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Title: **ASSESSMENT OF SOLAR HOME SYSTEM CONTRIBUTION TOWARDS SOCIOECONOMIC DEVELOPMENT AND ELECTRICITY ACCESS RATE IN RWANDA**

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In partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN RENEWABLE ENERGY

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Declaration A

I, the undersigned, declare that this dissertation "Assessment of Solar Home System Contribution towards Socioeconomic Development and Electricity Access Rate in Rwanda" is my original work, and has not been presented for any degree in the University of Rwanda or any other universities. All sources of materials that will be used for the dissertation work will have been fully acknowledged.

Jean Paul MUGABE: Digitally signed by MUGABE Jean Paul ____________

Approved by:

Dr. Maxime BINAMA

Supervisor Signature

Dr. Antoine MUSENGIMANA

Co-Supervisor Signature

DEDICATION

To my wife Janviere INGABIRE

To my supervisor Dr. Maxime BINAMA

To my co-supervisor Dr. Antoine MUSENGIMANA

To my classmates

ACKNOWLEDGEMENT

I would like to begin by extending my profound appreciation to the Almighty God for His continuous graces, strength, sustenance, and, above all, His unwavering faithfulness and love throughout my academic journey, starting from the commencement of my studies up to the completion of my master's degree. My sincere thanks are extended to Dr. Maxime BINAMA, my supervisor, for his invaluable guidance, support, and encouragement throughout the course of my research. Additionally, I express my gratitude to my Co-Supervisor, Dr. Antoine MUSENGIMANA, for providing valuable feedback and insightful suggestions.

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ABSTRACT

Energy stands as a crucial prerequisite for combatting poverty and fostering socio-economic growth within a nation. The absence of a reliable energy supply constitutes a significant hindrance to a country's development. This study seeks to evaluate the impact of solar home systems (SHS) on socio-economic development and the augmentation of electricity access rates in Rwanda. Following a concise review of previous research elucidating the significance, advantages, and potential of SHS, the primary focus is on scrutinizing how SHS shapes socio-economic development and expedites electricity access in Rwanda.

In rural areas of Rwanda, where households are often dispersed across various hills with limited access to convenient roads for efficient electricity distribution, solar energy emerges as a promising solution to meet the electricity needs of remote households in developing countries. SHS incorporates photovoltaic (PV) modules that convert light energy into electrical energy, and batteries store the energy for use during periods without sunlight, especially at night. The research leverages data collected from a survey conducted among 102 households in four Rwandan districts, each representing one province. Solar energy holds the potential to significantly enhance rural livelihoods. Opting for Solar Home Systems (SHS) instead of kerosene lanterns contributes to a reduction in indoor air pollution, positively impacting the health and well-being of rural families. Despite the higher initial cost of SHS, ongoing expenses are lower compared to spending on candles and kerosene.

The implementation of SHS in rural Rwanda yields clear positive impacts, encompassing economic benefits as households utilize SHS for income-generating activities. Improved conditions related to education, health, household tasks, access to information, communication, entertainment, and safety perception bring transformative changes to traditional social life, enhancing the overall quality of life for rural inhabitants. Children and women at the household level experience the most significant benefits, spending most of their time at home using solar electric lighting and household appliances.
Moreover, numerous non-SHS households indirectly benefit from SHS-equipped homes, gaining access to facilities such as TV, radio, mobile phones, laptops, and study resources. Positive environmental effects are evident as the substitution of traditional lighting fuels leads to savings in carbon dioxide emissions. Survey findings underscore that running costs are less than 5000 Rwandan francs, emphasizing the affordability of these costs for SHS owners.

Contents

List of tables

LIST OF FIGURES

List of Acronyms and Abbreviations

ACE-ESD	African Center of Excellence in Energy studies for sustainable development
SHS	Solar Home System
NST1	The National Strategy for Transformation 2017 –2024
EDPRS	Economic Development and Poverty Reduction
PV	Photovoltaic
MININFRA	Ministry of Infrastructure
REG	Rwanda Energy Group
EDCL	Energy Development Corporation
EUCL	Energy utility Corporation
RURA	Rwanda Utilities Regulatory Authority
NEP	National Electrification Plan
DC	Direct Current
AC	Alternating current
GE	Grid Extension
SAS	Stand Alone Solar
IPPs	Independent Power Producers
UN	United Nations
FONERWA	fund for environment and natural resources for Rwanda
REP	Rwanda Energy Policy
ESSP	Energy Sector Strategic Plan
EARP	Electricity Access Roll-out Program
SWH	Solar Water Heaters
MWh	Megawatt hour
$PMPP$	Maximum power point
TV	Television
DVD	Digital Versatile Disc
SSA	Sub-Saharan Africa
VAT	Value-added tax

Chapter One: INTRODUCTION

One of the most important components needed to reduce poverty and propel a country's socioeconomic development is energy. When there is insufficient or no energy, a nation's development goals cannot be realized. Rwanda's National Transformation Strategy (NST1) for 2017–2024 aims to place the country among the first in Africa to achieve universal electricity. Recognizing that universal energy access is essential to realizing the desired transformation of society, NST1 intends to provide power to every family by 2024. Rwanda is known for its thousand hills and its undulating terrain. Many rural families are dispersed throughout the hills, and many of them lack easy access roads for effective distribution of energy. Adopting solar energy seems like a viable way to keep up with the growing demand.

1.1. Background

Over the last thirty years, significant progress has been made in improving the accessibility of electricity worldwide. The proportion of the population with access to electricity has increased significantly over time, according to reports from the International Energy Agency (IEA) in several years (2002, 2004, 2012, 2022a). It was 49% in 1970, 59% in 1990, 73% in 2000, 81% in 2010, and 90% in 2019. However, as the IEA's 2022b analysis noted, an estimated 770 million people did not have access to power as of 2022. According to the IEA's 2022a findings, most of this population, or almost 95%, lives in Sub-Saharan Africa (578 million people, or 75% of the world's population) and Developing Asia (155 million people, or 20% of the world's population) [1].

Significant progress has been made in improving the accessibility of electricity worldwide over the last thirty years. Global access to electricity has increased significantly; according to data from the International Energy Agency (IEA) in several years (2002, 2004, 2012, 2022a), it was 49% in 1970, 59% in 1990, 73% in 2000, 81% in 2010, and 90% in 2019. The IEA's 2022b study states that despite these advancements, data from 2022 shows that almost 770 million people still do not have access to electricity. 95% of this population lives in two regions: Developing Asia (155 million people, or 20% of the world's population) and Sub-Saharan Africa (578 million people, or 75% of the world's population), according to IEA data from 2022a [1].

The literature claims that access to power is necessary for developing nations to better their socioeconomic condition since power has a significant impact on things like education, money, health, and the environment. It has been shown that the biggest barrier to economic progress in rural places is a lack of access to energy [2].

Clearly, the main emphasis for accelerating the rate of electrification is on creating isolated or grid-based systems. But the other 10% of the population lives mainly in isolated and rural locations, where connecting to a grid or isolated grid is likely to be prohibitively expensive for economically disadvantaged households who are widely separated. The implementation of cost-effective solar home systems (SHS) in rural areas has the potential to close the existing 10% disparity in access to energy. Some rich nations and international organizations have started SHS initiatives in distant rural areas of developing nations with low rates of electrification throughout the last thirty years [1].During the formulation of the Economic Development and Poverty Reduction Strategy (EDPRS) II, the Rwandan government distinctly opted to broaden the sources of electricity beyond the traditionally dominant grid. Consequently, households located outside the designated regions with a national grid presence have been encouraged to opt for alternative and more cost-effective connections[2]

Current access targets state that all people should have access to electricity by 2024, without exception, and that companies should be fully connected by 2022. The goal of Rwanda Energy Group (REG) is to add about 500,000 new electrifications annually, comprising roughly 200,000 off-grid and roughly 300,000 on-grid[2].

Solar home systems offer a financially and economically viable solution for electrifying rural areas, especially when households are scattered, and each has relatively low electricity demands—a common scenario in many rural parts of Rwanda. While solar energy comes with a high cost per kilowatt-hour, it becomes an economically efficient option when only small quantities are needed, particularly in remote locations. Although the initial costs are higher compared to alternatives like small generators, the ongoing operational costs are often lower. To overcome the initial cost barrier, incentives such as subsidies and credit schemes can be employed [2].

The Solar Home System (SHS) emerges as a preferred technology for meeting the electricity demands of rural households, depending on the geographical location and living standards of the country's population. SHS proves cost-effective as it eliminates the need for extensive transmission lines and can generate both DC and AC power, catering to various types of loads. Comprising essential components like solar panels, batteries, charger controllers, and wires, SHS operates by harnessing sunlight to generate electricity in a coordinated manner [3].

1.2. Problem statement

In Rwanda, as country of thousand hills, many its population live in remote areas far from electrical distribution network, scattered on different hill and hillsides. This makes technically hard and expensive to have access to electricity. The government of Rwanda has put more effort to attain universal energy access, where the access rate was at 72% as of June 2022 [4]Nevertheless, let’s not forget that the government of Rwanda’s target is to provide electricity to all Rwandans (100%) by 2024, which is next year. This target is supposed to be achieved by exploiting all possible sources of energy. This has led to a wide adoption of off-grid electrification mode where, among the so far available technologies, Off-grid solar systems have been proposed as one of best alternatives available, owing to its feasible and sustainable nature vis-a-vis Rwanda’s geographical and socio-economic characteristics. While we still have one year to 2024, which is the time at which the Government of Rwanda had targeted the completion of a 100% electrification of Rwanda. There have been no studies that show how SHSs are contributing to a quick achievement of this goal. It is from this background that the present project intends to investigate the SHS’s so far attained level of contribution toward the improvement of energy access levels in Rwanda. In this regard, the present project, being the first of its kind on the Rwandan territory, intends to investigate contribution of SHS towards universal electricity access.

1.3. Objectives of the research

1.3.1. Main objective

This dissertation's primary goal is to evaluate how Solar Home Systems contribute to Rwanda's social and economic development and accelerate the country's electrification process in order to provide universal access.

1.3.2. Specific objectives

Specific objectives are:

1. To assess the role of SHS on socio-economic development in Rwanda

2. Evaluate the maintainability, Reliability and affordability of solar Home system
3. Assessing the level of SHS awareness and policy implementation
4. To develop some Recommendations for the households that are best fit for electrification by means of SHS.

1.4. Research questions

The research aims to investigate the role of solar home systems (SHS) in promoting socio-economic development in Rwanda. The study will explore the maintainability, reliability, and affordability of solar systems, as well as the implementation of SHS awareness and policy. Additionally, the research will examine how to assess and recommend the types of households that can be effectively electrified through the implementation of solar home systems.

1.4.1. Scope of the study

This study, which centers on evaluating the impact of Solar Home Systems (SHS) on socio-economic development and the advancement of global electricity access in Rwanda, specifically focuses on electricity generated through photovoltaic solar systems utilizing SHS in the country. The analysis excludes consideration of other solar energy-based technologies. Rwanda Energy Group, along with its subsidiaries EDCL and EUCL (Energy Utility Corporation, will contribute data related to electrification rates and the average cost of household electrification. The research will also involve policymakers and government entities due to their crucial role in Rwanda's solar energy sector, with secondary data being collected from both the private sector and governmental institutions. Among Rwanda's renewable energy resources, solar power stands out as the most promising. The study asserts that harnessing solar energy could help address the country's increasing electricity demand through the implementation of appropriate policies, rules, and regulations. Consequently, the research aims to ascertain the specific contribution of SHS to achieving universal energy access in Rwanda.

1.4.2. Significance of study

The significance of studying and assessing the contribution of Solar Home Systems towards the expedition of global electricity access in Rwanda is as follows:

1. Economic Development: Access to electricity through Solar Home Systems can stimulate economic growth by powering businesses, supporting entrepreneurship, and creating employment opportunities.

