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DECLARATION

This research thesis is my original work and has never been presented for a degree or any other academic award in any University or institution of learning.

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APPROVAL

I confirm that the work reported in this research thesis was carried out by the candidate under my supervision and has been submitted with my approval.

Name:	Signature:	Date:
Dr Wilson Bashaija		4th/November/2021

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GOD BLESS YOU ALL

DEDICATION

To my husband, to my three sons, to my parents and siblings, I dedicate this work

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LISTE OF ACRONYMS AND ABBREVIATIONS

%: Percentage

BRD: Banque Rwandaise pur la Developement

CAPEX: Capital Expenditure

CIMERWA: Rwanda Cement Company

CO2: Carbon Dioxide

EARP: Environmental Assessment and Reviews Programs

EDCL: Energy Development Corporation Limited

EDPRS: Economic Development and Poverty Reduction Strategies

EICV5: The 5th Integrated Household Living Condition Survey

En Dev's: Energizing Development

EPD: Energy Private Developer

ESSP: Energy Sector Strategic Plan

EUCL: Energy Utility Corporation Limited

FM: Frequency Modulation

FONERWA: National Fund for Environment and Climate Change

GDP: Gross Domestic Product

GOGLA: Global Association for the Off-Grid Solar Energy industry

GOGLA: Global Off-Grid Lighting Association

HV: High Voltage

ICT: Information, Communication and Technology

IEA: International Energy Agency

IPPs: Independent Power Producers

IRENA: International Renewable Energy Agency

Km2: Square Kilometer

KNES: Kenya National Electrification Strategy

KPLC: Kenya Power and Lighting Company **kV:**

Kilovolt

MININFRA: Ministry of Infrastructure

MW: Megawat**t**

NEP: National Electrification Program

NISR: National Institute of Statistics of Rwanda

NREL: National Renewable Energy Laboratory

NST1: National Strategy for Transformation

O&M: Operation and Maintenance

PAOP : Power Africa Off Grid Project

PAYGO: Pas as You go

PEC: Peat Energy Company

PPAs: Power Purchase Agreements

PV: Photo Voltaic

RDB: Rwanda Development Board

RE: Renewable Energy

REF: Renewable Energy Funding

REG: Rwanda Energy Group

REMA: Rwanda Environment Management Authority

REN: Renewable Energy Network

REP: Rwanda Energy Policy

RURA: Rwanda Utilities Regulatory Authority

RWC: Renewable Energy Consumption

Ruff: Rwandan Fran

SACCO: Saving and Credit Cooperatives

SAS: Stand Alone Solar

SDGs: Sustainable development Goals

SEI: System Engineering and Integrations

SHS: Solar Home Systems

SREP: Scaling Renewable Energy Program

SSA: Sub- Saharan Africa

UN: United Nations

US: United States

USAID: United Ststes Agency For International Development

USD: United States Dollars

Wp: Watt Peak

ABSTRACT

The energy policy in Rwanda is targeting to provide the sustainable, reliable and affordable electricity access to all the population. To achieve this, different sources of energy have been exploited. The private companies were encouraged to enter in the energy sector. Solar and hydro power are the potential renewable source of energy that are exploited by energy private developers. Off grid electricity supply have been promoted for its quality of cost effectiveness compared to the grid extension. The goal of this research is to evaluate the off-grid sub sector in the national agenda of full electrification by 2024. To examine the access of the off-grid electricity connectivity, to investigate the affordability of the off-grid electricity, to assess the reliability of the off-grid electricity and lastly to assess the sustainability of the off-grid electricity all on Program of full electrification in have been our specific objectives. The methodology used is mainly the document qualitative analysis even though the quantitative calculations have been done from the EICV s and REG data that are available online. The results show us that the solar energy dominates the off-grid sector specially the Solar Home Systems that are distributed mainly in rural areas of the country and that it occupies about one a quarter of the electricity access. Subsidies and loans that the government provide are the big support that address the affordability problem and it is the engine to the growth of the off-grid sub sector. SHS are the one that dominate the off-grid electricity market and are much appreciated by the users for they are clean and modern but the reliability on them is questionable for a big percentage of their users use the other source of lightening beside the SHS. All dimensions of rural electrification sustainability show that our country does a great job even though we can't ignore that there is still a journey ahead. The study recommends to put more effort in the solar mini grid in order to make the solar energy accurate in the long run and to continue to strengthen the rural and households' development as a way to increase and sustain the electricity demand.

CHAPTER ONE: INTRDODUCTION

1.1. Background of the study

The world projection is to attain a 100% electrification of its population by 2030. While grid extension is projected to provide 30% of new household electricity access. (GOGLA, 2018) According to the International Energy Agency, decentralized systems are the most cost-effective solutions for the vast rural population far from power grids, accounting for more than 70% of those who gain access (IEA1, 2017). In 2012, 1.1 billion people worldwide lacked access to electricity; by 2014, this figure had risen to 1.06 billion. Approximately three times the size of the United States population (Rasul, 2014) During the period 2012-14, urban areas gained access to electricity faster than rural areas. Over the last decade, In metropolitan areas, an additional 81 million people now have access to electricity. However, despite a 7 million population increase in rural areas , between 2012 and 2014 only 6 million people gained access each year (Purnamita et al, 2017).

