with a wage salary in most cases also have health insurances while those without wage salaries do not. Households with a non-farm business have a 19.8% health expense less than those that don’t have a non-farm business.

Education levels of both the household head and the spouse have different impacts on health expenses. HH head with primary education spends 23%more than the households with a head who does not have primary education. A household with a spouse who has a primary education level also spends 40.9% more than the household with a spouse who did not go to school, The HH with a spouse who has

secondary education spends 25% more health expenses than a household that has a spouse who did not go to school while for the household with head and spouse who have university level of education spend 43.5% and 4.6% less than those with 0 level of education respectively. All estimates are statistically significant at 1% and 10% levels of significance except the effect on HH head with secondary which has a negative sign and it is statistically insignificant.

4.3. Impact of biomass access on household welfare

The following table points out the estimation results on the association between biomass access and income, poverty, education and health services in Rwanda.

Table 5: Association between biomass access & welfare changes in Rwanda

VARIABLES	(1)	(2)	(3)	(4)
Biomass access	-0.381***	0.095***	-0.139	0.028
	(0.039)	(0.011)	(0.119)	(0.115)
Age of household head	0.008***	-0.002***	0.021***	-0.019***
	(0.001)	(0.000)	(0.002)	(0.002)
Household size	0.205***	0.021***	1.388***	0.553***
	(0.007)	(0.003)	(0.028)	(0.026)
Household head is female	-0.080***	0.035***	1.482***	-0.553***
	(0.019)	(0.009)	(0.082)	(0.085)
Household located in urban area	0.007	-0.013	0.242**	-0.138
	(0.036)	(0.012)	(0.112)	(0.111)
Household has a wage salary	-0.258***	0.270***	-0.756***	-1.214***
	(0.018)	(0.009)	(0.068)	(0.065)
Non-farm business	0.432***	-0.000	-0.397***	-0.186***
	(0.018)	(0.008)	(0.064)	(0.066)
Dependence in HH	-0.158***	0.061***	0.154***	-0.271***
	(0.008)	(0.004)	(0.036)	(0.034)
HH head with primary	0.216***	-0.075***	0.631***	0.293***
	(0.018)	(0.009)	(0.071)	(0.077)
Spouse with primary	0.108***	-0.078***	0.141*	0.416***
	(0.021)	(0.010)	(0.082)	(0.081)
HH head with secondary	0.716***	-0.098***	1.424***	0.006
	(0.036)	(0.011)	(0.137)	(0.118)
Spouse with secondary	0.427***	-0.105***	0.424***	0.317**
	(0.043)	(0.012)	(0.158)	(0.125)
HH head with university	1.756***	-0.087***	1.971***	-0.158
	(0.070)	(0.014)	(0.292)	(0.232)
Spouse with university	0.961***	-0.088***	0.648**	0.024
	(0.085)	(0.018)	(0.314)	(0.277)
Constant	12.171***	0.030*	-1.183***	6.748***
	(0.050)	(0.017)	(0.167)	(0.164)
Observations	14,580	14,580	14,580	14,580
R-squared	0.448	0.251	0.432	0.102

Source: Results computed by author based on EICV5 dataset from NISR.

Note: We used robust standard errors that are reported in parentheses. The coefficients valued are statistically significant at *** p<0.01, ** p<0.05, * p<0.1 respectively.

In this section, the variable of interest is biomass access. According to the results in the table above, biomass access has a negative and statistically significant effect on household income. A unit increase in biomass access leads to a reduction of income by 38.1%. The Government of Rwanda aimed at reducing the biomass consumption by 50% by 2020.This shows that the Government's policy is really good as confirmed by the regression results. Carbon leakage from biomass production have a negative impact on human life [69].

Biomass energy consumption increases CO2 emissions. [52] However, this is different from the results of [70]. They studied biomass energy consumption, economic growth and carbon emissions using a simultaneous equation model in West Africa (Burkina-Faso, Gambia, Ghana, Senegal, Benin, Mali and Togo) and found that 90 % of the population were relying on traditional use of biomass. They also found that biomass consumption is associated with economic growth but also leads to very high increase in carbon dioxide emissions. It is only in Nigeria that they found a negative impact of biomass on GDP. A1 additional year of age of a household head leads to a 0.8% increase of income, a 1 additional number of household member increases income by 20.5%, female headed households have 8% less income than male headed household, household with a salary have less 25.8% (nearly the same as it was with electricity access) income, having a non-farm business increases income by 43.2% and dependence in the households has shown a reduction of income by 15.8%.

Level of education has also shown positive signs and statistically significant results as follows; households head with primary, secondary and university have an impact on income of 21.6%,71.6% and more than 100% respectively. While spouse education has shown 10.8%,42.7%,96.1% effects for those with primary, secondary, and university levels of education compared to the spouses without any level of education.

Looking at equation 2, a 1 additional unit of household access to biomass increases poverty by 9.5 percentage point. Biomass use has significant negative impacts on household welfare. Side effects of biomass use may include its production that will require land, which could have an impact on food security, carbon stocks which are land-based, and other environmental services [71].