2. Sustainable Energy Transition: Solar Home Systems are a renewable energy solution that reduces reliance on fossil fuels and helps mitigate the adverse environmental impacts associated with conventional energy sources.
3. Policy and Decision Making: Understanding the impact of Solar Home Systems on global electricity access can help policymakers develop targeted strategies, regulations, and incentives to accelerate energy access initiatives in Rwanda and other regions facing similar challenges.
4. Technology Deployment and Innovation: The study can facilitate the identification of technological advancements, best practices, and innovative approaches for the deployment and integration of Solar Home Systems.

1.4.3. Limitations of the study

When conducting fieldwork, one encounters a number of limitations, such as:

Lack of Documents: One issue is that it can be hard to get formal sources to provide documented inf ormation.The materials are kept confidential and in certain cases may be difficult to find.Time Restri ctions: A further drawback to fieldwork is time constraints.The time allotted for gathering data turns out to be inadequate.More effort must be spent on data processing and information collecting for a q ualitative investigation.It might also take longer to modify its design in light of new information and discoveries.

1.4.4. Study Structure

The first chapter functions as an introduction, giving readers a familiarization guide for my research topic and a sneak peek at how this project is structured. The second chapter of this dissertation explores a conceptual overview of Solar Home Systems in socio-economic development and reviews a selection of relevant literature. The research technique is covered in detail in the third chapter, while data analysis, findings presentation, and discussions are covered in the fourth chapter. The fifth and final chapter summarizes the study's findings and offers suggestions.

Chapter Two: LITERATURE REVIEW

2.1. Introduction

An energy source that is secure, cheap, and easily available is essential to a nation's socioeconomic development. Numerous facets of a nation's socioeconomic development are positively impacted by rural electrification, especially when it is achieved using solar power, according to recent studies. Under this context, solar energy is commonly recognized as a technology that holds promise for producing electricity in distant regions of developing countries. The primary goal of this chapter is to provide a thorough analysis of relevant research while highlighting the crucial role that solar electricity plays as a socioeconomic development accelerator. The study delves into various aspects that impact socioeconomic growth, including but not limited to household income, health, education, access to information, and other infrastructure services. This chapter's main goal is to evaluate how Solar Home Systems contribute to the socioeconomic development of emerging.

2.2. Access to electricity in Rwanda

Recently, Rwanda's power sector has witnessed significant growth, with installed capacity doubling since 2010. This expansion aligns with the country's increasing population and evolving socioeconomic activities, resulting in a rise in energy consumption. As of September 2019, 53% of Rwandan households had access to electricity. The country is blessed with abundant natural energy resources, such as hydro, geothermal, solar, and methane gas. The National Electricity Control Centre reported an installed power generation capacity of 224.6 megawatts (MW), with only 11.0% being imported [5]. The energy mix comprises 39.0% hydrological resources, 25.0% methane gas, 19.0% thermal sources, 4.0% peat, 2.0% solar, and 11.0% imports. The government is committed to achieving universal access to electricity, targeting 3.7 million households by 2024. In the fiscal year 2021/2022, 127,742 customers were connected to the national grid, and 116,713 households were connected to off-grid electricity. By June 2022, the electricity access rate had increased from 64.53% to 72%. However, by June 2023, 65.7% of Rwandan households had electricity access, with 47.6% connected to the national grid and 18.1% connected to off-grid systems like Solar Home Systems and microgrids. The slight decrease is attributed to updated household numbers from the recent 5th Population and Housing census conducted in August 2022[5].

During the development of the EDPRS II, the Rwandan government strategically diversified electricity sources beyond the dominant grid, incorporating off-grid connections. This approach encourages households located far from the planned national grid coverage to opt for more affordable alternatives like Mini-grids and Solar Photovoltaics (PVs), aiming to reduce the cost of accessing electricity while addressing historical constraints on government subsidies [6] [7] [8].

2.3. Rwanda Electrification plan

The limited progress in electrification within Rwanda serves as a hindrance to economic advancement. As of June 2023, only about 65.7% of Rwandan households had gained access to electricity, with 47.6% being connected to the conventional grid and 18.1% utilizing off-grid solutions, primarily through solar home systems. The government of Rwanda (GoR) has identified the expansion of electricity access as a key priority. The goal is to achieve universal access to electricity by 2023/24, ensuring that 100% of the population has access, with 52% connected to the national grid and the remaining 48% connected through off-grid technologies like micro-grids and standalone solar home systems. [4]

In Nation electrification plan 2023, the following situation are observed: 65.23% of all villages fall in on-grid zone (Grid Extension and Fill in and) it means 9,664 villages out of 14,816 villages. 34.35% of all villages fall in off grid zone (GE-Temporarily Solar Home Systems, SAS and Microgrid) it means 5,090 villages. 0.42% of all villages (62 villages) were not demarcated for any technology factoring in that the residents were relocated. Others are under the process of relocation due to the facts that they remain in areas marked as high-risk zones while others live in areas planned for strategic investments in agriculture such as tea plantation, etc. The national electrification plan is summarized as per the map below. [4]

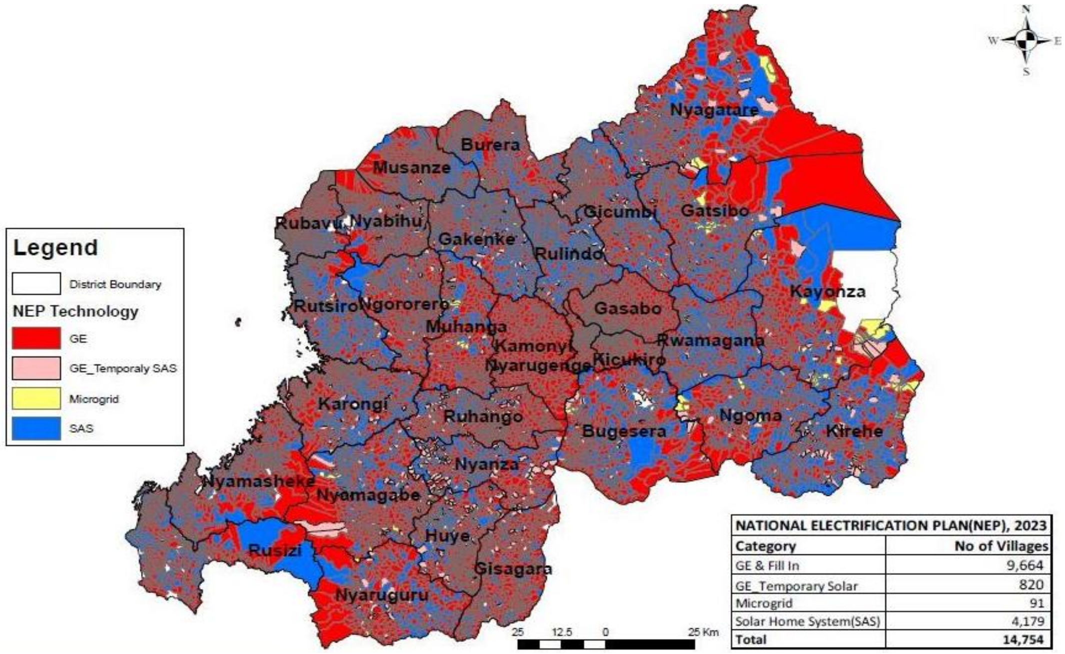

Figure 2.1: Map for National Electrification Plan 2023 [4]

Among the off-grid villages, a share of 91 villages (equivalent to 0.6%) are proposed for microgrid development while 4,999 (equivalent to 33.7%) villages are proposed to be electrified using Standalone Solar Home Systems. During the revised NEP 2023, the off-grid share increased compared to previous NEP 2022 as per the table below.

Table 2-1: NEP2023

SN	Technology	Number of villages 2023
1	Solar	1279
2	Minigrid	91
3	GE temporary SHS	820
4	Additional scope	2900
	Total	5090

2.4. Rwandan energy policies

The Ministry of Infrastructure (MININFRA) plays a pivotal role in shaping energy policies, overseeing project implementation, and establishing a conducive policy and legal framework for the sector. It provides recommendations on optimizing state subsidies, engages in budget preparation, and mobilizes resources [9]. Rwanda Energy Group Ltd (REG Ltd), positioned above EUCL and EDCL, serves as the apex entity, evaluating the operations of its subsidiaries and providing senior leadership, thus holding a key role in the sector [10]. Energy Development Corporation Limited (EDCL) is responsible for developing generation and transmission projects, exploring new energy resources, and implementing a cost-effective power development strategy. It autonomously manages its affairs, regularly reporting progress to MININFRA [10]. Energy Utility Corporation Limited (EUCL) oversees day-to-day operations in power generation, transmission, distribution, and final customer sales. It plans grids, promotes energy efficiency, and manages demand side programs, with key objectives including cost reductions, loss reductions, enhanced customer satisfaction, and economically dispatching generation [11]. Rwanda Utilities Regulatory Authority (RURA) regulates the power and gas sectors, overseeing licensing, tariff approval, sanctioning Power Purchase Agreements (PPAs), and enforcing technical standards [11].

While MININFRA holds primary responsibility, there are crucial inter-ministerial dimensions to energy policy. The Ministry of Natural Resources oversees resource exploitation and environmental impacts, and the Rwanda Development Board facilitates private developer involvement. Other contributing ministries include the Ministry of Trade and Industry, improving the business environment; the Ministry of Finance, mobilizing resources; and the Ministry of Local Government, promoting decentralized service delivery. The Rwanda Standards Bureau develops national technical standards, and the National Fund for Environment and Climate Change (FONERWA) implements green growth and climate change initiatives [12].

2.5. Key Existing Policies

In March 2015, the Rwandan government unveiled the Energy Sector Strategic Plan (ESSP) and the Rwanda Energy Policy (REP) as key documents guiding the nation's energy development. The ESSP translates policy directives into specific actions to achieve medium-term goals, while the REP establishes the overarching vision and framework. The REP, a high-level policy document, outlines rules, regulations, strategic directions, and guiding principles for Rwandan institutions and partners to follow, aiming to turn energy into one of Rwanda's most dynamic sectors and an attractive investment destination. The REP is built on three fundamental government principles: transparent and effective sector governance, facilitating business operations and reducing barriers to private investment, and enhancing capacities and frameworks [13].

The Energy Sector Strategic Plan (ESSP) complements the REP, with two published versions (ESSP 2015 and ESSP 2018). The REP sets the long-term vision, goals, and approaches, while the ESSP provides targets and an implementation framework to measure progress [12].Addressing the electricity disparity between urban and rural areas is crucial for the realization of the second national program of Economic Development and Poverty Reduction Strategies (EDPRS II). The Rwandan government has implemented policies under the Rural Electrification Strategy to bridge this gap, involving four distinct programs:

Establishing facilities for low-income households to access modern, clean, and sustainable energy through basic solar power systems. Developing a policy to make solar power products financially accessible to the private sector and end users. Allowing the private sector to develop mini grids with government assistance in site identification and frameworks [12].Expanding the electricity network through Energy rollout programs. The Electricity Access Roll-out Program (EARP) has significantly increased grid access from 364,000 households in June 2012 to over 700,000 households in 2017. The Solar Rwanda Program, planned for 2012-2015, aimed to install 12,000 Solar Water Heaters (SWH) by 2015. However, by the end of 2017, only 2,464 SWHs had been installed, and the program is ongoing. Advocating for a diverse renewable energy mix, especially with solar adoption, could create jobs, boost the economy, generate revenue from trading carbon credits, and preserve the environment. Implementing new regulations to enforce this initiative would make such a transition feasible [12].