Off-grid solutions aren't a new concept. They have done so for decades in remote places. Until 1995, Off-grid solar PV applications were more common than grid-connected systems in regions that were not connected to the national grid (Ruud et al, 2015). Globally, Off-grid renewable energy systems was serving about twenty-six million houses, including twenty million homes served by solar home systems, 0.8 million homes served by tiny wind turbines and five million homes served by minigrids (Enongene et al ,2019). In China, Stand-alone systems have primarily been employed in rural parts of north and northwest, where extending the main grid would be prohibitively expensive or complex. Since the mid-1990s, PV systems have been employed in these locations. According to a recent World Bank report on renewable energy, 2 million individuals in west of
China are connected from PV systems. The vast majority of the country’s PV installations were connected on grid in 2011, while 20 MW were off-grid. China disposed 65.6 GW of small hydro units by 2012 and it had 430.94 MW of stand-alone small wind turbine capacity built by 2010, and this amount was predicted to rise to 997 MW by 2015 and 2,955 MW by 2020 (Lin, 2015)

In East Africa 78% of the total population of 158 million did not have access to electricity in

2018.Burundi has target of attaining 40% of its population by 2030 and Tanzania 90% by 2035 (Ross, 2018).In 2019,GOGLA did study about the economic impact of solar energy and all findings was positive where 89% in the studied sample has reported their health improved since buying the SHS.34% undertook more economic activities,86% said children have more time to do their homework and 28%of the household generate additional income once they purchase an SHS (GOGLA , 2019). Kenya's economy is ranked the fifth largest in Sub-Saharan Africa, and the second largest in East Africa, behind Ethiopia (Robertson, 2019). According to estimates from December 2018, there are 700,000 off-grid connections in Kenya. Kenya National Electrification Strategy (KNES) has established a goal of electrifying 1,105,000 houses in 14 underserved counties by 2022, with a total of two million new connections projected by then. These households are located 15 kilometers from the Kenya Power and Lighting Company (KPLC) services (PAOP, 2019).

Aside with SHS sales, the sector has seen an increase in appliance sales, with a total of 69,361 appliances sold in the second half of 2018. The majority of the appliances that were sold were televisions. Despite its strong SHS sales results, Kenya's solar home system sector is not without its hurdles. High expenses, difficult security circumstances, scant population, poor infrastructure, limited willingness or ability to pay, and occasionally pastoral geographies that remain underserved are among these problems (PAOP, 2019). Rwanda is the African developing, small and locked country located in the East Africa. The number of its population is around 12 million and 72% of its population live in rural area. Rwanda's GDP per capital was $695.69 in 2017 (World Bank, 2018). In 2017, the electricity rate was 40.5% where 11% was off-grid and 29.5% on-grid (RDB, 2017). The Rwandan government has set a goal of reaching 100 percent electrification by 2024, 52 percent through grid connections and 48 percent through off-grid options, in line with global projections (NST1, 2017). The high connection fee (54.7 percent of unconnected households in 2016) and distance from grid infrastructure (36.5 percent of unconnected households in 2016) were the main barriers that prevented households from gaining grid connectivity, according to the Multi-tier Energy Access Tracking Framework survey. (Bryan et al, 2018).

Access to electricity is the act that people and businesses in a given area have the ability to link to electricity provided by a grid or a smaller non grid connected supply. if the electricity is not affordable, the physical connection to the electricity cannot be profitable. The seventh Sustainable Development Goal commits to ensuring that everyone has access to affordable, dependable, sustainable, and modern energy. In Rwanda only 34.74% of the population households were connected to electricity in 2018, in urban was 89.062% and rural it was only 23.4% (World Bank,2018). The most common method for estimating affordability of use is to calculate the percentage of household income spent on energy. The high electricity unit prices and a critical low level of income are the two possible reasons of the electricity unaffordability. The greater affordability of use would be achieved in a direct way, if the electricity burden of households is reduced, or efficiency of use is improved it increase the electricity connections (Vivien et al, 2000).

The reliability of the off grid electricity is more sensitive in order to be seen as an alternative solution of electrification. Studies showed that it is strongly depends on ensure the Operation and Maintenance(O&M) where a well trained and organized community and the financial availability all are needed (Feron et al, 2016). Lastly like all other projects,the off grid electrification projects have to be sustainable to be successful.The role of off grid subsector in the program of full electrification in Rwanda will be meaningful if the service it gives is sustainable.Studies in different countries about the sustainability of rural electrification projects have been done and it is evaluated in 4 dimensions namely institutional,economic,environmental and social sustainability
(Heksi et al, 2018).To assess the current off grid electricity sector role in the country ‘s vision is a valuable work that will help policy makers (author perspective)

1.2. Statement of the Problem

Over one billion people on the world especially in Rural areas don't have access to electricity. The 7th Goal in Sustainable Development Goals commits to ensure access to affordable, reliable, sustainable and modern energy for all. In Rwanda only 34.74% of the population households were connected to electricity in 2018, in urban was 89.062% and rural it was only 23.4% (World Bank,2018).