Education levels of household head and spouse have also shown a significant effect on reducing

poverty in Rwandan households. Household head primary, secondary, and university education levels probably reduce poverty by 7.5%,9.8%,8.7% point respectively while spouse primary, secondary, and university education levels reduce poverty by 7.8%,10.5%,8.8% point respectively compared to households with non-educated heads and spouses. Overall when we remove electricity and put biomass in the equation, the overall impact of education on poverty increases.

Having a 1 more dependent in a household increases the probability of being poor by 6.1 percentage point. Increase of the household size by 1 also increases the probability of being by 2.1% point. Female headed household have a 3.5 percentage point probability of being poor compared to male headed household and households located in urban areas have a probability of 1.3% point of being poor compared to those located in rural areas. It is surprising that households with a wage salary have a 27%-point probability of being poor and this estimate is statistically significant. One additional year of age reduces poverty by 0.2% point as it is in the electricity access equation while owning a non-farm business gives no effect on poverty. Only the coefficient on urban location of the household is not statistically significant, all other estimates are statistically significant at both 1 and 5 percentage levels of significance.

Education expenses reduce by 13.9% due to biomass access and the coefficient is negative and statistically insignificant. Households headed by females spent more than 100% on education than men headed households while households with wage salary spent 75.6% less than households with no wage salary a coefficient that is larger compared to that with electricity access. A1-unit increase in the household size leads to an increases of more than 100% education expenses and age of the household head has an effect of 2.1%. A1-unit increase in dependence also increases household education expenses by 15.4%. Households with non-farm businesses spend 39.7% less than those households without non-farm businesses. It is nearly equal to that spent with electricity access in the equation.

Education of the household head and spouse also have a significant positive effect on education expenses of the household. For household with a head that has studied primary, secondary and university spend 63.1%,142%,197.3% and 14.1%,42.4%,64.8% (for spouses) more than those with heads who have not studied at all.

Biomass access increases health expenses by 2.8% and the coefficient is not statistically significant. According to [72] ,in the job settings for biomass plants, exposure to fungi and endotoxins may be associated with respiratory disorders. And Accidental leak of hydrogen sulfide in biogas plants can lead to death or adverse health effects. Living close to biomass power plants can lead to additional risks for many symptoms and odor irritants. All these resulting into health risks

One year plus of the age of the household head decreases health expenses by 1.9%, the household size by 1 household member increases health expenses by 55.3% and households located in urban areas have a 13.8% less health expenses than a household located in rural area. Dependence in the household has shown a negative and statistically significant impact of 27.1% on HH health expenses. Female headed households also have 55.3% less health expenditures compared to male headed households and households with a wage salary have a 121% health expenditure lower than the households with no wage salary. Households with a non-farm business have a 18.6% health expense less than those that don't have a non-farm business.

Education levels of both the household head and the spouse have different impacts on health expenses. Household head with primary education has a positive effect of 29.3% on health expenses while household spouse with primary education has a positive effect of 41.6% and spouse with secondary education level pays 31.7% more compared to the household with heads and spouse without any level of education. These estimates are statistically significant at a 5% level of significance. Household spouse with university, secondary levels of education, households head with secondary and university levels of education are not statistically significant at any level of significance.

CONCLUSION AND RECOMMENDATIONS

Energy access is considered as a vital element for economic development in many developing countries (Rwanda inclusive). Given the increase in the production and access of energy as well as consumption of energy, this study aimed at investigating the impact of energy access on households' welfare. This study aimed to examine the association between energy access and welfare in Rwandan households. It estimated the effect of energy access on household welfare with a focus on electricity and biomass. These two types of energy are dominantly used by households. The data used are the cross sectional data for EICV5 survey (integrated household living conditions survey-5) that was conducted over a 12-month cycle from October 2016 to October 2017. This study has used simple OLS with the focus on income, education expenses, poverty and health expenses as welfare determinants.

Results show that a1 unit change in the electricity access was found to be associated with 35% increase in HH income,14.5% decrease in poverty,65.9% increase in education expenditure and 80% increase in health expenditure. All the estimates were statistically significant at both 1% and 5 % levels of significance. Biomass access had a negative and statistically significant effect on household income of 38.1%. A 1 additional unit of household access to biomass increased poverty by 9.5 percentage point and the coefficient was also statistically significant. Education expenses reduced by 13.9% and health expenses increased by 2.8% due to biomass access. These two coefficients were statistically insignificant. 0.028. Electricity access has also shown to increase education expenses, income as well as reducing poverty. While biomass access increases poverty, and reduces income.

The negative impact of biomass use on welfare revealed that the government's proposition of reducing biomass access to 50% and increasing electricity access to 100% of the population because electricity access is a good policy to continue to implement. The results also show that the increase in electricity access that the Government is focusing on is a great policy to continue to implement. Put in other words, the Government of Rwanda should strengthen the biomass energy consumption reduction strategy and put much emphasis in electrification.

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