UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

OFF-GRID ENERGY USE AND HOUSEHOLD WELFARE IN RWANDA

A dissertation submitted to the African Center of Excellence in Energy for Sustainable Development in partial fulfillment of the requirement for the degree of Masters of Science in Energy Economics

Student Names: **Laurence MUKAYIRANGA**
Registration Number: **220000090**

Supervisor's Names: **Dr. Aimable NSABIMANA**

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DECLARATION

I, Laurence MUKAYIRANGA, hereby declare that the work presented in this project dissertation is my original work, and has not been presented for a degree in University of Rwanda or any other universities. All sources of materials that will be used for the dissertation work will have been fully acknowledged.

Names: Laurence Mukayiranga _____

Signature

Date of Submission: November 5,2021

This Masters dissertation has been submitted for examination with my approval as a university advisor.

Dr. Aimable NSABIMANA _____

Thesis Advisor Signature

DEDICATION

I dedicate this Masters dissertation to my God, God who is above of all things, my shepherd and my salvation, my source of power wisdom, knowledge and inspiration.

This Masters dissertation is dedicated to my mother **Annonciathe MUKARUBAYIZA, Brothers** and **Sisters** who helped me in different things.

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ABBREVIATIONS AND ACRONYMS

ACE-ESD:	African Center of Excellence in Energy for Sustainable development
CIF:	Climate Investment Funds
EDCL:	Energy Development Corporation Ltd
EDPRS:	Economic Development and Poverty Reduction Strategy
EICV:	Integrated Household Living Conditions Survey
EnDev:	Energizing Development
EUCL:	Energy Utility Corporation Ltd
IEA:	International Energy Agency
MDGs:	Millenium Development Goals
MININFRA:	Ministry of Infrastructure
MoU:	Memorandums of Understanding
NISR:	National Institute of Statistics of Rwanda
OLS:	Ordinary Least Square
PAOP:	Power Africa Off-grid Project
PAY:	Pay as you Go
RBF:	Results-Based Financing
REG:	Rwanda Energy Group Ltd
SDGs:	Sustainable Development
SE4All:	Sustainable Energy for All
SHS:	Solar Home Systems
SWAP:	Sector Wide Approach
TV:	Television
UNPD:	United Nations Development Programme
UR:	University of Rwanda
USAID:	United States Agency for International Development
WB:	World Bank

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ABSTRACT

One of the biggest issues to rural growth of the economy in developing countries is insufficiency entrance to renewable energy. Energy access can improve educational and health outcomes, labor productivity, job creation, and economic growth, as well as allow for more effective use of information and communication technology. Rwanda's government intends to achieve middle-income status by 2030. To that end, the government has implemented a nationwide electrification program, which has increased electrification rates from 6% in 2008 to 50% in 2019. The study identifies the main driving forces behind Rwandan households' decision to use off-grid energy. The results indicate that the location of residence, home ownership, household size, type of marriage, household income level, and homeowner all play a crucial role in clarifying the likeliness of off-grid energy use within the household. Further the results show that electricity is more likely to be used in urban households, where household with high income more often use electricity compared to others. The study also demonstrates the significant impact of utilizing stand-alone systems energy as a means of electrification on household welfare in Rwanda.

CHAPTER ONE: GENERAL INTRODUCTION

1.0. Introduction

1.1. Background

Off-grid means that a location is not connected to the public power grid, as well as possibly other services such as water and gas. It is widely acknowledged that electrification improves household quality of life and poverty alleviation while also stimulating the economy at large. The immediate advantage of electrification is improved illumination, which encourages students to study for longer periods of time and, as a result, leads to improved educational outcomes. Other household tasks may benefit from lighting. Women's sewing, social events after dark, and other activities are examples. Radios and televisions, for example, increase rural households' access to information while also providing entertainment for family members. The United Nations' 193 Member States adopted a historic agreement in 2015 to achieve a prosperous, sustainable peacebuilding by 2030. The UN 2030 Agenda is based on 17 integrated Sustainable Development Goals (SDGs) with 169 targets that include everything from Zero Poverty (SDG1) to Partnerships for the Goals (SDG17). The seventh Sustainable Development Goal (SDG 7) aims to ensure that everybody has access to affordable, dependable, renewable, and modern electricity (Bisaga et al., 2020). Since energy access can boost educational and health outcomes, labor efficiency, job development, and economic growth, as well as make greater use of information and communication technology, this is a good thing(Asian Development Bank et al., 2019). Unfortunately, globally, more than 1 billion people do not have access to electricity (International Energy Agency, 2017), and the distribution is more biased towards poor rural communities especially in developing countries. For example, in sub-Saharan Africa, as at 2018, only 47.66 percent of the total population had access to electricity. However, between urban and rural population, access to electrification was 78.097 percent for urban and 31.535 percent for rural (World Bank Data, 2020). Clearly, SSA's low rate of electrification means that staying on track with the sustainable development agenda will be difficult without substantial increases in electrification, especially in rural areas where welfare results are generally low. (Article, n.d.). Making such an expenditure, however, would necessitate evidence-based research into the effect of

electrification on welfare indicators. In this regard, Africa has a big void (Asian Development Bank et al., 2019).

The current research project examines Sustainable Development Goals 7 through the lens of the off-grid solar energy supply, which provides reliable energy in resource-constrained areas where traditional grid solutions have failed. Some nations, like Rwanda, recognize the potentiality of off-grid energy supply to achieve last kilometers consumers and also have integrated them into national plan. (Bisaga et al., 2020).