Rwanda's population is estimated to be around 12 million people, with 2.7million households. In 2019, there was 2.709 households with off grid access, this is 13% of the Rwandan households (REG,2019). It was projected that by 2024, Nearly 1.4 million homes will require off-grid power, based on the existing goal of 48 percent of households that will be connected to the off-grid electricity (EPD,2020).

Given this rate of growth in off grid sector, it is very problematic that in the remaining period, the 48% expected percentage will be attained. Strong commitments like Energy policies, regulations, and strategies toward the targeted number of accesses are in place. This study aims to focus on the assessment of how the off-grid subsector is playing its role: Access on the off-grid electricity connectivity, The affordability of the off-grid electricity, the reliability and the sustainability of the off-grid electricity are very crucial to ensure the program of full electrification in Rwanda.

1.3. **Objectives of the study**

In this research, there are both general and specific objectives:

1.3.1. Main Objectives

The current research is guided by both general and specific objectives:

The general objective of this study is to assess the role of off grid on the program of full electrification in Rwanda. This general objective will be guided by the following specific objectives

1.3.2. The Specific Objective

The specific objectives of this study are:

- To examine the access of the off-grid electricity connectivity on the Program of full electrification in Rwanda
- To assess the sustainability of the off-grid electricity on Program of full electrification in Rwanda
- To investigate the affordability of the off-grid electricity on the Program of full electrification in Rwanda
- To assess the reliability of the off-grid electricity on the Program of full electrification in Rwanda

1.4. Scope of the study

This research has 2 areas indicating the scope and these are geographical and content scope. These are shown in the following arguments:

1.4.1. Content Scope

This study focused on the assessment of the role of the off-grid subsector on the program of attaining the full electrification in Rwanda. To examine the access to the off-grid electricity connectivity on the Program of full electrification in Rwanda to investigate the affordability of the off-grid electricity, to assess the reliability of the off-grid electricity and to assess the sustainability of the off-grid electricity are points that helped us to more understand the role of the off-grid subsector on the Program of full electrification in Rwanda

1.4.2. Geographical Scope

Geographically, this research had been carried in Rwanda so as to analyze the contribution of offgrid in ensuring the full electricity and see the extent to which the full electrification can be the target of Rwanda as referred to the Government policies including Vision 2020, NST1.

1.5. Expected outcomes and significance of the study

This research was done so that it would contain outcomes in relation to the useful inputs

1.5.1. Expected Outcome of the Study

The expected outcome of this study is to show that the off-grid subsector contributes to the government program of attaining full electrification, to present people who are gaining from the off-grid electrification and the quality of the service (electricity) they get. This will help the policy makers to get a picture of where to put more effort and how to reach that community which is still behind while it was supposed to be part of the off-grid solutions.

1.5.2. Significant of the Study

Increased number of new clients of off grid electrification service: This study proposes solutions after sorting out the challenges that are in the sector

Improvement of lives in rural area: Off grid solutions are mainly for rural area far from the grid connection. In that place people live primarily by agriculture. The electricity changes live in rural area for some small businesses are created and then the second source of income

Improvement of people s health and well-being: the cleaned houses, the good and nearer health services, the cleaned lightning the flexibility for students to revise all are the benefits

CHAPTER TWO: LITERATURE REVIEW

2.1. Introduction

The ultimate purpose of this study is to assess the role of off grid subsector in the program of full electrification in Rwanda. This chapter helps to understand the off-grid electrification and how it contributes in the acceleration of electrification targets especially in the rural Areas of the developing countries where it's more costly to extend the grid.

2.2. Rwanda and Its Energy Sector background

2.2.1. Rwanda Introduction

Rwanda is a landlocked African country located in East and Central Africa region below the Equator at 1.94030 South and 29.87390 East and its total surface area is 26.338 km square. Rwandan population is around 12 million and 72% live in rural areas, density is 491.73 people per square kilometer, a 2.58% increase from 2019. The GDP per capita was $695.69 in 2017 (NISR, 2021) and the recent reported GDP is of USD 10.33 billion dollars in 2020 (NISR, 2021). Rwanda's economy is strongly depended on agriculture for it contributes 24.07 % of GDP through the production of coffee and tea (NISR, 2019). In addition to agriculture, other leading sector includes trade, hospitality, and financial services all have contributed to overall economic growth (RDB, 2018).

Rwanda has a subequatorial climate and is located between 1° and 3°south of the equator. The average annual temperature for the entire country is 18° though within the country there are differences in temperature depending on the region where the northern and the west are cooler than the lower lying East (SEI, 2009). Rwanda recognizes the significance of environmental protection. EDPRS1 and EDPRS2 clarify that the natural resource and environmental protection are emergent because the natural disasters that are more frequent in our country which are caused by the growing population's demand on natural resources namely land, water and other nonrenewable resources (UN Rwanda,2010).

Different strategies for environmental protection have been developed such as the National Strategy for climate change and low carbon development and Rwanda's strategy for sustainable development has been developed (REMA, 2017).