2.6. Deployment of SHS in Rwanda

Over the past ten years, Rwanda has seen a steady growth in the availability of power. By 2020, it is anticipated that 55% of households—compared to just 9% in 2009—will have access to electricity. Forty percent of linked households were in urban and peri-urban areas, served by the national grid, while fifteen percent were in rural areas, served by off-grid systems. High upfront expenditures and challenging topography are obstacles to grid expansion, especially when trying to serve last-mile residents[14].

By 2024, 48% of the population will be electrified through off-grid options and 52% through on-grid connections, according to government pledges. A degree of uncertainty was introduced into the industry in 2019 with the release of the Ministerial Guidelines for Minimum Standards for Solar Home Systems (SHS) and the National Electrification Plan (NEP) (see Section 4). But since then, the government has clarified more about the requirements for SHS system eligibility and the regions where their off-grid sales are allowed. The Energy Development Corporation Limited (EDCL) will oversee the monitoring of all installed SHS across the nation using the soon-to-be-completed Off-Grid Monitoring Information System (OMIS) [15].

Rwanda wants to link 1.7 million people off the grid by 2024, mostly with Solar Home Systems (SHS). There are 418,502 of these connections that the Energy Development Corporation Limited (EDCL) has documented. For off-grid access through SHS, the government establishes requirements such as a minimal service level, system performance benchmarks, and connections via mini-grids. Reported off-grid connections for 2019–2020, however, did not meet the yearly target of 250,000 required to meet the 48% overall goal. Although there isn't a specific study on SHS demand, consumer expenditure on energy services and alternative illumination shows that people are eager and able to pay. According to recent poverty surveys conducted in Rwanda in 2016–17, 75% of the country's non-electrified population pays less than USD1.67 a month for energy-related costs, which include phone charging, candles, batteries, and kerosene [15].

2.7. Suppliers of SHS in Rwanda

The strategy for Rwandan rural electrification was approved in June 2016 and lays out plans for Rwandan households to "have access to electricity through the most cost-effective means possible by developing programs that will facilitate both end users' access to less expensive technologies and increase private sector participation in the provision of these solutions." (RES, MININFRA, 2016).
As part of this plan, the Energy Development Corporation Ltd. (EDCL) inked Memorandums of Understanding (MoUs) with 27 private businesses to expand the nation's supply of off-grid solar home systems, strengthening the nation's supply chain and enabling solar systems to be installed in more locations. Because of this, 14% of Rwandan households are now able to obtain electricity using off-grid methods, mostly solar home systems[16].

2.8. Solar Home Systems (SHS) Overview

Direct solar energy conversion to electrical power is known as photovoltaic solar energy conversion. A photovoltaic (PV) system's solar cell is a crucial component that makes the photovoltaic effect possible. A small amount of electric current is produced in the cell when sunlight interacts with the semiconductors. Photovoltaic modules, often called panels, are made up of many cells that are coupled to produce useful voltages and currents. Stand-alone solar photovoltaic systems are widely used, especially in rural electrification projects for homes, businesses, or social organizations. Solar Home Systems (SHS) is the typical designation for this system [17].

Even though SHS only generates a little over 100 W of electricity, it is sufficient to run lights, radios, TVs, and medical refrigerators. Even though SHS may seem expensive at first, it works well for small-scale electricity delivery in places where grid connection is difficult. Its use is especially appropriate when there is very little demand or when the cost of acquiring fuel is very high. Fuel prices are rising, thus SHS technologies might end up being more affordable than off-grid options[17].

2.9. SHS architecture

The fundamental principle behind solar power technology is the photovoltaic effect. When sunlight strikes the solar cell's semiconductor material (usually silicon), it generates an electric current due to the interaction of photons with electrons [18].

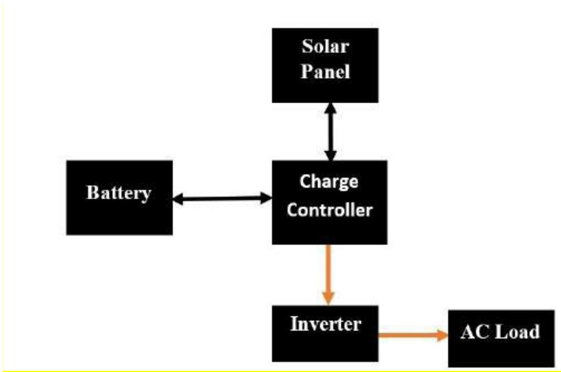

Figure2. 1: Block diagram of solar home system components [19]

To store energy for use later when there isn't any sunlight, particularly at night, SHS is equipped with photovoltaic modules that convert light energy into electrical energy [20]. Typically, SHS employ energy-efficient fluorescent or Light Emitting Diode (LED) lamps and appliances to maximize the amount of power given. They run at 12 volts direct current (DC). A standard 50WP SHS can run a tiny 15-inch black-and-white television for up to five hours and four compact fluorescent bulbs[21].People can choose the size of solar system they want to buy based on their own power needs and financial situation. Solar systems have a number of uses, such as: supplying electricity for electronics such as TVs, radios, and DVD players. In isolated locations, Solar Home Systems (SHS) are essential for providing mobile phone charging. The extension of energy access through off-grid alternatives has been made possible by technological developments and the cost of off-grid systems, which have led to an increased connection rate through initiatives like the energy Access Roll-out Program (EARP)[20].Estimating power consumption and taking into account the specs of PV modules, batteries, inverters, and charge controllers—all of which come in a variety of capacities and price points—help establish the size of these systems. To install and maintain these components correctly, professional experts are required. Sales support can be needed in the event of a component failure [22].

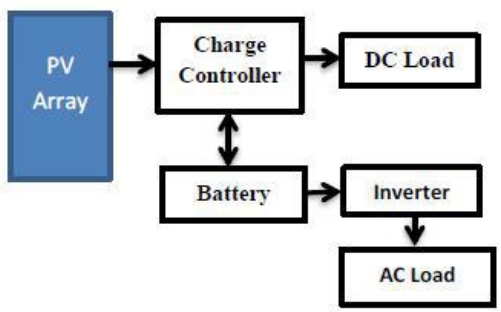

Figure2. 2: SHS with both AC and DC Loads

2.10. Solar Panel Construction

Solar panels are made up of modules, which are collections of connected solar cells. The solar panel array is then built from many modules. A back sheet and a glass cover serve as protective encapsulation for the solar cells, which are structurally supported by an aluminum frame. The optimal capture and conversion of sunlight into electrical energy is achieved by the design of the solar panels [18].

2.11. Solar Inverter

Solar inverters are an essential component of solar power systems. They convert the direct current (DC) electricity produced by solar panels into alternating current (AC) electricity, which is compatible with the electrical grid and can power household appliances and devices. Inverters also perform important functions like monitoring and controlling the performance of the solar system [24].

2.12. System Monitoring and Control

Solar power systems often include monitoring and control systems to optimize performance and ensure efficient energy production. These systems track various parameters such as solar irradiance, panel temperature, and energy output. They enable system owners to monitor the performance, detect faults, and maximize the energy yield of their solar power systems. [25]

2.13. Sizing of PV system

Prior to purchasing a solar system, people should give the first stage of system sizing the highest priority. This involves specifying several different things, including energy consumption, the number of PV panels, the kind of wires used for system connections, and the capacities of the inverter and battery. The system should be built to produce enough energy to meet demand and offset system energy use to avoid problems associated with power and energy scarcity. There are several developed size techniques, with differing degrees of ease and dependability[26].

2.14. Efficiency of solar cell

The parts of photovoltaic modules called solar cells are what convert sunlight into electrical energy. The maximum power point (PMPP), the product of the input solar irradiance (G) under normal test conditions, and the surface area (A) of the PV panel are the computations used to estimate the energy conversion efficiency of a solar cell. As a result, the PV cell's size affects the generated current[27].

$$\eta = \frac{P_{MPP}}{GA} \qquad \ldots\ldots\ldots\ldots \text{Equation 2.1}$$

2.15. The electrification of solar home systems serves as a catalyst

The United Nations General Assembly pledged in 2000 to work towards achieving the Millennium Development Goals (MDGs) by 2015, recognizing the significance of reducing rural poverty through rural development and expanding access to modern energy technologies. Although energy, particularly electricity, was not initially widely acknowledged as a basic human requirement, its importance for meeting basic needs like health, agriculture, education, and information, as well as its correlation with per capita income and human development index, has become evident. Rural electrification, while not a guaranteed solution to poverty, has a substantial impact on poverty alleviation [28].

Solar energy, especially through Solar Home Systems (SHS), has emerged as a development method providing solutions for various sectors, including households, agriculture, healthcare, education, telecommunication, and infrastructure. It contributes to rural life by creating income-generating opportunities, improving environmental conditions by replacing fuel lamps, and enhancing energy access in remote areas. Solar electrification is considered a viable alternative to grid-electricity supply in rural areas, emphasizing the global connection between energy, sustainable development, and poverty reduction [28].

Studies from different regions, including India and Bangladesh, highlight the positive impacts of solar electrification on education, standard of living, economic activities, and overall well-being. The multifaceted effects include increased access to information, improved health, and expanded income-generating activities. However, challenges such as maintenance issues and the need for user awareness and technical training underscore the importance of effective management of solar energy technologies [28].In conclusion, solar energy, particularly through SHS, plays a crucial role in enhancing the quality of life in rural areas by addressing various socioeconomic development goals. It facilitates improved education, health, access to information, and indoor lighting, contributing to the overall well-being of communities. The connection between solar energy strategies and broader socioeconomic development requires increased attention for comprehensive and effective outcomes [28].

2.16. SHMs and Socioeconomic Development Structure

The table below displays a framework for socioeconomic development and SHS. It is a prime example of the complex impact that SHS has on rural off-grid communities' quality of life. It lists the social and financial advantages that recipients in rural areas can receive from SHS. The framework focuses on specific topics including rural solar electrification-based micro enterprise connections with diverse sectors, health, education, and the environment. Its foundation is a combination of models and conclusions from pertinent literature [33].

2.17. SHS facilitates health benefits.

In off-grid communities, public health stands as a vital sector, and solar energy holds significant potential for enhancing rural well-being. The adoption of Solar Home Systems (SHS) in lieu of kerosene lanterns play a crucial role in diminishing indoor air pollution, a major contributor to the

health challenges faced by rural families. The World Bank identifies indoor air pollution in developing countries as one of the top four global environmental issues. This form of pollution is linked to respiratory infections, responsible for nearly 20% of the annual 11 million child deaths worldwide.
Solar energy actively contributes to improved health by mitigating respiratory infections and conjunctivitis, both commonly induced by indoor pollution. Although quantitative data on the exact reduction in indoor air smoke from kerosene lanterns using solar light is lacking, solar-powered electric water pumps offer clean water access with reduced collection efforts. Moreover, solar energy applications extend to maintaining the viability of vaccines and supporting medical equipment in rural health clinics. In the context of the capability approach to poverty, a healthy life is considered a crucial indicator. For safe childbirth, women in labor require consistent access to clean light. The absence of electricity in rural clinics creates challenging conditions during childbirth, emphasizing the need for pragmatic policies that advocate environmentally friendly technologies like SHS to effectively operate remote rural health centers.

2.18. SHS catalysis information communication technology.

For the information and communication demands of off-grid rural and peri-urban areas, solar energy offers an alternative power source. By using SHS to power radios, televisions, or computers, rural households can obtain information on health, education, business, agriculture, and the environment (Greenstar, 2004; Amankwah, 2005). In Bangladesh, SHS is being utilized to power the equipment needed to provide information and communication technology (ICT) services to rural and peri-urban communities through internet-connected community centers and rural business centers. SHS offers internet-based and wireless services at remote Union Digital Centers. It has reinforced local institutions, produced additional money that progressively lowers rural poverty, and produced new jobs and skills.