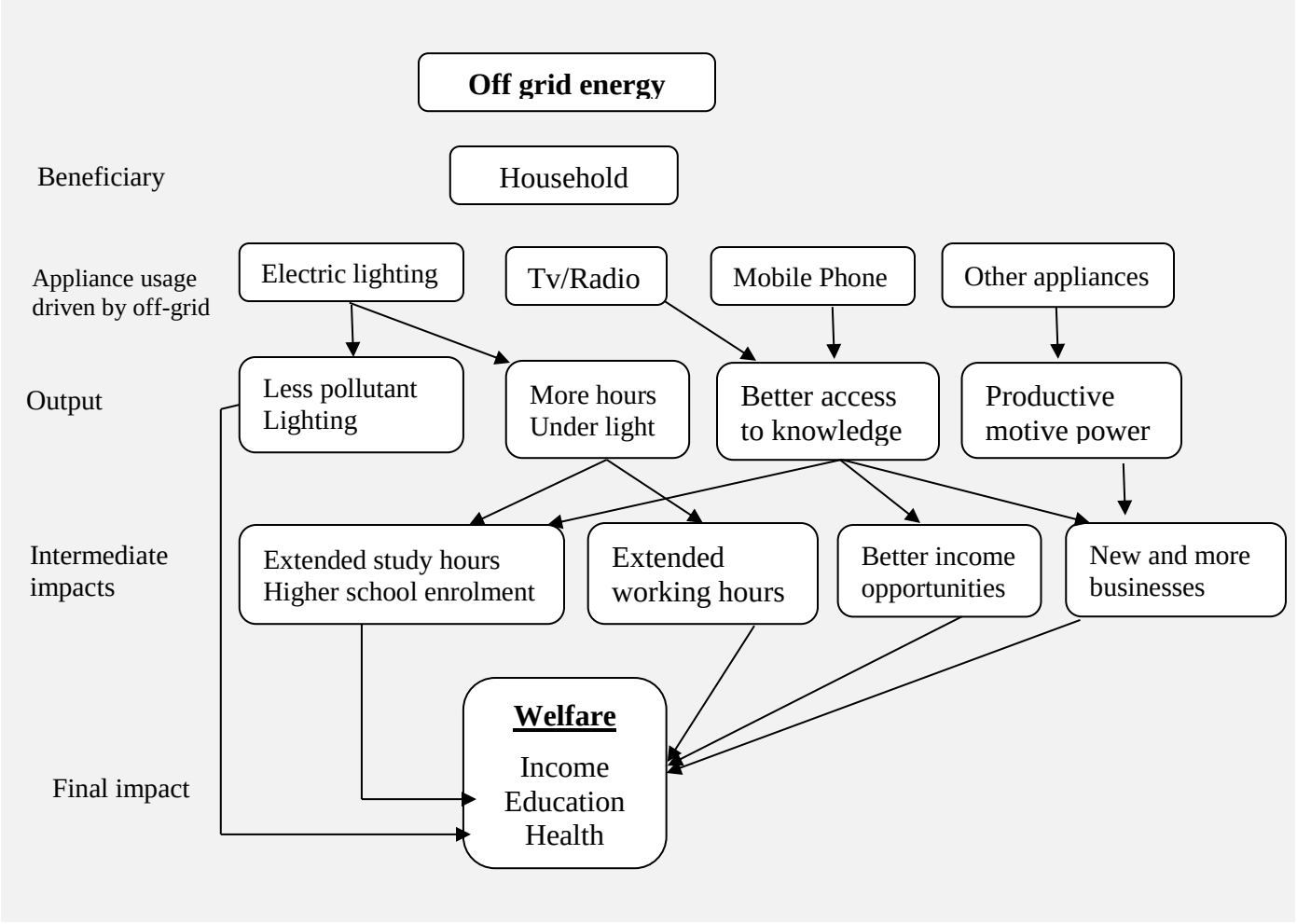

Figure 1: Theoretical framework

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Access to electricity in Rwanda has progressively grown exponentially. In 2009, roughly 9% of households seemed to have reliable electricity, especially in comparison to 55% by 2020. (MININFRA, 2020). Of the households that have been attached, 40% have been linked through the internal grid, mainly in urban and outskirts, and 15% had been attached via off-grid systems, primarily in remote regions (MININFRA, 2020). Elevated initial costs, particularly once attempting to reach steadily for the households from remote areas, difficult landscape, the relative isolation of rural families, falling prices, and restricted accessibility are all barriers to grid expansion. Off-grid residential solar processes as well as other dispersed technologies can assist consumers who are not attached to the grid in these situations (Bisaga, 2019; Kennedy et al., 2019; Niyonteze et al., 2020). Residential solar accessibility account for approximately 14 percent of the overall off-grid connections, more than 1.7 million persons, with photovoltaic mini-grids and oil lamps accounting for the remaining 1 percent of off-grid interconnection (EnDev,2019). Moreover,than 20 service investors had also agreed to sign Letters of Intent (LoI) with Rwanda's authorities (REG, 2018). Rwanda's government has formed strong alliances with off-grid green energy companies. The Rwandan off-grid solar sector has been among the quickest increasing in Africa, thanks to close cooperation and regular consultations with the financial market, tax deductions on solar technologies, and huge backing from collaborators such as the Climate Investment Funds (CIF) and Energizing Development (EnDev) throughout its Results-Based Funding (RBF) facility. Mobile infrastructure, which is also encouraged by the Rwandan government, has permitted solar firms to manage inventive Pay as You Go (PAYG) marketing strategies, providing essential funding to families without reliable electricity and empowering monitoring systems. This latter allows for the collection of true energy data, which can then be used to forecast future energy consumption trends, notifying scheme design changes and prioritize investments (Bisaga et al., 2017; Bisaga, 2020). Attempts to popular and frequently access to energy under the Economic Development and Poverty Reduction Strategy (EDPRS) I and II have included the Electricity Access Rollout Programme (EARP) and Sector Wide

Approach (SWAp) building project collectively headed by Rwanda Energy Group Ltd (REG) and the World Bank (WB) between 2009 and 2017 (Knight, 2016). The government-owned REG is made up of two effective implementation bodies which are: The Energy Development Corporation Limited (EDCL) and the Energy Utility Corporation Limited (EUCL), and are in charge of power generation and utility provision of services, respectively (REG, 2018; Bisaga et al., 2020).

The market opportunity for off-grid energy solutions in Rwanda obviously varies throughout in three important market segments: Solar home systems (SHS), Mini-grids, and Solar pumping. Rwanda's solar home systems market is still in its infancy. Over 250,000 solar home system and numerous lanterns were sold by five big corporations in total. Affordability is the most crucial matter for the industry, which has resulted in a drop in solar home system sales. Despite the maturity of the solar home system market, the mini-grid industry remains small at the moment. Rwandan mini-grid developers are ready to scale up, but funding problems and nationwide electrification planning have stymied progress, though stakeholders are working to resolve the problems. Solar pumping also gives the private company a viable opportunity to participate in the productive use of off-grid energy. Current donor funding, as well as the involvement of providers, resellers, and home consumers, had also increased awareness of the market segment's possibility. The connections among electricity as well as other industries such as agribusiness, wellbeing and schooling represent significant possibilities for off-grid businesses to expand into new markets, create new product lines, and keep increasing their effect. PAOP's Regional Advisors in both East and West Africa assist businesses as well as USAID tasks in understanding and implementing opportunities for integrating productive uses of electricity into their operations and activities. (Engagementrwanda, n.d.).

Although several researchers have done their work on similar topic, they used few varibales to model the impact of off-grid energy supply on the population's welfare. For instance, Iwona Bisaga(2020) who used the qualitative analysis to test the reslationship betweeen off-grid and sustainable development goals in rwanda and the resarrch carried out by (Michael et all, 2017) who investigated a first step up the energy ladder, low cost solar kits and household's welfare in rural Rwanda, their research considered budget effect, health and environmental effect, productivity of domestic production and their research used the methodology whereby the average treatment on the treated,

intention to the treated effect were done. Moreover, the research carried out by (Jörg Peters & Maximiliane Sievert,2016) about the impacts of rural electrification revisited the african context, the research considered variables such as health, electricity, study time, income and productive use of electricity. unlike the research of the past researchers, the current research will consider the variables such as income, health, education to solve the problem of omitted variables for better estimating the impact of off-grid energy supply on the population's welfare.

1.2. Statement of the Problem

For a country's socioeconomic development and human well-being, modern, clean energy services are important. Hygiene and sewage, universal health care mechanical energy, farming, schooling and information technology are examples of other utilities, are also dependent on them (Fuso Nerini et al., 2019). Despite the vital role that electricity plays in providing essential services, nearly 1.1 billion people (or 17% of the world's population) lack access to electricity, and 2.7 billion lack improved cooking facilities (World Energy Council, 2017). More than 95 percent of them live in Sub-Saharan Africa (SSA) and Asia with high concentration in their respective remote areas (Agreement et al., 2018).