2.2.2. Rwandan electricity

2.2.2.1 Electricity Production

The generation reports from Power Africa in Rwanda show the current installed capacity is 218MW that hydropower occupies 98 MW, Thermal 103MW and solar 12 MW of electricity generation in Rwanda. For long, Hydro power has been potential and it is shown by the number of 23 plants that are now operating in different place within the country (REG, 2017a).

2.2.2.2. Transmission

Rwanda's transmission network includes three main voltage level: 70,110, and 220 kV. The power is transmitted from different points generation plants across the country and this help to facilitate regional interconnectivities of about 1278.82 km of High Voltage (HV) transmission lines and currently there are 27 substations in the whole country (REG,2020). Energy Utility Corporation Limited (EUCL) manages and plans the transmission and the distribution of grids in areas where electrification has already occurred, while also promoting energy efficiency and demand side management programThe main challenge they face is a lack of sufficient budget to improve efficien cy by reducing losse on the existing transmission line, and customers' income per capita is low for p aying their electricity bills (REG, 2017a).

2.2.3. Electricity Sources Potential

Rwanda has a lot of domestic energy resources, however most of them are yet undeveloped. Hydropower, methane gas, peat energy, solar energy, and waste energy are some of the energy sources used to generate electricity.

Biogas

In Rwanda, biogas technology was created as a way to overcome the challenges of wood-based thermal needs for cooking and lighting in places without access to the power grid (Marge, 2009). It has been successful in cooking for different prison and boarding schools and even households have adopted this technology yet it is not the case in lightning. Efforts should be made to boost biomass energy generation through research and development and technology. This will be advantageous because biomass is one of Rwanda's most promising sources of energy. (MARGE, 2009).

Peat

Peat appears to be a promising alternative energy source, with Rwanda's dry peat reserves estimated to be worth 155 million megatons. Their energy output capacity is at 700 MW, and extraction might take up to 30 years. Nowadays there are two Power plants one in Gishoma and the other in Gisagara and they are respectively expected to generate 15MW and 80 MW (MININFRA, 2015). Investors in peat mining are still few and is a constraint in the sector for the only one known is the company called PEC which operate in the southwestern Rwanda (Hakizimana et al, 2016)

Hydropower

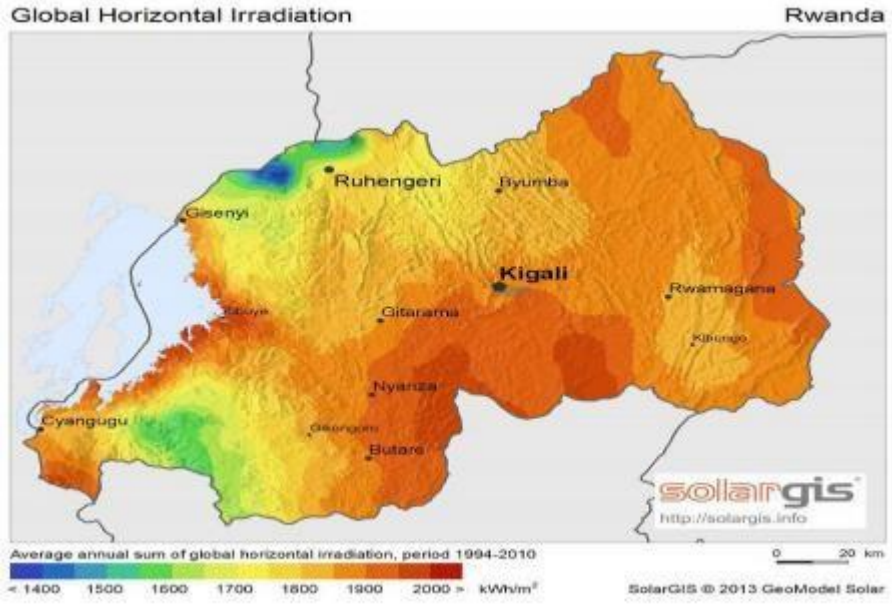
Hydropower has been for long and today is still among the main source of electricity generation in Rwanda.it is known since the 1960s (Bimenyimana, et al., 2018). Nowadays Hydropower contributes above 50% of the overall installed capacity. Some hydropower plants are owned by the government or regional shared, other are owned by the private or leased but still supply its product to the grid, they are 37 as it is published by REG. Other mini and Pico grid operate in isolation and supply to a small community around them (REG,2021)

Solar energy

The solar energy is contributing much to the electricity sector in Rwanda. The 5 solar power plants available supply 12.230 Mw to the national grid (REG,2021). The solar energy has been a good opportunity to the off-grid companies to enter in the Rwandan electricity market. The solar home systems, solar irrigation water pump, solar water heaters, solar lantern all are the products available

in our country that user the modern technology of the solar energy. The global solar radiation in Rwanda ranges between 4.8Kwh m2 day-1minimum and 5.5KWh m2 day-1 maximum given its geographic location (Rutibabara et al, 2018). This impressive opportunity allows the government of Rwanda to accelerate the rural electrification using PV systems at the low cost compared to the grid extension (EDCL, 2018a).