2.19. SHS promotes agriculture and rural enterprises.

Agriculture plays a pivotal role in ensuring food security and fostering economic development. Securing reliable water access is essential for sustaining agricultural production, and solar photovoltaic (PV) water pumping emerges as a solution, particularly for dry land irrigation. By addressing energy challenges related to agriculture and off-farm activities—enabling irrigation, food processing, and preservation, as well as various manual productions during evening hours—there is potential to enhance income generation in rural households and enterprises. Power outages and low voltage negatively impact electricity-powered pumps for irrigation, leading to reduced crop production. Additionally, diesel-powered pumps face challenges due to escalating petroleum prices amid energy crises. Investigating alternative energy sources, such as Solar Irrigation Systems (SIS), is crucial for ensuring both food and energy security. SIS is considered an innovative, cost-effective, and environmentally friendly solution, allowing farmers to cultivate paddy multiple times a year and contributing significantly to greenhouse gas emission reduction [29].

Solar Home Systems (SHS) play a role in supporting micro-enterprises by extending their operational hours after sunset. This is particularly beneficial in rural areas, where solar power can be used to operate rice mills and enable small stores to expand their inventory using solar-powered refrigerators [30]. Solar PV-powered devices like icemakers offer opportunities for village micro-enterprises, including fishing, ice cube sales, and cold drinks. This, in turn, leads to the development of businesses involved in manufacturing, wholesale distribution, retail sales, and services such as system design, installation, and consulting. The introduction of SHS in rural areas creates avenues for villagers to establish small businesses like mobile phone charging shops, computer training centers, and TV and mobile retail outlets.

2.20. Empowering Women and Marginalized Groups through Solar Home Systems (SHS)

Programs utilizing solar photovoltaic technology in isolated, rural, and off-grid communities have had a big impact especially on women and children. There will be more time for economic activities, recreation, and education for women and children. After dusk, women can sew or raise chickens for extra cash, all while enjoying hassle-free lighting. Solar accessory sales, maintenance, and repair employ many women. It gave women in their community’s respectable jobs (Khalid Md. Bahauddin et al, 2010: 104). Women in rural areas spend two to six hours a day gathering firewood since there is no power [31]. One can argue that solar energy is a public good. Solar energy can help the impoverished in lonely and distant places to benefit from contemporary technology. With the internet, a solar-powered computer, and a mobile phone, people may easily access government decisions. Their ability to engage and express their views on a wide range of public matters guarantees that the impoverished and marginalized are included in a nation's plans for economic expansion and advancement. Good governance is ensured by these actions [31].

2.21. Theoretical Framework

To demonstrate correlation between the various aspects of socioeconomic development, a few variables are chosen and identified for the economic, social, technological, and environmental dimensions of sustainable development. A conceptual framework, as shown in figure 3, is required to give a common framework that offers a fundamental knowledge of the relationship between many components of solar electricity and socioeconomic growth.

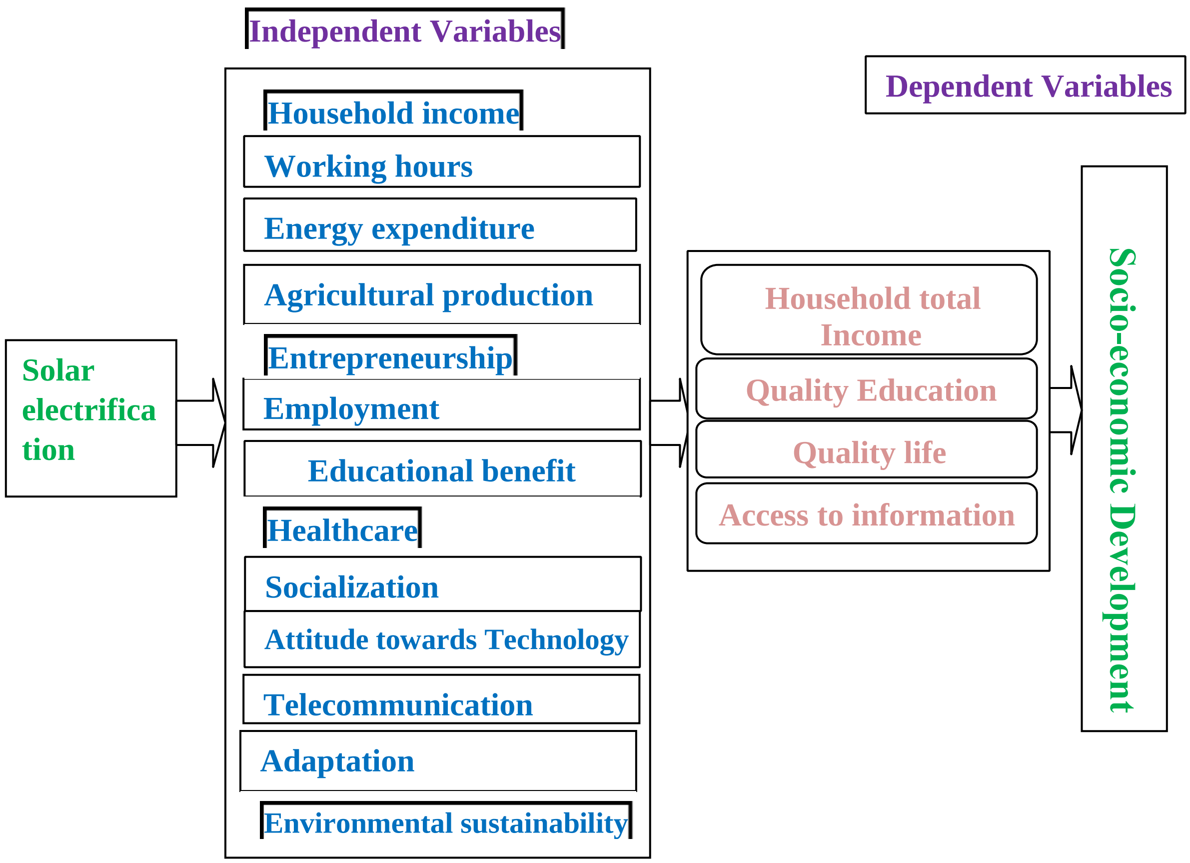

Figure2. 3:Conceptual analytical framework

2.22. The contribution of SHS toward the improvement of Energy access levels in other countries.

The adoption of solar home systems (SHS) has seen a significant rise in Sub-Saharan Africa (SSA). Pico-solar product sales, including single-light lanterns and small SHSs of 10 W or less, surged from under 500,000 in 2011 to 11.3 million in 2015 in SSA. This region contributes to 70% of the global sales of SHSs, with Kenya, Ethiopia, Uganda, and Nigeria ranking as top markets for off-grid solar systems [32].

For the approximately 770 million people worldwide lacking electricity, stand-alone SHSs emerge as a pertinent electrification solution. Projections for achieving universal access to electricity by 2030 estimate that SHSs will constitute 25% to 60% of all new connections. Local solar distribution and installation companies, referred to as solar firms, are crucial players in delivering SHSs, especially in rural and challenging-to-access areas. Since the early 1990s, solar firms have been recognized as vital catalysts for large-scale SHS deployment, promoting cost-effective and rapid electricity access, creating job opportunities, fostering income generation, and enhancing the sustainability of electrification, economic development, and innovative practices in communities and industries[33].

2.23. The contribution of SHS toward the improvement of Energy access levels in Bangladesh

Bangladesh's human development index places it 139th out of 188 countries, despite notable socioeconomic progress in recent years. It was always believed to be extremely costly and impossible to expand Bangladesh's national electrical system to the country's rural areas, where over 60% of the population lives. Consequently, in 2010 42.49% of Bangladesh's rural areas lacked access to power. Six years later, mainly because of increasing efforts to promote SHSs, the rural Bangladesh connection rate had nearly doubled, reaching 69%. A public-private partnership SHS financing initiative was formed by Bangladeshi authorities in 2003, and it is run by the government organization IDCOL [33].

2.24. The contribution of SHS toward the improvement of Energy access levels in Kenya

In the 1980s, the solar business was primarily dependent on projects sponsored by donors; however, in the present, the private sector is driving this growing market. Kenya plans to sell a million solar-powered household systems (SHSs) a year. More people are realizing that improving rural socioeconomic situations requires electrification as a necessity. In Kenya, Arne Jacobson assesses the social effects of rural electrification by solar energy. Only about 4% of rural Kenyan households had connection to the electrical grid in the early 1980s. With both the governmental and corporate sectors aggressively working to achieve universal energy access through the promotion and growth of SHS consumption, solar electricity has emerged as a potential option for rural electrification[33].

Over the past 20 years, Kenya has experienced a significant increase in rural electrification, with rates rising from 6.7% in 2000 to 57.6% in 2017. 35% of rural families now have access to power thanks to off-grid technologies including solar lamps, mini-grids, and SHSs. SHSs provide many off-grid homes and businesses in peri-urban and rural areas with an affordable way to afford flexible power access. On the other hand, continuous research and cost-cutting have made PV technology more widely available. PV panels were temporarily free from VAT in the local area, and the cost of solar PV electricity has dramatically lowered[33].

Chapter Three: DATA COLLECTION AND METHODOLOGY

3.1. Research methods

In this dissertation, quantitative research methods were used, with which I collected data from households having SHS. The study population was made of households using SHS in rural areas of Rwanda. A sample size of 102 households were selected from four different districts, one district per province.

To get information about all installed solar home systems countrywide is not possible, that is the reason I took one sample district in each province. The methods of questionnaires, interviews, and field visits were used to collect data from the existing SHS.

3.2. Sample of population

During sampling, I chose one district per province and a small population for research, totaling 102 households.

3.3. Questionnaires.

Data collection was done using questionnaires and relevant responses. To obtain field data, several inquiries pertaining to the goal of the study were addressed.

3.4. Household survey

Empirical household level data were collected through a household survey conducted in one district per province to reveal quantitative and qualitative information from SHS users. Overall, 102 interviews in rural households were conducted using a designed questionnaire based on selected variables of the study. The dependent and independent variables are selected for the purpose of the study shown by the following table 3.1.

Table 3-1: Variables, Indicators, Operational definition, and level of measurement

1. Dependent Variable			
Type	**Indicators**	**Operational definition**	**Level of measurement**
Socio-economic Development	Aggregate household earnings	Combined income from various sources within a household	Interval

		Enhancement of education quality	Interval & Dichotomous
	Education level Quality of life/Health condition	Enhancement of health	Interval & Dichotomous
	Information accessibility	Access to radio, television, mobile phones, internet, etc.	Interval
2. Independent Variable			
Type	Variable	Operational definitions	Level of measurement
Demographic	Age	Present age of respondent	Interval
	Family members	Number of family members dependent on the respondent.	Interval
	Marital status	Is the respondent in a marital relationship or not?	Nominal
Economic	Household income	Average monthly earnings of a household.	Interval
	Energy expenditure	Total spending for lighting and additional purposes.	Interval
	Agricultural/Business production	Production increased in agriculture/business activities	Interval
	Entrepreneurship	Opportunity creation for business in rural area	Interval
	Employment	Fresh prospect for business/production.	Dichotomous
	Working hours	Extended operating hours for manufacturing/commerce.	Interval
Social	Educational benefit	Increased study duration and availability of educational program	Interval
	Healthcare	The household setting experiences a decline in the occurrence of diseases and establishes improved access to health-related amenities, fostering health benefits.	Interval

	Socialization	Solar Home Systems (SHS) reduce domestic chores, create more free time, enhance recreational opportunities, and facilitate communication, contributing to an improved quality of life.	Dichotomous & Interval
Technological	Attitude towards technology	The respondent's inclination toward or against utilizing solar devices to enhance the quality of life.	Interval
	Telecommunication	Interaction through mobile phones and the internet	Interval
	Adjustment	Respondent's contentment with SHS	Dichotomous
Environmental	Environment sustainability	Cost-effective, easily attainable, and dependable energy that diminishes harm to the environment through minimal carbon emissions.	Dichotomous

The primary data collection tool employed is the questionnaire (refer to Annexure-1), which incorporates a combination of closed and open-ended questions to gather both quantitative and qualitative data on Solar Home System (SHS) utilization in households pre- and post-implementation.