According to the International Energy Agency (IEA), improvement in urban electrification has been twice as quickly as in remote regions since 2000, where Sub-Saharan Africa will become the least electric powered region in terms of the total number of electricity underprivileged and percentage of total population. According to the IEA (2017), the present consumption of electricity in Sub-Saharan Africa is 43 percent, with advancement toward widespread rural electrification by 2030 being unbalanced all over nations. In recent years, the urgency of the situation has prompted increased efforts to solve the problem of energy poverty. Energy access is now a separate target in the new Sustainable Development Goals (SDGs) for 2015-2030, a reversal from the Millennium Development Goals (MDGs), which did not recognize it as a crucial strategic development point(Bisaga, 2018).

The United Nations decade of Sustainable Energy for All (SE4All) initiative began in 2014, and the International Finance Corporation (IFC) and World Bank Lighting Africa Program began in 2007. With a slew of new systems and initiatives on the horizon, ensuring universal access has risen to the top of the priority list for ensuring long-term development. The importance of off-grid energy systems

in achieving universal access has been recognized by both the governmental and non-governmental sectors, as they provide a more cost-effective and time-efficient alternative to expanding grid connections for providing access to remote rural populations with lower demand and capacity to pay(MININFRA, 2020). In Rwanda, access to electricity has gradually increased within the past years. About 9 percent of families had access to reliable energy in 2009, compared to 55% in 2020 (MININFRA, 2020). As of February 2021, 60.9 percent of Rwandan households had connections to the internet, with 45 percent connecting to the national grid and 15.9 percent using off-grid networks (mainly solar) (Rwanda Energy Group, Electricity Access 2020, n.d.).

The current research evaluated the impact of using off-grid as source of electricity on household's welfare.

1.3 Objectives

1.3.1. Major Objectives

To examine the association between off-grid energy system and the welfare of Rwandan households.

1.3.2. The specific objectives

1. To identify driving forces affecting the household consumption and poverty level
2. To evaluate the effects of off-grid use on the Rwandan household welfare

1.4. Scope of the study

This study focuses on establishing and analyzing the impact of using off-grid energy system as factors determining household choices for electrification source, econometrically in Rwanda hence household transition to different means of electrification energy and this analysis will be carried out in STATA tool.

1.5. Expected Outcomes and Significance of the Study

1.5.1. Expected Outcome of the Study

Using off-grid energy system in household has significant positive impact on welfare outcomes. We discovered that using off-grid energy system raises household consumption per capita and average years of schooling in the household and decreases the number of family members who register illness(Diallo, 2019).

1.5.2. Significant of the Study

There is still a lot of reliance on traditional energy use in rural areas which resulted to environmental emissions, according to this issue Rwanda has a target of introducing modern energy like off-grid solar homes systems expected to improve household's welfare in whole remote areas.

CHAPTER TWO: LITERATURE REVIEW

Electricity is generally accepted as being essential for improving the quality of life of families and more broadly, economic growth. Greater levels of family illumination are an obvious advantage of trying to connect to the power grid. With more light in the residence, children spend more time studying, adults have more flexible work hours for household tasks and reading novels, and home-based business owners stay open later in the evening hours, generating more things for sale. After rural residents attach to the grid, television sets, enthusiasts, and a variety of other home appliances become more inexpensive. While farmers shift from manual to off-grid irrigation and small businesses start utilizing electric equipments, rural electrification can boost productivity and income.

Matter of fact, a considerable amount of literature mentions the numerous direct and indirect benefits of electricity, such as (Khandker 1996);(Filmer and Pritchett 1998); (Roddis, 2000); World Bank 2002, 2004, 2008; Barnes, Peskin, and Fitzgerald 2003; Kulkarni and Barnes 2004; Cabra al, Barnes, and Agarwal 2005; Barnes, Peskin, and Fitzgerald 2003; Barnes, Peskin, and Fitzgerald 2003; Barnes, Peskin, and Fitzgerald 2003; Barnes, Peskin, and Fitzgerald 2003; Barnes, Peskin, and Fitzgerald 2003; Barnes, Peskin, Given the numerous advantages of electricity, connectivity to and other advanced sources of energy has indeed been viewed as crucial to achieving the UN Millennium Development Goals MDGs; UNDP 2005. Numerous developing countries have benefited from bilateral and multilateral grants for rural electrification projects over the last few decades. The majority of these projects aimed to improve welfare programs, such as earnings or schooling, as well as economic growth. To achieve these objectives, project features have included reinforcing governance structures, contributing to power-sector reform, and developing tariff and subsidization guidelines. However, original source of causality has been a main question in assessing rural electrification's development: Do people with higher incomes adopt electricity, or does electricity result in higher family incomes and improved livelihood security? It is impossible to ascertain whether and to what extent these goals are accomplished in the absence of appropriate evaluations of the effects of rural electrification projects. Numerous overall research examining the relationship among rural electrification and development have been performed. Despite the work of Saunders et al. 1975, Butler, Poe, and Tendler 1980, Fluitman 1983, Barnes 1988, and Barnes et al. 2003, few

studies have rigorously examined the correlation between electrification and rising incomes. The majority of previous assessments measured the effects of rural electricity by trying to compare families either with or without electricity at a fixed moment in time. Generally, such evaluations have not evaluated the nature and scope of the benefits realization, let alone determined if the evaluated benefits are ascribable to electrification. The purpose of this research is to close that gap by verifying the reliability of cause and effect between outcomes and rural electrification and measuring the economic advantages of electrification using sound estimation methods that account for the underpinning endogeneity bias of power grid. Indeed, there is a substantial body of literature addressing the numerous advantages of energy (e.g. Khandker 1996; Filmer and Pritchett 1998; Roddis 2000; World Bank 2002, 2004, 2008; Barnes, Peskin, and Fitzgerald 2003; Kulkarni and Barnes 2004; Cabral, Barnes, and Agarwal 2005).

Electricity use in the contemporary, developed world improves all aspects of life quality. From the effects on productivity levels to the weather patterns halls in which people are sleeping, to the modes of mass transit individuals use to get to work or school, to how people are spending their free time. Every one of these aspects of life would be drastically different for most people if they did not have access to plentiful, relatively inexpensive, and sustainable power (Bridge et al., 2016). Given its numerous advantages, access to electricity and other renewable energy sources has indeed been described as critical to the achievement of the United Nations Millennium Development Goals (MDGs, UNPD 2005,). Over the last few decades, regional and international support community have financially supported rural electrification programs in several developing countries. The vast bulk of these programs seeking to enhance social welfare (e.g., education or income) as well as economic growth. To accomplish these goals, mid - project have included organisational reinforcement methods, providing inputs to electricity reconfiguration, and developing tariff and subsidy guidelines.

Bridge et al. (2013) and Khandker et al. (2013) apply the same rule in this thesis (2013). They investigated the impact of off-grid solar energy on Rwandan income, education, health, and labor productivity.

The majority of previous assessment research evaluated homes with and without power at a specific real time to assess the effect of rural electricity. The type and magnitude of the collect benefits, it's just whether the observable advantages are the result of electrification, are usually not measured in such evaluations.

This thesis aims to close the gap by examining the criteria of the causal relation between building results and rural electrification, as well as trying to quantify the economic advantages of electrification using sound econometric methods that account again for electricity connection's inherent endogeneity bias. Our approach emphasizes the findings of this literary works in order to identify the problems implicated and whether they could be viewed, as well as to comprehend the scope to which off-grid renewable power makes a significant contribution to the welfare of Rwandan households.