Figure 8. Global horizontal irradiation map of Rwanda



Source: Solargis Rwanda, 2013

Photo 1: Global horizontal irradiation

2.2.4. Off grid sub sector in Rwanda

2.2.4.1. Off grid electricity access in Rwanda

To lower the cost of electricity access, households located distant from the planned national grid's coverage are pushed to employ independent solar photovoltaic technology. The Rwanda Rural Electrification Strategy, approved in June 2016, lays out procedures for ensuring that every household in Rwanda has access to electricity through the most cost-effective means possible, including developing schemes that allow both end users and the private sector to participate in providing these solutions. (MINIFRA,2019).

The off-grid sector is expanding. Rwanda's energy strategy has implemented it in order to strengthen and expand the country's electricity access. Diverse factors such as improved clarity and harmonization of preferential techniques for grid and off-grid energy access activities for various target population groups, Increasing energy access through distributed renewable technologies by developing new approaches and expanding innovative collaborations; increasing flexibility and competition by simplifying licensing and increasing the attractiveness of the off-grid electricity market to private operators; by scaling up creative partnerships, boost rural access to appropriate off-grid alternatives. Increase competition and flexibility in the provision of off-grid services, as well as financial support methods for both provision and consumption. (MININFRA, 2015)

Rwanda has achieved significant progress toward its objectives, increasing its on-grid connectivity from 6% in 2000 to 37% in 2019. (Power Africa, 2019). Despite this promising development, the small beginnings suggest that off-grid solutions have a potential to survive. It accounted for 13% of the population in 2019. These numbers demonstrate that, while other countries' markets may be larger in absolute terms, Rwanda's off-grid alternative has a major impact on the overall energy sector. Rwanda's government has also shown its commitment to off-grid solutions by setting goals for off-grid solutions to serve 48 percent of the country's population by 2024. (MININFRA, 2018).

There are a number of elements that determine the most cost-effective method of connecting populations. The size of the community, population density, distance from the national grid, landscape, and economic activity level are all factors to consider. Mini-grids are more likely to be feasible in densely populated areas or areas with high energy-intensive economic activity, while standalone systems are more cost-effective in sparsely populated areas or poorer area. From the feasibility studies done, Off-Grid Solar is the most cost-effective solution for many households in rural areas located far from the grid (IEA, 2014)

2.2.4.1.1. Mini grids in Rwanda

Mini grids are small distribution systems with a power generation source such as hydro or solar that are not connected to the national power grid. These grid systems are likely to have a part in Rwandan energy provision, but they only account for 0.11 percent of the electricity generating technology mix because to their high investment costs. The cost of a minigrid connection in Rwanda is expected to be roughly $1500 per connection, according to the feasibility study, which is greater than the cost of a grid connection (MININFRA, 2016). As a means of lowering CO2 emissions, Rwanda's government has committed to creating 100 solar PV small grids in diverse rural locations. The mini-grid project's goal is to provide energy during East Africa's frequent power outages. Energy 4 Impact and Mesh Power are two other Rwandan startups working on rural electrification. 77,000 rural inhabitants now have access to electricity, and 7,000 employments have been created as a result of these enterprises (Solar Plaza, 2017). Mini grids are becoming more popular in developing nations, such as Rwanda, as a way to increase energy security, power quality, and dependability, as well as avoid power outages caused by natural catastrophes (Kempener et al, 2015).

Because of Rwanda's high population density, mini-grids are a viable option for the Rwandan market, albeit there are currently only a few in use. Rwanda already has a number of mini-grid developers, and more are expressing interest in entering the electricity business. Regulations drafted in 2017 address a number of common issues about mini-grids, including licensing, tariffs, and the provisional nature of grid arrival.

The National Electrification Program (NEP) was completed in June 2019, and developers are anticipated to continue building now that they know where they can. Because rural areas have low demand and a high up-front cost, 40 to 70% of capital expenditure (CAPEX) must be subsidized for a mini-grid to be economically viable. Grants and incentives for CAPEX and productive use have been the primary sources of funding for mini-grid solutions. In addition, the World Bank's Renewable Energy Funding (REF) program offers mini-grid developers a loan financing option. Initially, Rwanda's mini-grids were tiny hydropower plants that were not developed privately. Minigrids of this type have grown more realistic as the cost of solar energy has reduced, and they will likely play a critical role in Rwanda's future full electrification program. The table below covers Rwanda's private hydro and solar energy mini-grid projects.

Table 1: Private Mini-Grid deployments in Rwanda

Company	Technology	Size	Number of connected Households
Mesh Power	Solar DC	1 kW x 57 systems	2046
Mesh Power	Solar AC/DC Hybrid	4 kW AC/1kW DC	78
NESELTEC	Solar AC	30kW	183
RENERG	Solar AC	30kW	121
Absolute Energy	Solar AC	50kW	505
ECOS	Hydro	11kW	303

Source: EnDev, 2017

As the table above shows, Mesh Power company was the first Mini grid that was serving a big number of households in 2017 for it served more than 2000 households. NESELTEC, RENERG and Absolute Energy was the other solar energy companies with the size of 30kW, 30kW and 50kW respectively. As we can see, Absolute Energy was the one which served a big number,505 households, with a solar Alternative Current technology. other companies with the same technology serve only around 100 households. ECOS was the only hydro mini grid with the size of 11kW and 303 customers