The questionnaire is structured to cover the following areas:

Demographic Information: This section aims to capture data on the age, gender, marital status, education level, and educational status of the household head and spouse.

Socioeconomic Information: Designed to collect data on the economic situation, lighting energy sources and expenditures, household productive activities, entrepreneurship, employment, working hours, attitudes towards and adaptation of SHS technology, and environmental and social aspects of SHS approaches. The questionnaire prompts respondents to provide relevant information for the current situation and the period preceding SHS usage. Data collection is conducted in randomly selected districts representing each province (excluding Kigali City), namely Kamonyi, Rwamagana, Nyamasheke, and Gakenke in the Southern, Eastern, Western, and Northern Provinces, respectively.

A total of 102 SHS-owned households have been surveyed in various villages, selected randomly due to the prevalence of SHS-owned households in each village. Secondary data sources, including journals, reports, working papers, and documents on solar energy in Rwanda, are utilized. Additionally, personal experiences and informal interviews contribute to gathering supplementary information. The author is responsible for overseeing data collection, with interviews lasting approximately 45 minutes due to the comprehensive questionnaire. To ensure understanding among rural participants who may not speak English, the questions are translated into Kinyarwanda. After the data collection phase, the collected questionnaires are entered into the Statistical Package for Social Sciences 15 (SPSS 15) for statistical analysis. Regarding income-related analysis, households are divided into three income groups: low-income (below 200,000 Rwf/month), middle-income (200,000 Rwf - 500,000 Rwf/month), and high-income (above 500,000 Rwf/month), approximately representing equal thirds of the total number of households.

3.5. Data Analysis Methodology

The methodology for data analysis used is Descriptive statistical analysis with which I was able to visualize the collected data in tables, graphs, and charts to make analysis and interpretation easier. Using Excel sheet, I was able to draw the different graphs representing the collected data.

Chapter Four: DATA ANALYSIS, RESULTS AND DISCUSSIONS

4.1. Introduction

Development relies on energy, and as global concerns grow over escalating fuel costs and carbon emissions, there's a notable worldwide shift towards renewable energy alternatives such as solar and wind power. Solar energy emerges as a pivotal contributor to furnishing a reliable and sustainable energy source for a nation's development. This study aims to evaluate the impact of solar home systems on both socioeconomic progress and electricity accessibility in Rwanda. To substantiate this goal, a meticulously designed questionnaire was administered to 102 households chosen randomly across four districts. The ensuing sections delve into an analysis of the survey findings. Notably, the Energy Development Corporation envisions solar home systems as the means to electrify 1.7 million Rwandans.

4.2. An overview of sample districts

As stated in the methodology, the survey is conducted in four districts, one in each province.The selected districts are Rwamagana, Gakenke, Kamonyi and Nyamasheke in Eastern, Northern, southern and western Province respectively. The questionnaire was given to the SHS owners and the numbers of respondents are 42, 20,20 and 20 in Ramayana, Gakenke, Kamonyi and Nyamasheke respectively.

4.3. Household characteristics

As shown in figure4: 1, a total of 102 respondents were interviewed for primary data collection in the survey, with 78% of respondents being male and 22% being female.

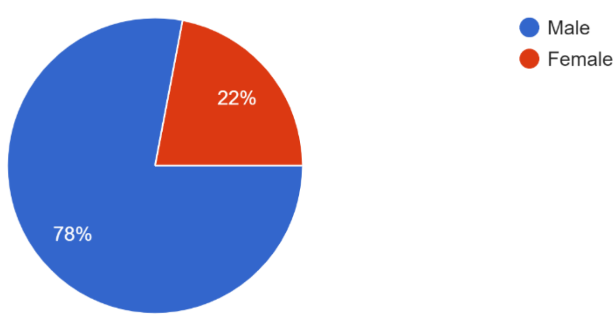

Figure4. 1:Gender of respondents

The respondents' ages range from 18 to 65. Figure4:2 depicts the percentage distribution of respondents' ages. It appears that respondents aged 30-40 (49.5%) participate more than respondents of other ages.

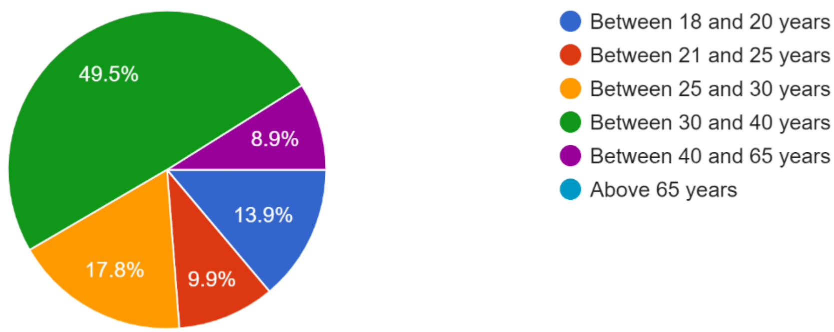

Figure4. 2:Respondent's age group

The level of education among the household is illustrated in figure 7 below, it was observed that a where a big number above 65% of the respondents have completed the high school education. Only a group of less than 8.9% completed primary school. This an indicator that the awareness of SHS can be achieved easily.

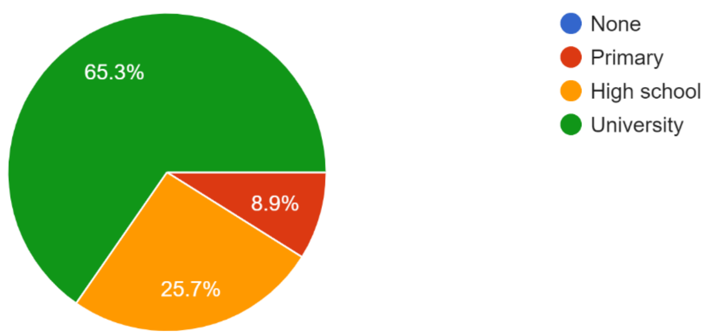

Figure4. 3: Level of education of respondents

4.4. Social Economic Impacts

4.4.1. Household occupation

Private and public servant are the main household that own SHS. From Fig. 8, it can be seen about 90 % of household occupation are employed or self-employed and only 10% are unemployed. This is an indicator that they are able to buy SHS and pay running charges.

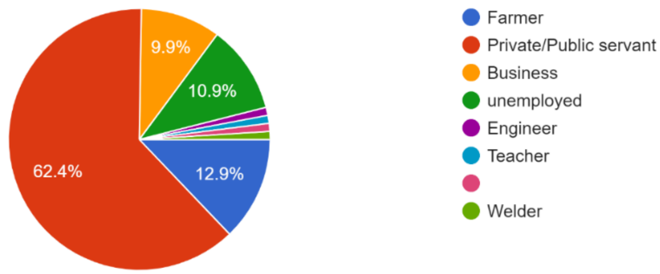

Figure4. 4: Household occupation

4.4.2. Family earnings and financial situation

More than 68% of surveyed household earns above 100,000 rwf per month as illustrated in the graph 4 below. A big number of households earns between 200,000 rwf and 500,000 rwf per month. Less than 20% of households earns between 20,000 and 50,000 rwf. This is an indicator that the households can buy SHS.

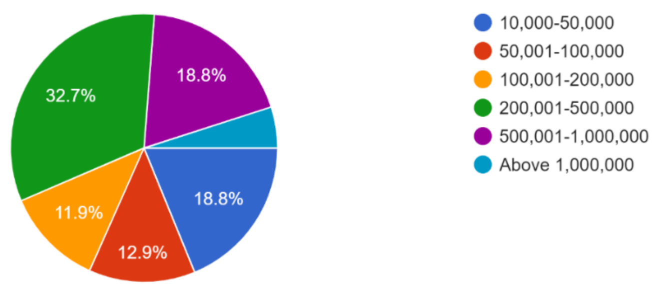

Figure4. 5: Households Income

A big number of respondents revealed that their living condition was marked by a positive change, this was confirmed by more than 90% of all respondents. Only 8% of households said that their life stayed the same after having SHS. This is an indicator that the SHS have positive economic impact on the owners.

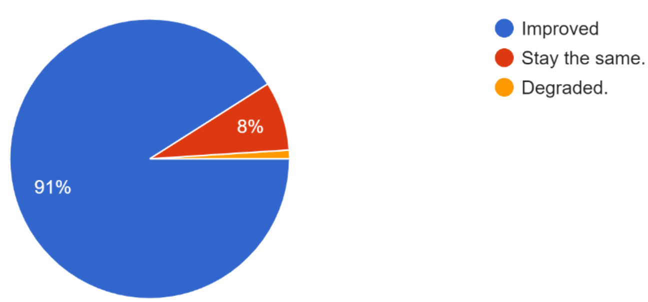

Figure4. 6: Household economic condition after installation SHS

4.4.3. Family illumination origins and costs

Before the introduction of SHS, candles were the predominant method of illuminating households. Preceding the implementation of SHS in the districts under examination, kerosene ranked as the second most utilized lighting source following candles. Figure 4.7 illustrates the outcomes related to the energy sources employed for lighting and the associated expenses before the installation of SHS.

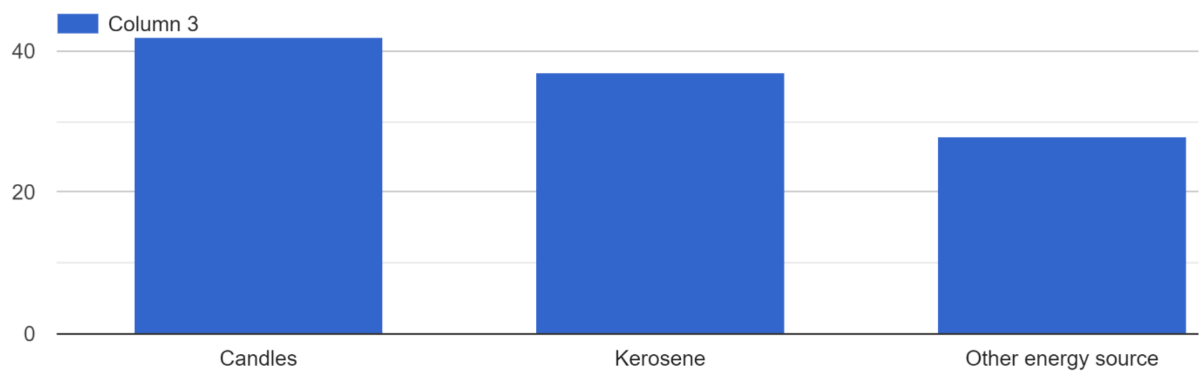

Figure4. 7: Household lighting sources

The surveyed SHS owners revealed the expenditure on lighting before having SHS for more than 60%. is above 5,000rwf per month where more than 16% of them spent more than 10,0000rwf. This is an indicator that the households can pay the running costs ranging between 5,000Rwf to 10,000Rwf

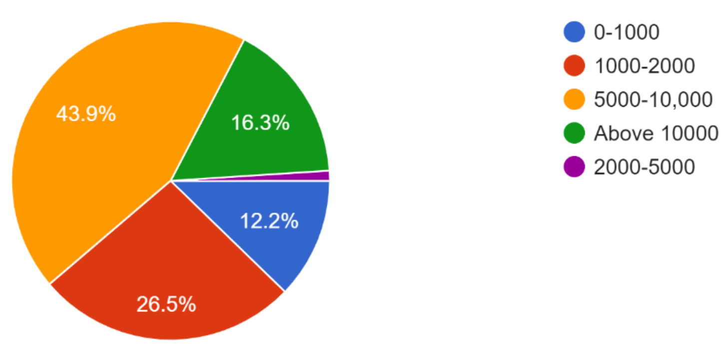

Figure 4.8: Monthly expenditure towards lighting

A big number of SHS owners upto 46% got it by installment payment, the second big group 29% of SHS owners paid the whole amount per month. Only 25% of SHS owners got it by subside. It is an indicator that 75% of households can pay the SHS either in installments or by paying the hole amount.