CHAPTER THREE: METHODOLOGY

This chapter presents the mythology applied to achieve the current research objectives. It starts with research design and source of data discussions and then details the data cleaning and analysis processes.

3.1. Description of the study area

Rwanda is a developing country located in East Africa region. It is a landlocked country with an area of 26338 square kilometers and around 12 million inhabitants. The majority of its population (82.7 percent) live in rural areas (World Bank, 2020). The country has made a tremendous improvement in terms of achieving its development goals as outlined in different local, regional and internal agenda. Although the country is among many other sub-Saharan countries with low electricity access especially in rural settings, it aimed at achieving one hundred percent electricity access by 2024. The emphasize was put on increasing off grids connectivity to reduce connection cost in remote areas. The recent statistics from Rwanda energy group Ltd. shows that among households with electricity access, only 17.8 percent of them use off grids (REG, 2021). The current research not only assesses the adoption of off grids connectivity in rural Rwanda but also assessed the impact of using off grids as opposed to non-users of any type of electricity.

3.2. Research Design

The current study is a quantitative analysis of cross-sectional secondary data from the 2016/2017 Integrated Household Living Conditions Survey (EICV 5).

3.3. Data and source

This research used secondary data from EICV5. This is a nationally-representative household survey conducted every 5 years to provide information on wellbeing of the population include health, education, income, expenditure, consumption, poverty, inequality among others. It is an open dataset which is accessible from the national institute of statistics of Rwanda (NISR) website (https://microdata.statistics.gov.rw/index.php/catalog). This dataset is grouped into 35 dimensions to allow usability. However, one can relate them based on the unique household identification.

3.4. Study population

EICV5 interviewed 14,580 households country wide. However, the author limited the current research to only non-users of national on-grid supply living in rural areas which are 10,123 households. Thus, 10,123 households' data were used in this research.

3.5. Sample size and Sampling techniques

In the current study, the author did not sample households. This means that all households that met inclusion criteria were considered. Thus, 10,123 households 'data were used.

The sampling of these households was done by NISR during the surveying period that lasted 12 months. It was conducted in 10 cycles to allow capturing seasonality information on income and consumption indicators. NISR used 2012 census frame to conduct a district level stratification of villages (primary sampling units) by type of place of residence (Rural/Urban). After a new listing of households within selected villages, households were selected proportionally to the villages households' size. Lastly information on person and household level were collected from all selected households. This sampling methodology produced 1,260 sample villages and 14,580 sample households at the national level. In the urban strata, it produced 245 sample villages and 2,526 sample households, and in the rural strata it produced 1,015 sample villages and 12,054 sample households.

3.6. Dependent variable

The outcome variable for this research is population welfare as measure by 4 different indicators: equivalised household consumption, food budget share, non-food budget share, and poverty level.

3.7. Independent variable

The current study used the following independent variables: Use of Solar panel in lighting, use of batteries in lighting, use of torch/phone in lighting, use of others lighting tools, Age of household head, Age of household head squared, The size of household, Household member with salary or wage (yes=1), Household head is female (yes=1), Number of rooms in rural household, The household owns TV set (yes=1), Household owns radio set (yes=1), Household owns mobile phone (yes=1), Household head with primary education, Household head with secondary education, Household head with tertiary education.

3.8. Data cleaning process

The outcome variables (equivalised household consumption, food budget share, non-food budget share, and poverty level) were directly obtained from "EICV5_Poverty_file.dta" file. The independent variables (Use of Solar panel in lighting, use of batteries in lighting, use of torch/phone in lighting, use of others lighting tools) were computed from "s5cq16" variable in the "cs_S0_S5_Household.dta" file. The computation was done by drop information of on-grid supply users households and urban households. Then, recoding of values was also performed to finally make these dummy variables.

The rest independent variables (Age of household head, Age of household head squared, The size of household, Household member with salary or wage (yes=1), Household head is female (yes=1), Number of rooms in rural household, The household owns TV set (yes=1), Household owns radio set (yes=1), Household owns mobile phone (yes=1), Household head with primary education, Household head with secondary education, Household head with tertiary education) were also computed and recorded from "cs_S1_S2_S3_S4_S6A_S6E_Person.dta" file.

The detailed data cleaning process was prepared as a different STATA file for reproducibility purposes.

3.9. Methods of analysis

This research is an impact evaluation research. The literature has given credits to both instrument variable and propensity score matching regression models to outperform other models in such researches. However, in the presence of endogeneity; that is when one the independent variable is correlated with the error term or when the adoption of the intervention was not at random like for this case where the adoption of off-grid supply is determined by factors like affordability and government policies among others; these models becomes prune to estimation errors. In this research, the author used both descriptive analysis and Ordinary Least Square (OLS) analysis to answer the research objectives.

The simple linear regression model was used to estimate the change in outcome variables when control variables change by a unit. The equation (1) illustrates the OLS model:

$$\mathbf{Y_h = Z_h\beta + \varepsilon_h} \qquad \mathbf{(1)}$$

Where: $\boldsymbol{Y_h}$ is a vector of outcome variables (household food share, household non-food share, equivalised consumption, and poverty level); $\boldsymbol{Z_h}$ is a vector of rural household attributes and control variables (such as education of household head and age of the head of household); $\boldsymbol{\beta}$ is the vector of parameters to be estimated, and $\boldsymbol{\varepsilon_h}$ is the stochastic disturbance term.

From equation (1),

$$\boldsymbol{\beta = (Z_h^T Z_h)^{-1} Z_h^T Y_h} \qquad \mathbf{(2)}$$

The OLS estimator was thus estimated using the STATA module "reghdfe".

In addition, the cumulative density functions (CDF) were used to compared the households' welfare indicators (equivalised household consumption and share of food in household consumption) among both users and non-users of off-grid energy supply in rural Rwanda. The CDF (equation 3) returns the probability of a value less than or equal to a given outcome say between the minimum and the maximum values.

$$\boldsymbol{CDF = P(X \leq x), for\ all\ x} \in \mathbb{R} \qquad \mathbf{(3)}$$

Where X is a random variable (equivalised household consumption and share of food in household consumption). The area under the CDF curve is therefore the estimated probability.

CHAPTER FOUR: ANALYSIS, DISCUSSION AND INTERPRETATION

This chapter presents the results of analysis. It begins with descriptive analysis where mean, standard error, minimum, and maximum statistics are presented for all variables used in this research. The cumulative density functions are then presented for outcome variables among users and non-users of off-grid supply. Lastly, the effect of both treatment and other households' attributes on outcomes variables was presented for each type of off-grid energy use.

4.1. Descriptive Analysis of the data

4.1.1. Household characteristics

Table1 shows that in rural Rwanda, torch or phone are the primary source of electricity used in lighting (Mean = 0.62; SE=0.49). Moreover, the majority of households in the same region spent above 70 percent of their expenditures on food consumption. Considering the family size, the same table indicates that on average there are roughly 5 household members in rural Rwanda. In addition, 65 percent of rural households has at least one household member with salary or wage. only 27 percent of these households are headed by females. Lastly, considering the education level of the head of household, the same table indicated that the majority of the heads (74 percent) has no formal education. Table 1 displays the details.