2.2.4.2. Affordability of Off-grid in full electrification

2.2.4.2.1. The cost of the off-grid electricity

Solar PV system costs have dropped drastically around the world over time. This is also true in Sub Sahara Africa, but because to political instability and financial constraints and technological risks, SSA's costs are substantially higher than the global average. For the vast majority of the rural poor in Sub Sahara Africa, solar PV power installations remain an exceedingly expensive source of electricity (Shahsavari et al,2018). At US$0.83 per kW h, the levelized cost of electricity for solar PV installations is high. SHS will take between 8.7 and 16.9 years to become competitive with conventional diesel generators, assuming a 4% annual rate of decrease in PV system costs and a 7.67% annual rate of decrease in PV system prices (Mahamat ,2018).

When it comes to the cost of decreasing greenhouse gas emissions by solar PV electrification, the range is considerably wide when compared to the present price of market CO2 emission permits or current estimates of the social cost of carbon of around $1,500 per ton of CO2. (Feng et al,2013).

Unless sponsored from overseas, off-grid solar PV systems are not feasible for rural households in SSA. Rather than putting solar PV systems on individual homes, a country's strategy should support rural electrification by expanding grids. (Baurzhan et al, 2016). About Minigrids, high payment default rates, regulatory difficulties, excessively optimistic demand predictions and low electricity demand in remote areas are the challenges that drive up the cost of Mini grid electricity (Peters,2019)

2.2.4.2.2. The tariff of off grid electricity

Like in other Sub Sahara Africa countries like Kenya and Ethiopia, the Rwandan Private mini-grids have higher tariffs compared to the on-grid electricity because they include a cost recovery tariff and the demand is low in rural areas (Mugisha et al, 2021). There is a lack of efficient tariff maintenance because generation capacity and demand are not coordinated. The tariff will rise if demand does not keep pace with growing generation capacity. Generation costs and losses should be regulated, as well as resource diversification and raising the amount of clean power generation in the entire generation mix, to address this issue. (Uwisengeyimana et al,2017).

2.2.4.2.3. The household level of income

Among the factors influencing the adoption of the SHS in rural area, the level of income has been mentioned as the biggest. To the household that have the solar home systems on loan, they have the amount that they must pay monthly and many households in the rural area of the developing countries don’t have the reliable source of income (Rebane ,2011). Some studies proposed that because of that problem of the reliable source of income, smaller cash-only systems can be a good option to credit-based systems because they are more affordable. (Nieuwenhout et al, 2001). Solar home systems supplied on a pay-as-you-go (PAYGO) basis have dominated the off-grid market to date, which is comparable to the situation in other East African markets. The ability to pay in Rwanda, however, remains poor, according to the results of the 5th integrated household living condition survey (EICV5).

According to the report, 70% of off-grid families spent less than $1.67 per month on lighting and phone charging (Power Africa, 2019). Given the significant gap between most household expenses and the cheapest PAYGO solar home systems product, which cost RWF 3,500 per month ($3.87 per month) in 2019 (Power Africa, 2019), any Off-Grid company attempting to sell their product to the Rwandans would likely consider affordability as a key issue. The Rwandan government has identified this affordability restriction and works with development partners to offer subsidies.

2.2.4.2.4. Off grid electricity market

In Rwanda, an off-grid solution has electrified 14% of the population. Since 2014, more than 800,000 solar kits have been sold in Rwanda, according to the worldwide off-grid lighting organization (GOGLA) (Power Africa, 2019). Some of these solar kits contribute to the definition of electrification, while others do not. Because of the critical issue of ability to pay, the vast majority of solar kits sold in Rwanda to far are modest, with 97 percent of solar home systems and solar lanterns sold being 10Watt peak (Wp) on lower scales (Simon Collings, 2019). Given the stated aim of 48 percent off-grid access (REG, 2020), the entire market size for off-grid in Rwanda is estimated to be around 1.4 million households by 2024. (USAID, 2019). From 2017 to now, four corporations control 89 percent of the market (Power Africa, 2019). Sales volume climbed rapidly until mid-2017, when it took a little dip before leveling off (constant). Regulatory and uncertainty were listed as some of the key reasons for the fluctuation, as were the government's free distribution of solar household systems and affordability, as the easiest means to reach customers had already been served.

According to the Energizing Development EnDev’s Off-Grid sector status report, there are several handfuls of major players in the Solar home system sector. The table below show the market share for each major player for Solar Home Systems (SHS)

Table 2: Solar Home Systems Market share by Company

Company	Market share
Ignite	37%
BBOXX	32%
One Acre Fund	12%
Mobisol	8%
Others	11%

Source: Power Africa, 2019

As the table above indicates, ignite company was the one that have the big market share of the SHS for it occupied 37% of the market, followed by BBOXX which had 32%, the third was One Acre Fund with 12% and Mobisol had 8%. Those 4 companies were the main for they occupied 89% of the whole market and the rest occupies only 11%

2.2.4.2.5. Rwanda off grid rural electrification strategy

In Rwanda, the rural off grid electrification strategy comprises of 4 programs regarding Ubudehe program as Poverty category strategy reduction in which the government intervenes through electricity access facilitation (REG,2019)

In the first program, the target is Ubudehe category 1 only, where the government would provide electricity access subsidies to those households. The target is 154,000 households that met the eligibility criteria of Ubudehe category 1 and more than 2,000 systems have been acquired as donations from governmental institutions and private companies including 27 companies operating in Off-Grid electrification in Rwanda. 24 of the 27 companies have signed a collaboration agreement with EDCL and are participating in program 1 tenders. Depending on the funding available, the implementation goes through a procurement procedure.