Table 4-1: Purchasing mode of SHS

Payment method	Percentage
Payment by installment	46

Subside	25
Pay the whole amount of money	29

The survey showed that the cost of SHS for those who paid the whole amount is between 230,000 and 400,000rwf, this illustrated in the graph below. The maximum cost of SHS shown by respondents is 700,000rwf. It means that SHS are having different prices ranging from 230,000rwf and 700,000Rwf.

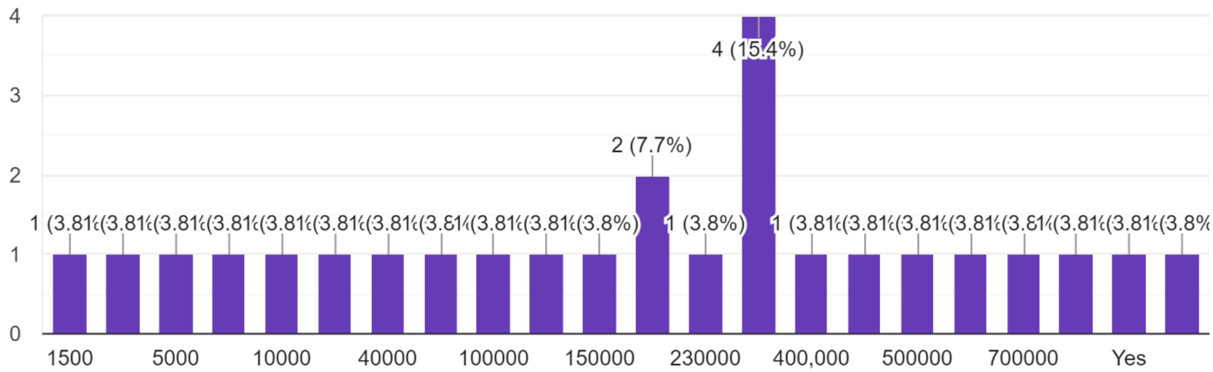

Figure4. 9: cost to pay the whole amount for SHS

4.4.4. Social economic development

The SHS is used to supply electrical power for a variety of devices, including chargers for phones, TVs, radios, and lamps. About 43% of homes use solar electricity to listen to radio, while about 45% of homes use it to watch TV. The study also shows that 44% of families charge their cell phones with solar electricity. Due to the high electricity usage, there is virtually little use of SHS for air conditioning and refrigerators.

According to the survey results, over 90% of respondents agreed that watching TV, listening to the radio, and owning a cell phone can contribute to socio-economic development. This is because these technologies can help people stay informed, connected, and productive. For example, TV and radio broadcasts can provide valuable information about government policies, weather, and market trends, while cell phones can facilitate communication and commerce. By leveraging these technologies, individuals and communities can enhance their knowledge, skills, and opportunities, which can lead to greater prosperity and well-being.

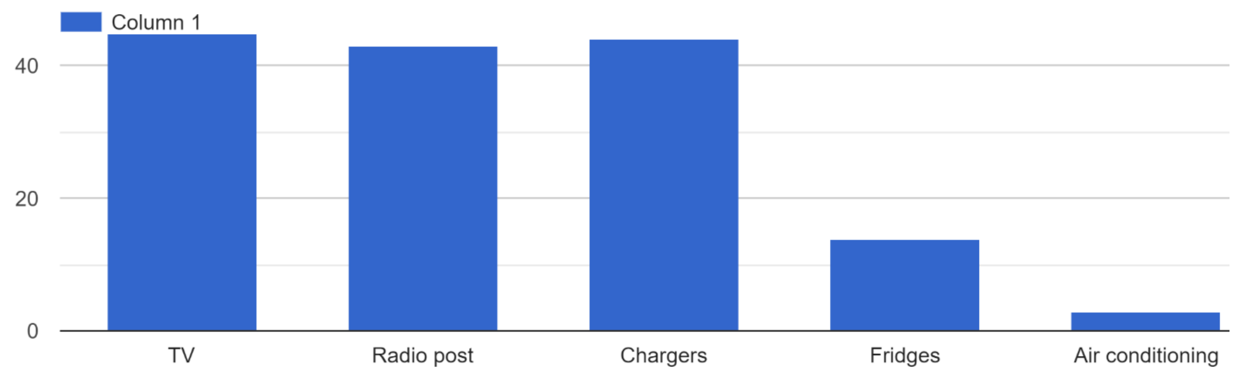

Figure4. 10: Electricity consuming devices

The survey results show that with SHS, the owners created the Productive activities that can help them to gain money where 64 % of house confirmed that it encouraged them to create business. The most dominant business opportunity with SHS is charging the telephone, the second and the third business opportunities for SHS are Hair shaving Saloon and video or cinema shows respectively. Creating new businesses can have a positive impact on the economic development of SHS owners. By generating their own income, people can become more self-sufficient and improve their quality of life. Additionally, new businesses can create jobs and stimulate economic growth in the local community. Therefore, supporting the creation of new businesses from SHS can be an effective way to promote economic development and improve the lives of SHS owners.

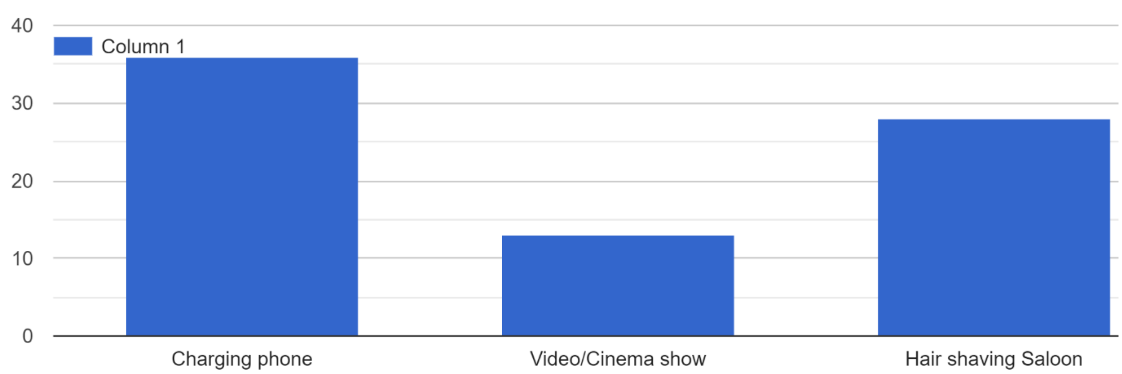

Figure4. 1: Business opportunities

4.4.5. Education

The survey revealed that all men, women and children will benefit from the use of SHS, however a big number of respondents said that the children benefit more by increasing the time of reading. More than 98% of households concur that SHS supports and prolongs reading time. Reading under kerosene light strains the eyes; however, solar electricity enhances living conditions in distant rural areas, promoting quality education. As per the survey, carbon-free illumination encourages rural children to dedicate more time to reading and studying. Children in households with SHS experience better lighting conditions and have additional time for reading and studying, integrating underprivileged children in areas without electricity into the mainstream of development and presenting challenges to achieving sustainable development.

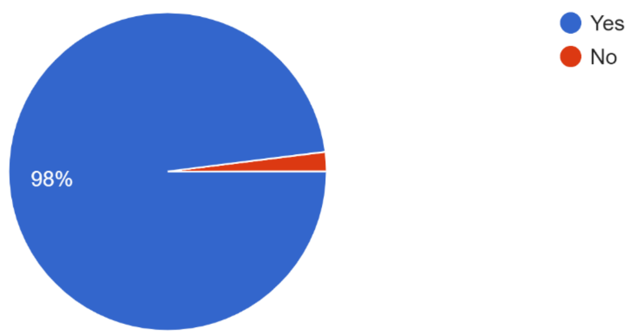

Figure4. 128: Time of reading extended

Reading is a powerful tool that can help reduce ignorance and illiteracy in society. When children read more, they are exposed to new ideas, concepts, and perspectives that they may not have encountered otherwise. This can help broaden their horizons and increase their knowledge base, which in turn can help them make more informed decisions and become more engaged citizens. Moreover, engaging in reading can contribute to the enhancement of literacy skills, which play a crucial role in success across various aspects of life, including education, employment, and personal development. The process of learning to read can strengthen and adjust fundamental abilities, such as verbal and visual memory, phonological awareness, and visuospatial and visuomotor skills. Hence, promoting increased reading among children can yield positive effects on their cognitive development and overall well-being.

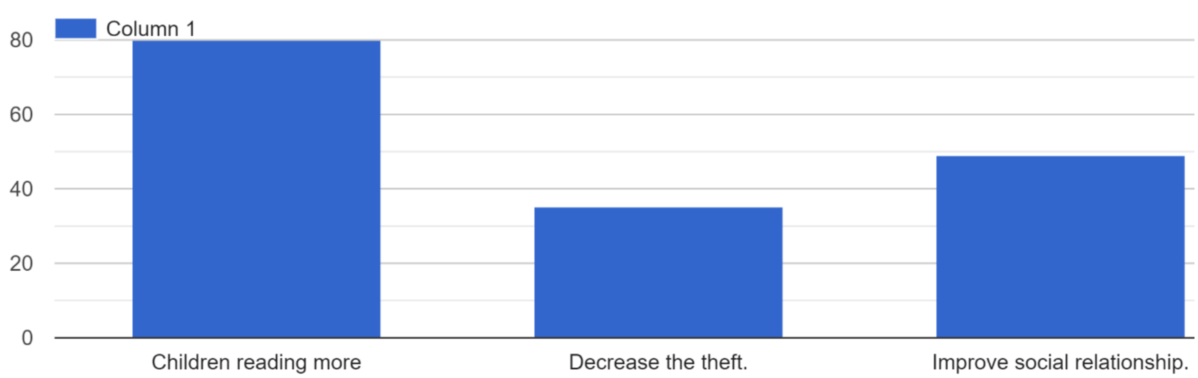

Figure4. 13: Changes observed after having SHS

4.4.6. Entertainment and social interaction

More than 99% of respondents confirmed that installing SHS creates entertainment facilities in households. Having electricity from SHS the households can Watch movies or TV shows, Listen to music or podcasts, Play video games, Read books or magazines, Engage in recreational activities.

Above 91% of SHS owners responded that after having SHS the neighboring families without electricity visited your home regularly being attracted by different activities worked under the presence of SHS such as watching TV, listening to radio, reading and studying under light, households works under light, charging cell phone, income generating activities under light, and others.

Watching TV is the most activity attracting the neighboring families to visit SHS owners while the second most attracting activity is charging cell phone. Receiving different families at home can increase social interaction and foster the friendship.