Table 1: Distribution of household and other demographic attributes

Variables	Mean values	Standard Error	Min	Max
Treatment variables				
Users of batteries in lighting	0.09	0.29	0	1
Users of torch or phones in lighting	0.62	0.49	0	1
Users of Solar panel in lighting	0.11	0.31	0	1
Users of others types of lighting tools	0.01	0.09	0	1
Outcome Variables				
Equivalized Consumption	249727	134513	59027	759895
Food shares	0.72	0.10	0.12	0.98
Non-food share	0.28	0.10	0.02	0.88
Poverty Incidence	0.41	0.49	0	1
Other household and demographic variables				
Age of household head	47	16	14	105
The number of members in household	4.39	2.01	1	14
Household member with salary or wage (yes=1)	0.65	0.48	0	1
Household head is female (yes=1)	0.27	0.45	0	1
Household head with no education	0.74	0.44	0	1
Household head with primary education	0.21	0.41	0	1
Household head with secondary education	0.04	0.20	0	1
Household head with tertiary education	0.00	0.06	0	1
Number of rooms in rural household	5.53	1.63	2	15
The household owns TV set (yes=1)	0.01	0.09	0	1
Household owns radio set (yes=1)	0.40	0.49	0	1
Household owns mobile phone (yes=1)	0.56	0.50	0	1
South province	0.31	0.46	0	1
West province	0.25	0.43	0	1
North province	0.18	0.39	0	1
East province	0.26	0.44	0	1

Sources: Calculated by authors using Rwanda EICV5 (2016/17) focusing on rural areas alone

4.1.2. Off-grid energy access and household welfare

The government of Rwanda recognized the role of electrification in nation development and improved standard of living of its population. Ideally the increased electrification implies the increase in job opportunities, schools' enrolment rates, and decreased expose to health threats. However, the current

research found that electrification doesn't always has a positive relationship with all development indicators.

For instance, Figure 1 indicates that solar panel users have a low level of expenditures on household food consumption and higher level of the equivalized household consumption comparing to households without electricity access or households that use either batteries or torch in lighting. An increased household consumption directed to non-food items indicates that the household is accumulating some durable assets and shifting from un health appliances to health appliances.

On the other side, both non-food and food consumption among households that use torches or mobiles in lighting is roughly the same. However, the small difference observed suggest that there is no much contribution of using torches or phones in lighting towards a better standard of living of household. That is the food share in those household total consumption is high while the equivalized consumption is low. (see Figure 2).

Moreover, the difference in household food expenditures and equivalized household consumption was not observed among batteries and other lighting tools users (see Figure 3 and Figure 4). This means that; although lighting devices may help remote households to engage in some activities, it is not as much as solar panel that may help in creation in new or more job opportunities.

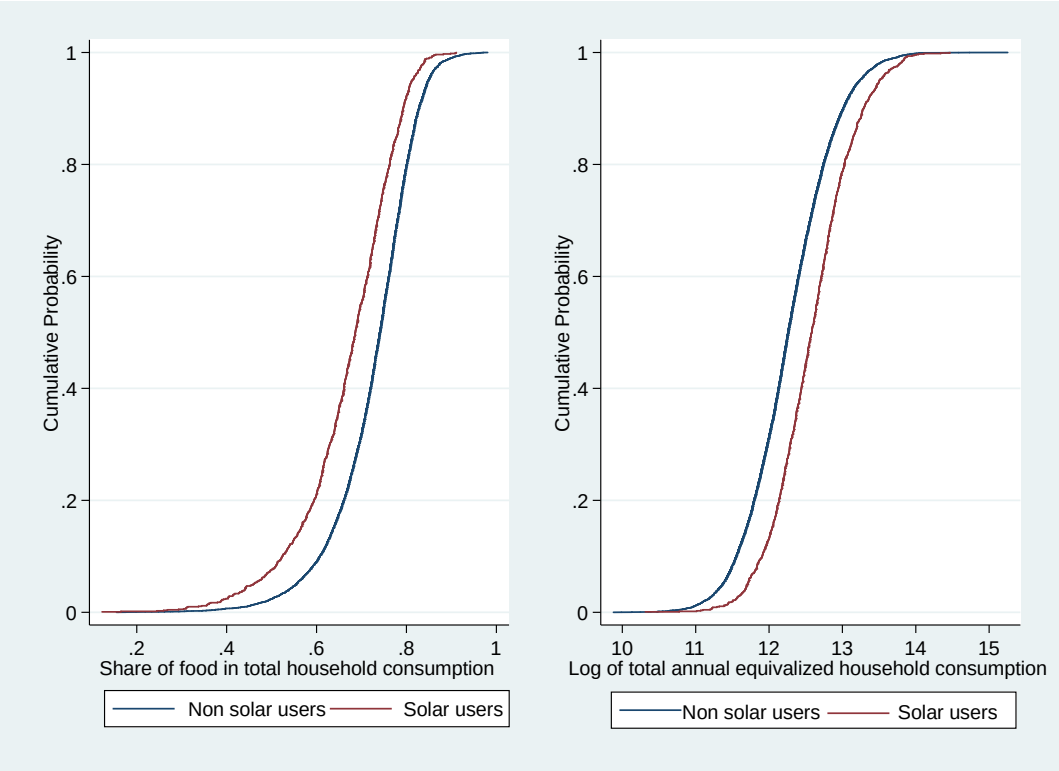

Figure 2: Combined CDF for equivalized household consumption and share of food in total household consumption

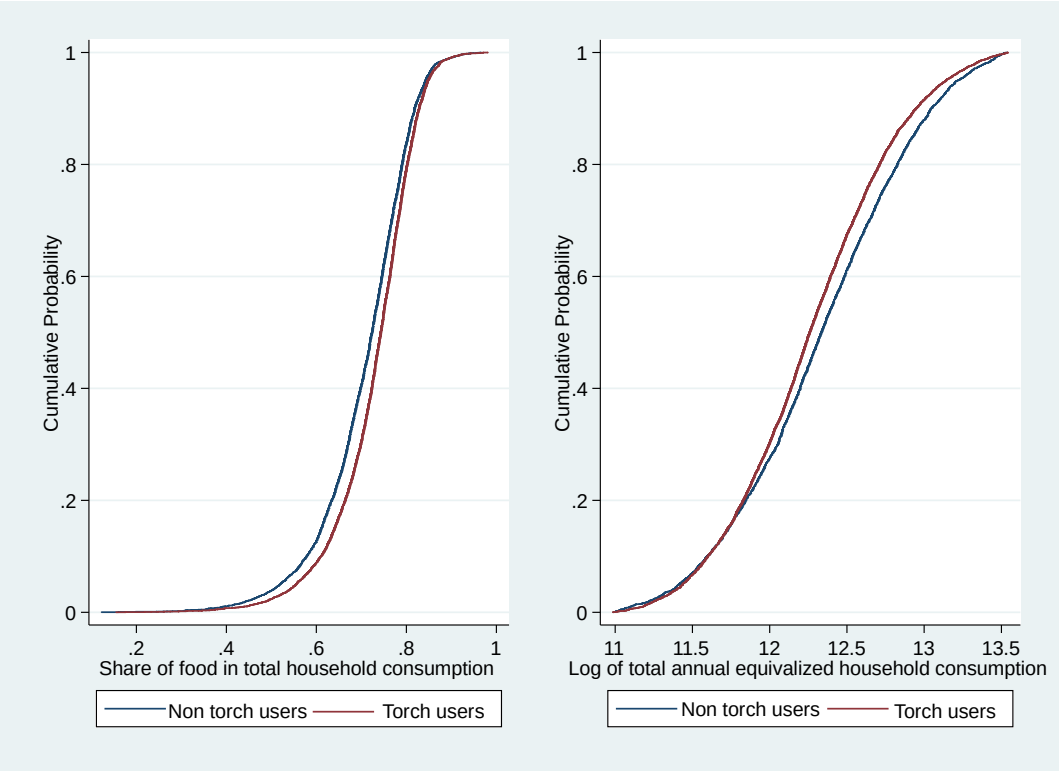

Figure 3: Combined CDF for share of food in total household consumption and equivalized household consumption among users and non-users of torch/mobile in lighting