In the second program, the target is Ubudehe category 2, 3 and 4 where the government will provide the risk mitigation facilities for Solar Home Systems (SHS). The program is aimed at ubudehe category

2, 3, and 4 households who will meet the eligibility requirements. The scaling up renewable energy program (SREP) budget will be utilized to implement this scheme, which will allow households to purchase solar systems using a loan from savings and credit cooperatives (SACCOs) rather than banks. This program will be implemented by 24 companies that have signed a collaboration agreement with EDCL (BRD, 2020). Any company can participate by signing an agreement with EDCL, and enterprises will be able to obtain a loan to invest in Off-Grid Solar

Home Systems businesses at a later stage

For the third program, the target is Ubudehe category 3 and 4 where the government provides the risk mitigation facility mini-grids. This program will be implemented using the Scaling Up Renewable Energy Program (SREP) fund, and enterprises will be able to obtain a loan to invest in mini-grid solutions. In Rwanda, there are already over 9 operating mini-grids, demonstrating the off-grid solution's potential contribution to the overall electrification initiative. (BRD, 2020).

The fourth program comprises of 3 and 4 Ubudehe category household and productive use areas where the grid extension programs (EARP) take place and EARP would contribute to implement a grid access program that focuses on productive use regions The coexistence of grid and mini-grids will need to be streamlined. Currently in Rwanda, 65.9% of Rwandan households are connected to electricity whereby the contribution of Off-Grid is 17.8% which comprise of 14% of Stand Alone Solar (SAS) and 3.8% of Mini-grids and 48.1% is connected to the national grid (existing grid and grid extension) (REG, 2020). Since the plan of 2024 is to reach 100% of electricity access including 48% for the contribution of Off-Grid (10% for Micro-grid, 7% for SAS/Microgrid, 21% for SAS and 7%existing Off-Grid) and 52% for Grid connections (31% of existing grid and 21% of Grid extension) (World Bank, 2020).

2.2.4.3. Reliability of Off-grid on full electrification

Mini-grids are becoming more popular in developed countries, such as Rwanda as a means of enhancing energy security, power quality, and reliability, as well as preventing power outages caused by natural disasters. The reliability and the lifespan of the solar panel modules is excellent, according to the recent research carried out by National Renewable Energy Laboratory (NREL). The researchers examined 54500 solar panels installed between 2011 and 2015 and discovered that only 5 out of every 10,000 solar panels failed each year, this is only 0.05 percent (Gloria et al,2019). Solar Global Irradiance in Rwanda ranges from 4 to 5.4kWh/m2/day, with roughly 5 peak sun hours due to its

equatorial regional location. According to Energy Sector Strategic Plan average daily irradiation in the cloudy season reaches about 4.5 kWh/m2/day, resulting in a high solar potentiality of over 66.8Twh per year, proving that solar energy may be reliable for meeting the lower demand of Rwandan households. (MININFRA ,2015).

2.2.4.4. Sustainability of Off-grid solutions on full electrification

The sustainable off grid solutions are surely the renewable energy. Renewable source of energy is seen as the sustainable supply for they meet two important criteria namely the infinite source and the environmentally friendly. Renewable energy sources include waste materials and biomass fuels, sunshine, wind, and flowing water (Dincer et al, 1998). While providing safe energy resources has many benefits, it is insufficient for the growth of a community or country. Growth also demands a long-term supply of energy supplies that are affordable and can be used without causing severe societal consequences. Long-term development requires renewable energy resources and technology. One of the advantages of the renewable energy is that the period between conception and operation is often quick due to the small scale of the equipment, allowing for greater flexibility in responding to unforeseen expansion and changes in energy demand. Solar energy resource exploitation is an important part of long-term development because when it is compared with other energy sources it has no finite source and it is easy cheap and easy to convert. Renewable energy resources have no negative environmental impact, and unlike fossil fuel and uranium resources, renewable energy resources may provide a continuous and long-term supply of energy that cannot be depleted. Uranium and fossil fuel supplies are limited, and mining and consumption can deplete them. As a result, a wide range of renewable energy technologies may be appropriate for use in urban areas. (Anon, 1995).