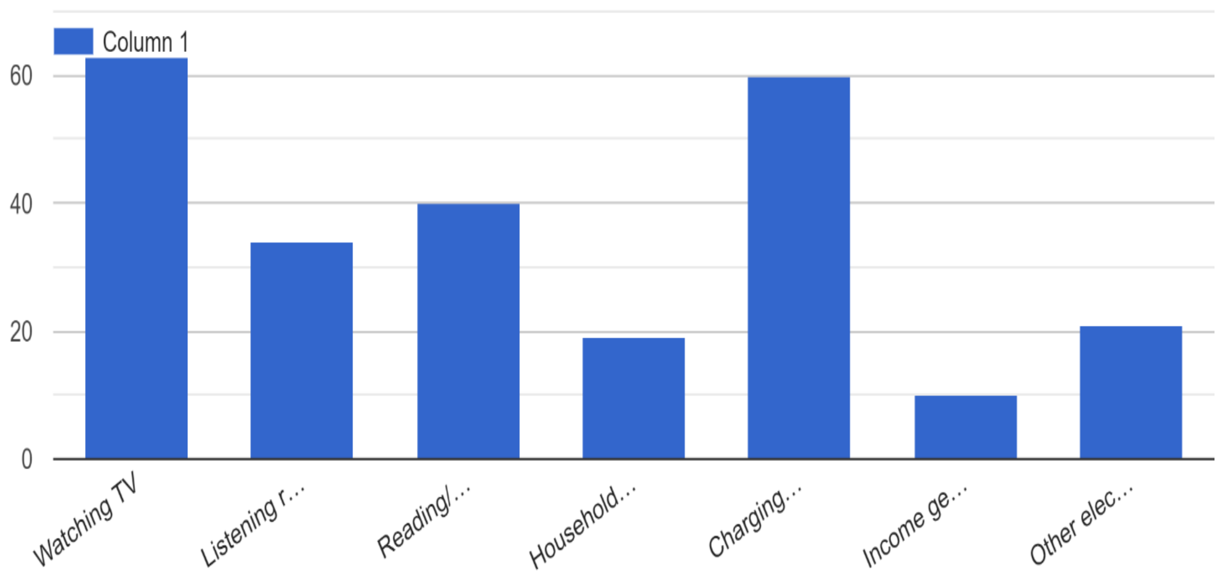

Figure4. 94: Activities attracting the neighboring families

Widespread television watching, the capacity to charge mobile phones, audio-visual communication, and other conveniences within SHS-equipped households enable economically disadvantaged families to embrace modern technology. In certain instances, less affluent households in the neighborhood share a single tube light from nearby SHS-equipped homes to illuminate their residences. Additionally, children from neighboring economically challenged households utilize the clear light provided by SHS-equipped homes for reading and studying. Visits from non-SHS households to neighboring residences with SHS contribute to raising awareness and disseminating knowledge and information through television and radio programs, as well as providing access to mobile phones and laptops.

4.4.7. Social and environmental impact

The acquisition of SHS has led to a notable positive change, particularly in the context of improved nighttime security, with the respondent reporting a reduction in theft incidents. Moreover, a significant majority of over 98% of respondents highlighted the positive impact of SHS on the household environment. This positive effect is attributed to a decrease in disease incidence, which was previously linked to the emission of greenhouse gases from traditional energy sources.

The global community, including organizations such as the United Nations, actively participates in initiatives focused on environmental protection and the mitigation of global warming to enhance overall human well-being and development. SHS stands out in this regard as it utilizes sunlight to generate electricity, eliminating the reliance on fossil fuels. This transition contributes significantly to the reduction of CO_2 and other greenhouse gas (GHG) emissions, particularly those associated with conventional lighting sources. Consequently, the deployment of SHS emerges as an environmentally beneficial strategy by actively lowering CO_2 levels and mitigating other harmful GHG emissions.

The environmental benefits of SHS extend beyond merely avoiding CO_2 generation; they encompass a broader reduction in overall CO_2 emissions. A precise evaluation of the total CO_2 emission savings from SHS necessitates accounting for emissions linked to kerosene use, alongside those originating from the manufacturing and transportation processes of SHS to rural areas. Unfortunately, the absence of comprehensive data on CO_2 emissions from the manufacturing and distribution of SHS poses a challenge in precisely quantifying these reductions. Consequently, the current calculations exclude emissions related to SHS transportation and manufacturing from the overall assessments concerning kerosene savings and CO_2 emission reductions.

Additionally, SHS owners corroborated a decline in accidents that were previously associated with alternative energy sources like kerosene, candles, and wood. Among these sources, kerosene and candles were nearly equally identified as the primary culprits behind home accidents. This attests to the safety benefits introduced by SHS in the household context. The enhanced safety perception resulting from SHS illumination, not only within households but also in neighboring areas, contributes significantly to the overall rural socioeconomic development in Rwanda. This is particularly impactful for household members, especially women engaged in domestic activities, creating a safer environment and reducing instances of theft. The multifaceted positive effects of SHS underscore its role as a catalyst for transformative change, not only in terms of energy access but also in enhancing safety, environmental sustainability, and overall well-being in rural communities.

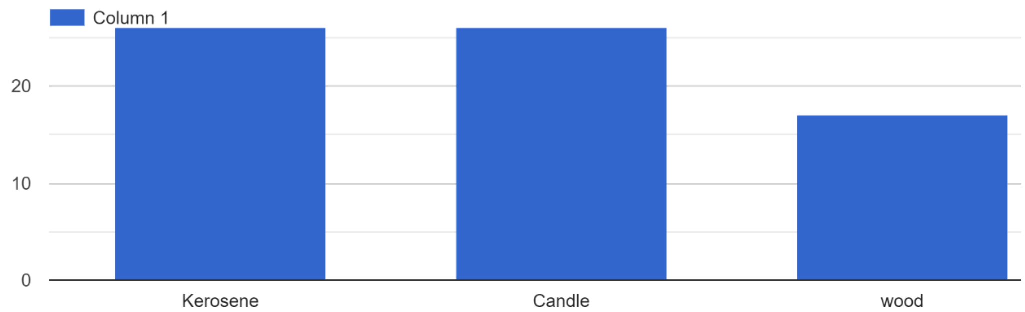

Figure4. 15: Cause of accidents before having SHS

4.5. Technical Performance

According to the survey results, more than 86% of surveyed SHS owners reported that their maintenance costs for Solar Home Systems fall within the range of 1000 to 5000rwf. Only 13.8% of households reported spending more than 5000rwf on maintenance costs. This is a positive indication of the better performance of Solar Home Systems

Table 4-2: Maintenance Cost

Maintenance cost (rwf/month)	Percent
1000-2000	51.7
2000-5000	34.5
Above 5000	13.8

4.6. Barrier and Challenges

The major challenges to accelerating the deployment of SHS are:

High Initial Cost of SHS: The substantial upfront cost of approximately $400 for SHS installations poses a significant barrier, especially for households in remote and impoverished areas. This cost may be comparable to purchasing a car, making it unaffordable for most of the target market. Even the down payment for an SHS loan can be burdensome for many families. Addressing this financial challenge is essential to make SHS accessible to a broader population.

Financial Accessibility: Local financial institutions lack a comprehensive understanding of the off-grid sector, leading to stringent lending conditions and high-interest rates. This financial barrier hampers enterprises in meeting these requirements, resulting in a scarcity of financial support for entrepreneurs and a limited availability of renewable technologies for end-users.

Inadequate Capacity of Local Key Actors: Local off-grid solar companies (OSCs) face capacity gaps in various aspects, including technology, supply chain management, deal negotiation, knowledge acquisition, and networking. Bridging these gaps is crucial for the effective deployment of SHS.

Supply Shortage of Off-Grid Products: Many local OSCs struggle to maintain sufficient stock of solar components when they have customers in need. This shortage is attributed to the financial constraints of local solar companies and the unavailability of reliable solar equipment suppliers in the local market.

Sales and Marketing Challenges: Local OSCs encounter difficulties in sales and marketing, characterized by inadequate training for sales teams, limited market research, positioning issues, and an inability to sustain a competitive advantage. Addressing these challenges is vital for successful market penetration.

Cultural Obstacles: Cultural factors contribute significantly to the slow adoption of SHS in Rwanda. Some households exhibit hesitancy due to a lack of awareness about the benefits of solar energy. Additionally, cultural preferences or a lack of trust in new technologies, as seen with a preference for traditional energy sources like kerosene lamps, pose challenges to widespread acceptance.

Policy and Regulatory Barriers: Existing policies and regulations may not be conducive to the growth of the off-grid solar sector. Streamlining policies and regulations to create an enabling environment for SHS deployment is crucial.

Lack of Local Manufacturing: Dependence on imported solar components contributes to the overall cost of SHS. Encouraging local manufacturing and reducing dependence on imports could enhance affordability.

Addressing these challenges requires a multi-faceted approach involving financial institutions, local enterprises, policymakers, and communities to create an environment conducive to the widespread adoption of SHS and promote sustainable energy solutions.

4.7. Consumer Perspectives

The survey revealed that more than 88% of SHS owners are satisfied by its benefits. Also the SHS owners revealed that it is possible to get it either by installment payment, as subside or by paying total cost.

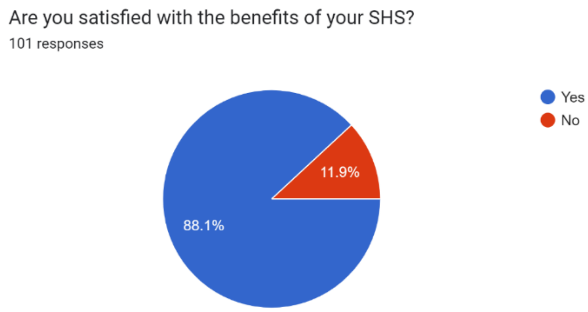

Figure4. 16: Satisfaction towards the benefits of SHS

4.8. Comparison with Grid Electrification

4.8.1. Comparison of Running cost

As of March 2023, the price of electricity is 0.207 U.S. Dollar per kWh for households and 0.077 U.S. Dollar for businesses on grid connected [35].

A household that consumes 30kWh per month will pay $30 * 0.207 = 6.21$USD per month equivalent to $6.21 * 1{,}234.50 = 7666{,}2$Rw.[1]

As per the survey results a big number of households spend above 5,000rwf per month towards other source of lights. The survey results shows that the running cost is less than 5000rwf, so it is obvious that SHS owners can pay the same running costs towards SHS. In addition, there are benefits because the SHS owner will not only get light as for the case of candle and kerosene but also, he will be able plug different devices like TV, radio post, cell phone among others and still he has the same expenses.

4.8.2. Installation cost

Referring to the access project of EPC Ruhango-Nyanza where EDCL signed the contract with Lumino Industries ltd, we can get the installation cost per household. In this access project 16538

[1] As of **November 23, 2023**, 1 US dollar (USD) is equivalent to **1,236.932427 Rwandan francs (RWF)**

households will get access to grid electricity and EDCL must pay in total US$9,455,972.88 and Rwf 1,166,992,708.

Converting from USD to rwf, we get: $US\$9455972.88 = 9455972.88 * 1234.5 = 11{,}673{,}398{,}520 Rwf$
Total contract cost in Rwf is given by: $11{,}673{,}398{,}520 + 1{,}166{,}992{,}708 = 12{,}840{,}391{,}228$Rwf
Installation cost per household is given by: $12{,}840{,}391{,}228/16538 = 776{,}417$Rwf
There are additional costs for internal house installations which are roughly 100,000Rwf.
Therefore, the final installation cost is given by $776{,}417 + 100{,}000 = 876{,}417$Rwf

The survey results revealed that the maximum installation cost for a SHS per household is 700,000Rwf which is less than installation cost for grid connected households. Most of the time people are not aware of the installation costs for grid connection because the infrastructure is established by government and people pays only subscription fees and inside house installation. The project is implemented in 18 months after signing the contract while SHS cannot exceed four months and the households get electrified. The current rate of access to electricity in Rwanda is 70%, considering the target of government of Rwanda of having 100% of access by 2024, the only way that expedite the global access in Rwanda is using solar home system.

Chapter Five: CONCLUSION, RECOMENDATIONS AND FUTURE WORK

5.1. Conclusion

In the contemporary era, a nation's advancement is intricately linked to its energy accessibility, a fundamental driver of industrial, agricultural, and economic progress. The significance of energy access is paramount for a nation to be recognized as developed. The application of solar electricity, particularly in remote and challenging-to-access regions for various domestic, communal, and emergency purposes, has the potential to elevate the standard of living and efficiency, not only in rural but also urban settings. Solar Home Systems (SHS) play a more profound role in fostering social development than mere economic advancement.