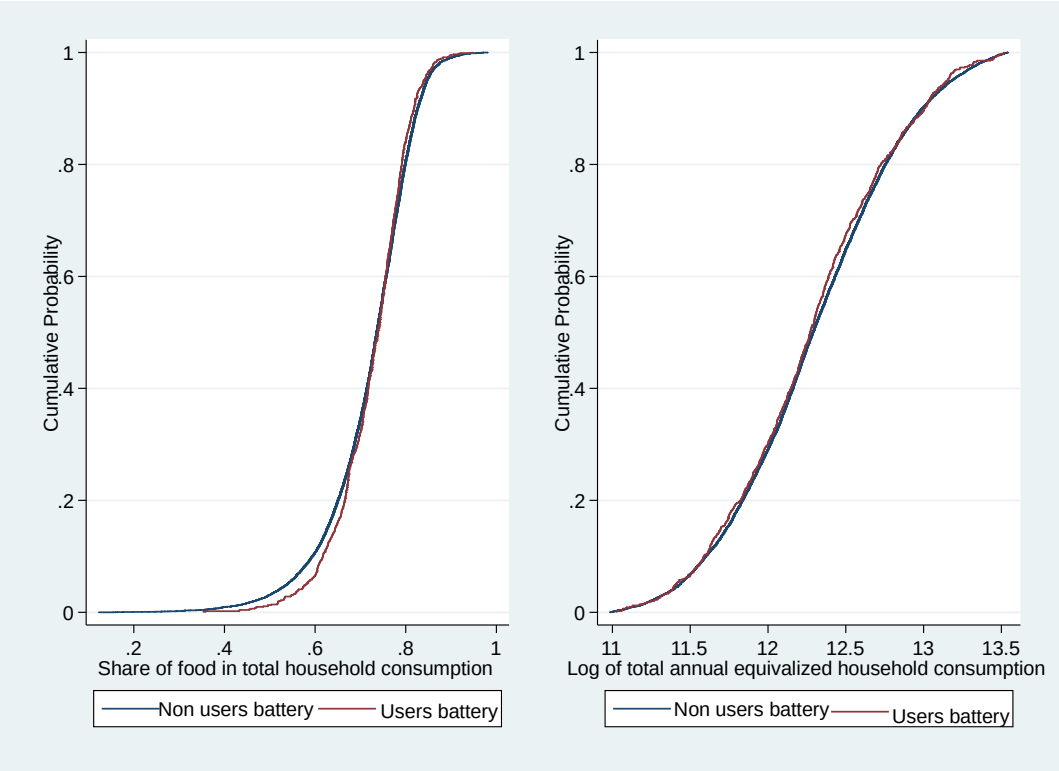

Figure 4: Combined cumulative density function for share of food in total household consumption and equivalized household consumption among users and non-users of batteries in lighting

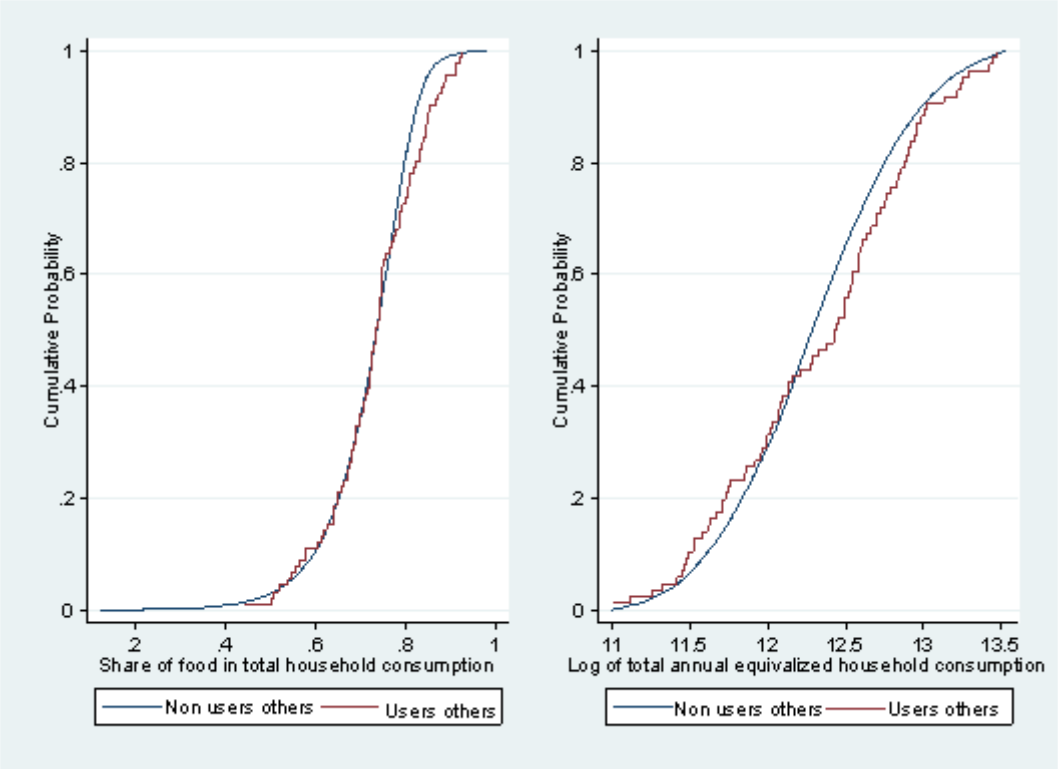

Figure 5: Combined CDF for share of food in total household consumption and equivalized household consumption among users and non-users of other lighting tools

4.2. Effect of off-grid energy supply on households' welfare in rural Rwanda

4.2.1. Solar panel lighting use and household welfare in rural Rwanda

The use of solar panel has a negative effect of poverty level (β=-0.128, SE=0.014) and food share (β=-0.021; SE=0.003) in the household. This is might be due to the result in increased working hours that increases also the average income in the household. Moreover, it also increases the schools' enrolment rates and increased studying hours. Therefore, shifting the spending priorities from foods to household assets accumulation and securing better future for household members. However, using solar panel has a moderate positive effect with equivalized consumption (β=0.168; SE=0.015) Table 2 displays the details.

As far as household attributes are considered, the same table indicates the age of household is positively associated with food share (β=0.001; SE=0.000) although the association is very weak. Older households' heads have actually a very low life expectancy and most of the time economically

inactive. A point highlighting the reason why most of their income is spent on foods just to remain alive. This particular group think of the way of consuming their wealth rather than investing.

On the other hand, the size of the household also affects its consumption patterns and thus affect the overall household economic status. Table 2 below indicates that there is a positive association between the size of the household and the household's poverty level (β=0.097, SE=0.002). This positive association was observed also for food share in household total consumption (β=0.004; SE=0.001). Since, these are rural households, the increase in household's members impose a higher dependency ratio in the same households and then the expenses priority is put on consumption rather than on any investment towards better standard of living.

Unlike the size of the household whose positive association with both poverty level and food share, the number of rooms in the household has a negative effect with both poverty level (β=-0.039; SE=0.003) and food share in the household total consumption (β=-0.008; SE=0.001). The increase in number of rooms indicates a higher average income level of the same household. Basically, most of the households in rural areas stay in their own homes. Thus, an increased rooms means ability to cover for construction cost and the need to more rooms to store yield from economic activities.

The same table also indicates that households headed by female have a positive association with poverty level compared to their counterparts (β=0.045; SE=0.011). This might be due most of those households in rural Rwanda are either households with widower women or divorced women as well as single mothers which are psychologically disadvantageous. However, those households have a lower proportion of the total household consumption that goes to foods (β=-0.012, SE=0.002). This could be attributed to a widely engagement of women in saving and lending cooperatives and other women promotion programmes in the country.

Unlike in urbans areas, the households with at least one member whose salary or wage are positively associated with poverty level (β=0.173, SE=0.010) and share of food in the total household consumption (β=0.022, SE=0.002). This particular group consists of mostly low earners without enough land to practice farming but work for others to be able to put foods on table. A reason explaining why most of their income is spent on foods rather than on securing a better future.

As expected, the access to information found to be also a driver of household welfare in rural Rwanda. This is measured by owning TV set, Radio set, and mobile phone. Users of these devices are considered as literate because they can get updated information on ways of doing business and easily interacting with each other towards income generation. This association is confirmed by the coefficients of -0.075, -0.099, and -0.129 for the relationship between owning TV set, Radio set, and mobile phone and poverty level respectively. It is also valid considering their corresponding consumption behaviors. Table 2 indicates also that these households have lower proportion of consumption that goes to foods.

Lastly the same table shows that households headed skilled people as measure by their education level have a negative association with both poverty level and lower food share in the total consumption. This association with poverty level was found for household heads with primary education level (β=-0.048), secondary education level (β=-0.093), and tertiary education level (β=-0.100) compared to households headed without any formal education or not completed primary education.

Table 2: Solar panel lighting use and household welfare in rural Rwanda

Variables	Equivalized Consumption	Food share	Non-food share	Poverty level
Use of Solar panel in lighting	**0.168*** **	**-0.021*** **	**0.021*** **	**-0.128*** **
	(0.015)	(0.003)	(0.003)	(0.014)
Age of household head	-0.002	0.001**	-0.001**	0.001
	(0.002)	(0.000)	(0.000)	(0.002)
Age of household head squared	0.000***	-0.000*	0.000*	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
The size of household	-0.142***	0.004***	-0.004***	0.097***
	(0.003)	(0.001)	(0.001)	(0.002)
Household member with salary or wage (yes=1)	-0.251***	0.022***	-0.022***	0.173***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head is female (yes=1)	-0.077***	-0.012***	0.012***	0.045***
	(0.011)	(0.002)	(0.002)	(0.011)
Number of rooms in rural household	0.051***	-0.008***	0.008***	-0.039***
	(0.003)	(0.001)	(0.001)	(0.003)
The household owns TV set (yes=1)	0.335***	-0.060***	0.060***	-0.075**
	(0.047)	(0.013)	(0.013)	(0.036)

Household owns radio set (yes=1)	0.133***	0.003	-0.003	-0.099***
	(0.010)	(0.002)	(0.002)	(0.009)
Household owns mobile phone (yes=1)	0.178***	-0.041***	0.041***	-0.129***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head with primary education	0.060***	-0.011***	0.011***	-0.048***
	(0.011)	(0.002)	(0.002)	(0.011)
Household head with secondary education	0.240***	-0.059***	0.059***	-0.093***
	(0.023)	(0.006)	(0.006)	(0.018)
Household head with tertiary education	0.394***	-0.123***	0.123***	-0.100*
	(0.108)	(0.028)	(0.028)	(0.058)
Constant	12.635***	0.739***	0.261***	0.228***
	(0.041)	(0.008)	(0.008)	(0.037)
Observations	10,064	10,064	10,064	10,064
R-squared	0.446	0.215	0.215	0.291
District FE	YES	YES	YES	YES

Note: The robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.2.2. Torch or phone use and household welfare in rural Rwanda

Unlike the observed effect of solar panel on household welfare, the use of torch/mobile phone, have a very low positive effect on both poverty level (β=0.015, SE=0.009) and household food share of the total consumption (β=0.010; SE=0.002). However, they have a very low negative effect on equivalized household consumption (β=-0.012, SE=0.010) (see Table 3). That means that the use of torch/mobile phone lighting devices has a weak association with rural households' welfare compared to the degree of association perceived considering solar panel lighting.

The observed direction and degree of association between other households' attributes (Age of household head, Age of household head squared, The size of household, Household member with salary or wage (yes=1), Household head is female (yes=1), Number of rooms in rural household, The household owns TV set (yes=1), Household owns radio set (yes=1), Household owns mobile phone (yes=1), Household head with primary education, Household head with secondary education,

Household head with tertiary education) and households' welfare in rural Rwanda remain the same as discussed in section 4.2.2. above. Table 3 displays the details.

Table 3: Torch or Phone lighting use and household welfare in rural Rwanda

Variables	Equivalized Consumption	Food share	Non-food share	Poverty level
Use torch/phone in lighting	**-0.012**	**0.010*** **	**-0.010*** **	**0.015***
	(0.010)	**(0.002)**	**(0.002)**	**(0.009)**
Age of household head	-0.003	0.001**	-0.001**	0.002
	(0.002)	(0.000)	(0.000)	(0.002)
Age of household head squared	0.000***	-0.000	0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
The size of household	-0.141***	0.004***	-0.004***	0.097***
	(0.003)	(0.001)	(0.001)	(0.002)
Household member with salary or wage (yes=1)	-0.263***	0.023***	-0.023***	0.182***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head is female (yes=1)	-0.078***	-0.011***	0.011***	0.046***
	(0.012)	(0.002)	(0.002)	(0.011)
Number of rooms in rural household	0.055***	-0.009***	0.009***	-0.041***
	(0.003)	(0.001)	(0.001)	(0.003)
The household owns TV set (yes=1)	0.432***	-0.068***	0.068***	-0.146***
	(0.048)	(0.013)	(0.013)	(0.037)
Household owns radio set (yes=1)	0.145***	0.001	-0.001	-0.108***
	(0.010)	(0.002)	(0.002)	(0.009)
Household owns mobile phone (yes=1)	0.188***	-0.042***	0.042***	-0.137***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head with primary education	0.062***	-0.011***	0.011***	-0.049***
	(0.011)	(0.002)	(0.002)	(0.011)
Household head with secondary education	0.249***	-0.060***	0.060***	-0.099***
	(0.023)	(0.006)	(0.006)	(0.018)
Household head with tertiary education	0.432***	-0.126***	0.126***	-0.127**
	(0.107)	(0.028)	(0.028)	(0.057)

Constant	12.642***	0.732***	0.268***	0.219***
	(0.041)	(0.008)	(0.008)	(0.038)
Observations	10,064	10,064	10,064	10,064
R-squared	0.439	0.214	0.214	0.286
District FE	YES	YES	YES	YES

Note: The robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.2.3. Batteries lighting use and household welfare in rural Rwanda

Unlike the observed effect of using torch/mobile phone devices in lighting, the use of batteries in lighting have no significant effect on poverty level, equivalized household consumption, and household food share of the total consumption. That means that the use of batteries in lighting has no significant association with rural households' welfare.