The provision of clear household lighting and enhanced air quality yields transformative impacts on education, health, information accessibility, communication, and entertainment, fostering an increased sense of safety within communities. Despite limitations in the utilization of SHS electric appliances, the availability of solar electricity significantly improves lifestyle. Reported enhancements in working conditions, extended household activities into the evening, and positive influences on various aspects like TV watching, productivity, and children's study hours exemplify the far-reaching effects. Additionally, SHS electricity positively influences educational conditions by ensuring clear light and fresh air, enabling extended study hours for children.

Health benefits encompass improved indoor air quality, simplified access to health information, and a notable reduction in accidents related to kerosene use. SHS-equipped households leverage TV, radio, and mobile phones for information, education, and entertainment, with solar electricity emerging as a pivotal factor for telecommunication in remote rural areas, facilitated by the widespread ownership of mobile phones. This multifaceted impact underscores the transformative potential of solar electricity in shaping not only energy landscapes but also the broader social and economic fabric of communities.

5.2. Recommendations

The misconception surrounding solar energy's perceived expensiveness warrants a nuanced understanding. While the initial capital outlay for Solar Home Systems (SHS) installation may appear considerable, it is more judicious to regard it as a strategic investment. This perspective becomes crucial considering the prevailing constraints on widespread electricity access within the country.

Dismissing solar energy in such a context could entail dire consequences for the well-being and economic stability of communities. Recent studies, including those conducted by prominent institutions like the United Nations and the World Bank, underscore the susceptibility of developing nations to the impacts of climate change.

In this context, the embrace of solar energy and other renewable sources emerges as a proactive measure for nations to not only secure their future energy needs but also fortify their resilience against the anticipated effects of climate change. Rwanda, endowed with abundant solar resources, positions itself favorably to harness the potential of Solar Home Systems (SHS) technology as a pragmatic strategy to avert an impending energy crisis. Beyond the immediate benefits of enhanced energy access, the adoption of solar energy holds the promise of contributing significantly to mitigating the reliance on high-cost diesel imports, thereby leading to tangible savings in foreign currency.

The recommendations emanating from the comprehensive field survey conducted underline the pivotal role of SHS in driving sustainable socioeconomic development in Rwanda. These insights underscore the imperative of acknowledging solar energy not merely as a technological innovation but as a transformative force capable of addressing multifaceted challenges, from energy security to economic sustainability, thereby paving the way for a more resilient and sustainable future.

5.2.1. Future work proposal

The research conducted on the "Assessment of Solar Home System Contribution towards Socioeconomic Development and Electricity Access Rate in Rwanda" has provided valuable insights into the impact of solar energy on rural livelihoods. As we move forward, there are several avenues for future work that can enhance the depth and breadth of our understanding. This proposal outlines potential areas for future research and describes the methodology that will be employed.

5.2.2. Future Work Areas

***Longitudinal Study**:* One area of future work involves conducting a longitudinal study to track the long-term impacts of solar home systems on socioeconomic development in Rwanda. This would involve revisiting the surveyed households at regular intervals over several years to assess the sustained effects on income generation, education, health, and overall quality of life. Long-term data collection will provide a comprehensive view of the transformative changes brought about by solar energy.

Comparative Analysis*:* Another avenue for future research is a comparative analysis of different renewable energy sources and their impact on socioeconomic development. This could include comparing the outcomes of solar home systems with other sources such as wind energy or mini-grids. Understanding the relative advantages and challenges of different renewable energy technologies can inform policymakers and stakeholders in choosing the most suitable options for specific contexts.

Policy Impact Assessment*:* Assessing the impact of existing energy policies and interventions on the adoption of solar home systems is crucial. Future research could delve into the effectiveness of government initiatives, subsidies, and support mechanisms in promoting the widespread use of solar energy. Additionally, it would be valuable to explore potential policy recommendations for further promoting solar energy adoption, especially in the context of rural electrification.

Technological Advancements*:* Given the rapid evolution of solar technology, future work can focus on assessing the impact of technological advancements on the efficiency and affordability of solar home systems. This could include studying the adoption rates of newer technologies, such as more efficient photovoltaic panels or advanced energy storage solutions, and their implications for rural households.

5.2.3. Methodology for Future Work

Longitudinal Study Methodology*:* For the longitudinal study, a robust methodology involving periodic visits to the surveyed households will be implemented. Surveys and interviews will be conducted to collect data on income levels, educational attainment, health outcomes, and any changes in electricity access. Statistical analyses will be employed to identify trends and correlations over time.

Comparative Analysis Methodology*:* To conduct a comparative analysis, a new set of households using alternative renewable energy sources will be identified. Similar surveys and interviews will be conducted, and the outcomes will be compared with the existing data on solar home systems. This will involve a mixed-methods approach, combining quantitative data analysis with qualitative insights from the households.

Policy Impact Assessment Methodology: Assessing policy impacts will require an in-depth review of existing energy policies in Rwanda. Interviews with policymakers, stakeholders, and beneficiaries will provide qualitative data on the perceived effectiveness of these policies. Additionally, quantitative analysis of adoption rates pre- and post-policy implementation will be conducted.

***Technological Advancements Methodology**:* To assess technological advancements, a thorough literature review will be conducted to identify emerging solar technologies. Surveys and interviews will be conducted to understand the willingness of households to adopt new technologies and the perceived benefits. Cost-benefit analyses will be employed to evaluate the economic feasibility of upgrading existing solar home systems.

5.2.4. Promoting productive use of SHS.

The results of the household survey indicate that using SHS encourages a few sources of income. These TV series, the hair salon, and the phone that charges. Furthermore, a lack of expertise and appropriate training is the reason these applications have not taken off to spectacular degrees. To enhance the activities that generate money for the home, adequate training and marketing materials are needed. Low-income households should get training from SHS dissemination groups on a range of useful SHS utilization strategies. The utilization of solar-powered appliances in Rwanda's socioeconomic environment also needs more research.

5.2.5. Promoting socio-economic benefits of SHS.

The improvement of rural residents' quality of life is the main purpose of solar energy. Installing SHS increases productivity and decreases workload by enabling household members to work longer hours, children to study for longer periods of time, and to watch television, listen to the radio, use cell phones by recharging their batteries and use household appliances. SHS also lessens the health concerns related to kerosene and enhances indoor air quality. The lack of light makes people in Rwanda's remote villages feel unsafe at night. SHS makes village streetlights possible, enhancing rural residents' nighttime safety.

5.2.6. Promoting positive indirect impacts of SHS

The microfinance system has made SHS readily available, yet some of the village's impoverished families cannot afford to purchase it. In this situation, encouraging sharing of the current SHS burden with nearby non-SHS homes could be implemented. Thus, electricity could help non-SHS poor households without requiring them to purchase SHS. This will lessen social prejudice and help low-income households get electricity. In rural communities, it is customary for SHS households to watch TV and charge their cell phones. This means that you can encourage various home-based enterprises that bring in money, such lending solar lights, charging cell phones, and offering refrigeration services, to name a few.

5.2.7. Promoting innovative application of SHS

SHS is now a global method of achieving long-term development. Solar energy is constantly working to incorporate new applications. More research is needed to use SHS in a wide range of productive activities in an efficient and effective manner.

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Appendices

Questionnaire

The purpose of this survey is to understand The Role of Solar Home Systems (SHS) towards social economic development and speeding up electricity access and make suggestions for effective planning and undertaking programs for its development. Please feel free to opine on this questionnaire if you have a useful insight into the subject matter.

The questionnaire is responded to by the owners of SHS.

Basic data:

Interview date	
District	
Sector	
Cell	
Village	

(A) Demographic information

(i) Basic information about the household.

Name	Sex (tick)	Age (year)	Marital status(Please select one of the following options to indicate your marital status)	How many years of schooling were completed?
	• Male • Female		• Single • Married • Divorced • Widowed	• None • Primary • High school • University

(B) Socio-economic information

i) Household income

	Occupation

01) What is your occupation?	☐ Farmer ☐ Private/Public servant ☐ Business ☐ unemployed ☐ other
02)How much do you earn in a month (rwf)	☐ 10,000-50,000 ☐ 200,001-500,000 ☐ 50,001-100,000 ☐ 500,001-1,000,000 ☐ 100,001-200,000 ☐ Above 1,000,000

03) Has the general living condition in your household improved, does it stay the same or degrade after SHS installation?

☐ Improved

☐ Stay the same.

☐ Degraded.

ii) Source of energy for lighting and expenditures

04) What were the sources of household lighting and its expenditures before SHS installation?

Energy source	Use a tick (√) to select the energy source
Candles	
Kerosene	
Other energy source	

05) What was your expenditures per month on lighting before SHS(in rwf)

☐ 1000-2000

☐ 2000-5000

☐ 5000-10,000

☐ Above 10000

06) How did you purchase the SHS?

☐ Financing/Installment ☐ Pay the whole amount of money

☐ Subside

07) If you pay the whole amount how much money have you paid and?

---------------------------- rwf.

08) How much maintenance/running cost do you need per month in rwf?

- ☐ 1000-2000
- ☐ 2000-5000
- ☐ Above 5000

09) How many years have you been using SHS?

- ☐ 1-5
- ☐ 5-10
- ☐ Above 10 years

iii) Productive activities

10) Did SHS push you to create business?

☐ Yes ☐ No

11) If yes, what kind of business

- ☐ Charging phone
- ☐ Video/Cinema show
- ☐ Hair shaving Saloon
- ☐ Other

C) Technological:

i) Attitude towards technology

12) What are the electricity consuming devices in your household?

- TV
- Radio post
- Chargers
- Fridges
- AC
- Other

Please tick mark the following question (1= Strongly Disagree, 2 = Disagree, 3= Neutral , 4 = Agree, 5 = Strongly agree)

13) Is TV beneficial for socio-economic development?	1	2	3	4	5
14) Is Radio beneficial for socio-economic development?	1	2	3	4	5
15) Is mobile phone beneficial for socio-economic development	1	2	3	4	5

ii) Adaptation

16) Are you satisfied with the benefits of your SHS?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

17) Men, Women, and children who benefit most from the electricity supply of the SHS?

- Men
- Women
- Children

D) Environmental

18) DO you think the installation of SHS improved the environment?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

E) Social

19) Have you observed any positive changes in daily life after installing the SHS in your household?

☐ Yes ☐ No If

yes which of the following changes?

- Children reading more
- Decrease the theft.
- Improve social relationship.

20) Do you agree that SHS makes it easy & extends the time to read in the evening?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

21) Do you agree that SHS improves the household environment by decreasing disease incidence?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

22) Do you agree that installing SHS creates entertainment facilities in households?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

12) Do you agree that installing SHS makes it easy for the family to get news and information?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

23) Do you agree that the installation of SHS helps socialization with relatives/neighbors in the evening?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

24) Do you agree that the installation of SHS increases the perception of safety in the evening?

☐ Yes ☐ No

If yes then what is the level? (1=Minimum, 5=Maximum).

1	2	3	4	5

25) Do your neighboring families without electricity visit your home regularly?

☐ Yes

☐ No

If yes, answer the following question(26)

26) Which of the following activities do the members of neighboring families do in your household?

- ☐ Watching TV
- ☐ Listening radio
- ☐ Reading/ Studying under lights
- ☐ Household works under lights/appliances
- ☐ Charging of mobile phone
- ☐ Income generating work under light

Other electricity-consuming activities ------------------------------------

27) In the past had there been any accidents in your house relating to the use of kerosene or other energy sources?

☐ Yes ☐ No

If yes, which of the following?

☐ Kerosene ☐ Candle ☐ others

Remarks:

Thank you very much for your kind cooperation