The witnessed direction and degree of association between other households' attributes (Age of household head, Age of household head squared, The size of household, Household member with salary or wage (yes=1), Household head is female (yes=1), Number of rooms in rural household, The household owns TV set (yes=1), Household owns radio set (yes=1), Household owns mobile phone (yes=1), Household head with primary education, Household head with secondary education, Household head with tertiary education) and households' welfare in rural Rwanda remain the same as discussed in section 4.2.2. above. Table 4 displays the details.

Table 4: Batteries lighting use and household welfare in rural Rwanda

Variables	**Equivalized Consumption**	**Food share**	**Non-food share**	**Poverty level**
Use batteries in lighting	**-0.026**	**0.004**	**-0.004**	**0.012**
	(0.016)	**(0.003)**	**(0.003)**	**(0.016)**
Age of household head	-0.003	0.001**	-0.001**	0.002
	(0.002)	(0.000)	(0.000)	(0.002)
Age of household head squared	0.000***	-0.000*	0.000*	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
The size of household	-0.141***	0.004***	-0.004***	0.096***
	(0.003)	(0.001)	(0.001)	(0.002)
Household member with salary or wage (yes=1)	-0.263***	0.024***	-0.024***	0.182***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head is female (yes=1)	-0.077***	-0.012***	0.012***	0.045***

	(0.012)	(0.002)	(0.002)	(0.011)
Number of rooms in rural household	0.055***	-0.009***	0.009***	-0.041***
	(0.003)	(0.001)	(0.001)	(0.003)
The household owns TV set (yes=1)	0.435***	-0.072***	0.072***	-0.152***
	(0.047)	(0.013)	(0.013)	(0.037)
Household owns radio set (yes=1)	0.146***	0.001	-0.001	-0.109***
	(0.009)	(0.002)	(0.002)	(0.009)
Household owns mobile phone (yes=1)	0.187***	-0.042***	0.042***	-0.136***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head with primary education	0.061***	-0.011***	0.011***	-0.049***
	(0.011)	(0.002)	(0.002)	(0.011)
Household head with secondary education	0.248***	-0.060***	0.060***	-0.099***
	(0.023)	(0.006)	(0.006)	(0.018)
Household head with tertiary education	0.434***	-0.128***	0.128***	-0.131**
	(0.107)	(0.029)	(0.029)	(0.057)
Constant	12.636***	0.739***	0.261***	0.228***
	(0.041)	(0.008)	(0.008)	(0.038)
Observations	10,064	10,064	10,064	10,064
R-squared	0.439	0.212	0.212	0.286
District FE	YES	YES	YES	YES

Note: The robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

4.2.4. Other lighting use and household welfare in rural Rwanda

In the same direction with the observed effect of using batteries in lighting, the use of other lighting devices has also no significant effect on poverty level, equivalized household consumption, and household food share of the total consumption. That means that the use of any other lighting devices has no significant association with rural households' welfare.

The perceived direction and degree of association between other households' attributes (Age of household head, Age of household head squared, The size of household, Household member with salary or wage (yes=1), Household head is female (yes=1), Number of rooms in rural household, The household owns TV set (yes=1), Household owns radio set (yes=1), Household owns mobile phone (yes=1), Household head with primary education, Household head with secondary education,

Household head with tertiary education) and households' welfare in rural Rwanda remain the same as discussed in section 4.2.2. above. Table 5 displays the details.

Table 5: Other lighting devices use and household welfare in rural Rwanda

Variables	Equivalized Consumption	Food share	Non-food share	Poverty level
Use other devices in lighting	**-0.064**	**0.012**	**-0.012**	**0.051**
	(0.055)	**(0.010)**	**(0.010)**	**(0.047)**
Age of household head	-0.003	0.001**	-0.001**	0.002
	(0.002)	(0.000)	(0.000)	(0.002)
Age of household head squared	0.000***	-0.000	0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)
The size of household	-0.141***	0.004***	-0.004***	0.096***
	(0.003)	(0.001)	(0.001)	(0.002)
Household member with salary or wage (yes=1)	-0.264***	0.024***	-0.024***	0.183***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head is female (yes=1)	-0.077***	-0.012***	0.012***	0.045***
	(0.012)	(0.002)	(0.002)	(0.011)
Number of rooms in rural household	0.055***	-0.009***	0.009***	-0.041***
	(0.003)	(0.001)	(0.001)	(0.003)
The household owns TV set (yes=1)	0.437***	-0.072***	0.072***	-0.153***
	(0.048)	(0.013)	(0.013)	(0.037)
Household owns radio set (yes=1)	0.146***	0.001	-0.001	-0.109***
	(0.009)	(0.002)	(0.002)	(0.009)
Household owns mobile phone (yes=1)	0.187***	-0.042***	0.042***	-0.136***
	(0.010)	(0.002)	(0.002)	(0.010)
Household head with primary education	0.062***	-0.011***	0.011***	-0.049***
	(0.011)	(0.002)	(0.002)	(0.011)
Household head with secondary education	0.250***	-0.061***	0.061***	-0.100***
	(0.023)	(0.006)	(0.006)	(0.018)
Household head with tertiary education	0.434***	-0.128***	0.128***	-0.130**
	(0.107)	(0.029)	(0.029)	(0.057)
Constant	12.634***	0.739***	0.261***	0.229***
	(0.041)	(0.008)	(0.008)	(0.037)
Observations	10,064	10,064	10,064	10,064
R-squared	0.439	0.212	0.212	0.286

District FE	YES	YES	YES	YES

Note: The robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

This research aimed determining the effect of using an off-grid energy system as a means of electrification on the welfare among households from rural areas in Rwanda.

The author used the nationally representative EICV5 data collected from 11 households that are not connected to the national on-grid in rural Rwanda.

The author employed the OLS model to estimate the effect of both off-grid energy access and other household characteristics on population welfare in the same region.

This research revealed that the use of solar panel, and being headed with person with higher education are the direct determinants of population welfare in rural Rwanda households. However, the use of other devices in lighting does not has a significant impact on population welfare in the same region.

Therefore, following the outcomes of the current research, the author recommends the following:

1. The government should continue to attract investors to avail solar panel to the remote households at an affordable price to increase the accessibility rate. The high voltage solar panel should be encouraged to use especially in locations with high economic activities to promote job creation.
2. The government should also support disadvantageous households to at least afford those small solar panel that can at least help in home lighting and allow students to safely study at home
3. In some locations, people live in villages, so, a common off-grid system should be encouraged to reduce the accessibility cost while increasing the energy per household to run their businesses.

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