The term "sustainability" has many different connotations in different situations, but it always implies a long-term outlook. Sustainability's main purpose is to encourage governments to consider environmental concerns when formulating energy laws. The first stage is public awareness and it has been established to guide the environmentally sustainable energy program. With the help of the media, as well as public and/or professional groups, this should be accomplished. Through public and government channels, important data on energy use, environmental repercussions, renewable energy resources, and other topics should be made available to the public. The second stage is environmental

education and training because any strategy that does not include a comprehensive education and training program is doomed to fail. As a result, this might be regarded a critical component of a long-term energy strategy. People should have access to a number of specialist agencies and training facilities as a result of this (Dincer et al ,2000). For a successful sustainable energy program, it necessitates effective information transmission, including public relations, training, and counseling, and is based on novel methods. Promoting renewable energy resources is a critical step in achieving environmentally sustainable energy plans. Renewable energy sources should be encouraged at all levels of government. This gives both short- and long-term policies a firm foundation. Financing, monitoring, and evaluation, as well as public participation, are all essential components of a successful and long-term energy program. (Gollwitzer et al, 2018).

Certain factors influence the decision to install an off-grid system in a remote location. In order to strengthen rural electrification policies, end-user comments, as well as their requirements and wishes, should be recognized. Technical maintenance and financial management are required within a decentralized network that has been installed. As a result, every town with technology should have a skilled administrator and operator (Rabetanetiarimanana et al,2018). Rural electrification projects are heavily influenced by acceptance criteria.

The European Union, for example, established a fee-for-service strategy to make energy technologies more accessible to the poorest households. Another option is to form local cooperatives that operate on a decentralized framework and thus offer compelling alternatives to either the public or private sectors (Radanielina, 2018).

2.2.5. Challenges within the Electricity Sector in Rwanda

The key policy objectives for Rwanda's energy industry are to ensure adequate, dependable, sustainable and more affordable power supply. may be a number of obstacles that must be overcom e first, such as through legislation and cost-cutting measures. High electricity costs, a lack of generation capacity, and demand that is out of whack. The key issues are a lack of reserve buffer and excessive system losses. (Uwisengeyimana et al, 2017). Inadequate investment in the development of projects for electricity generation, transmission, and distribution, as well as interconnection projects that can

facilitate and improve energy trade, Electricity losses, both technical and non-technical are significant. Insufficient maintenance, High supply costs due to insufficient investment in power production and supply in the past, which is sometimes accompanied by very low operational efficiency and a lack of financial planning; Tariffs that are inefficient; low access on electricity, The supply of electricity and customer service are both of poor quality. (MININFRA, 2015)

Affordability was identified as the primary challenge for the solar off grid companies. Customers who can buy multi-light solar house systems appear to have already done so, requiring businesses to cater to lower-income populations across all Ubudehe classifications. Due to limited employment possibilities and a strong reliance on subsistence farming, lower-income groups have unpredictable income. As a result, their energy needs are frequently at odds with other essential needs including nourishment, health, water, and education. While other challenges like End-of-life management, Customer awareness, Local finance and policy uncertainty are counted in the solar off grid, the off grid mini grid challenges are the Access to finance, Low demand, policy uncertainty (Rwanda Offgrid Sector Status Report 2018 Update August 2019)

2.2.6. Rwandan Energy Policies and Regulations

The Rwandan government produced the Rwanda Energy Policy (REP) and the Energy Sector Strategic Plan (ESSP) in March 2015. The REP sets the overarching vision and policy framework, whereas the ESSP turns policy directives and principles into real actions needed to achieve medium-term objectives. (MININFRA, 2015). Rwanda Energy Policy (REP, 2015) is a high-level policy statement that directs and influences decisions about the open and sustainable extraction, development, and use of Rwanda's energy resources. It establishes the governing rules and regulations, strategic directions, and guiding principles that Rwandan institutions and partners must accept and implement. The REP aims to make energy one of Rwanda's most dynamic sectors and subject to attract investments. It is based on 3 fundamental government principles: a commitment to open and effective sector governance; making doing business easier and eliminating barriers to private investment; and enhancing institutional, organizational, and human skills, as well as the legal and regulatory framework. (MININFRA, 2015). The REP and ESSP complement each other:

The REP lays out a long-term vision, sets high-level objectives, and suggests clear and coordinated strategies for accomplishing that vision.; The ESSP establishes goals and a framework for implementation against which progress toward policy implementation can be measured. So far, two Energy Sector Strategic Plans (ESSP 2015 and ESSP 2018) have been published. (MININFRA, 2015).

2.2.6.1. Rural Electrification policy

The second national program of Economic Development and Poverty Reduction Strategies (EDPRS II), aim to alleviate poverty and inequality, could not be achieved without the energy access for all. Thus, some strategies are in place to overcome the electricity disparities between rural and urban locations, the reason of rural electrification program.

According to Rwandan Ministry of Infrastructure, the government has set strategies which are shown in four distinct programs which are about putting in place the facilities that allow lowincome homes to employ simple solar power systems to obtain access to modern, clean, and sustainable energy services, developing a policy that allow solar power products to be more financially accessible to the private sector and end users ,allowing the private sector to develop and build mini-grids while the government assists with site identification and proper framework and continuing to expand the electricity network through Energy roll out projects (MININFRA, 2016). The Electricity Access Roll-out Program (EARP), has made some remarkable strides through the aforementioned program: access to the grid has increased from 364,000 homes in June 2012 to more than 700,000 homes in 2017 (EDCL, 2018a).

2.3. The Gap in the past Studies

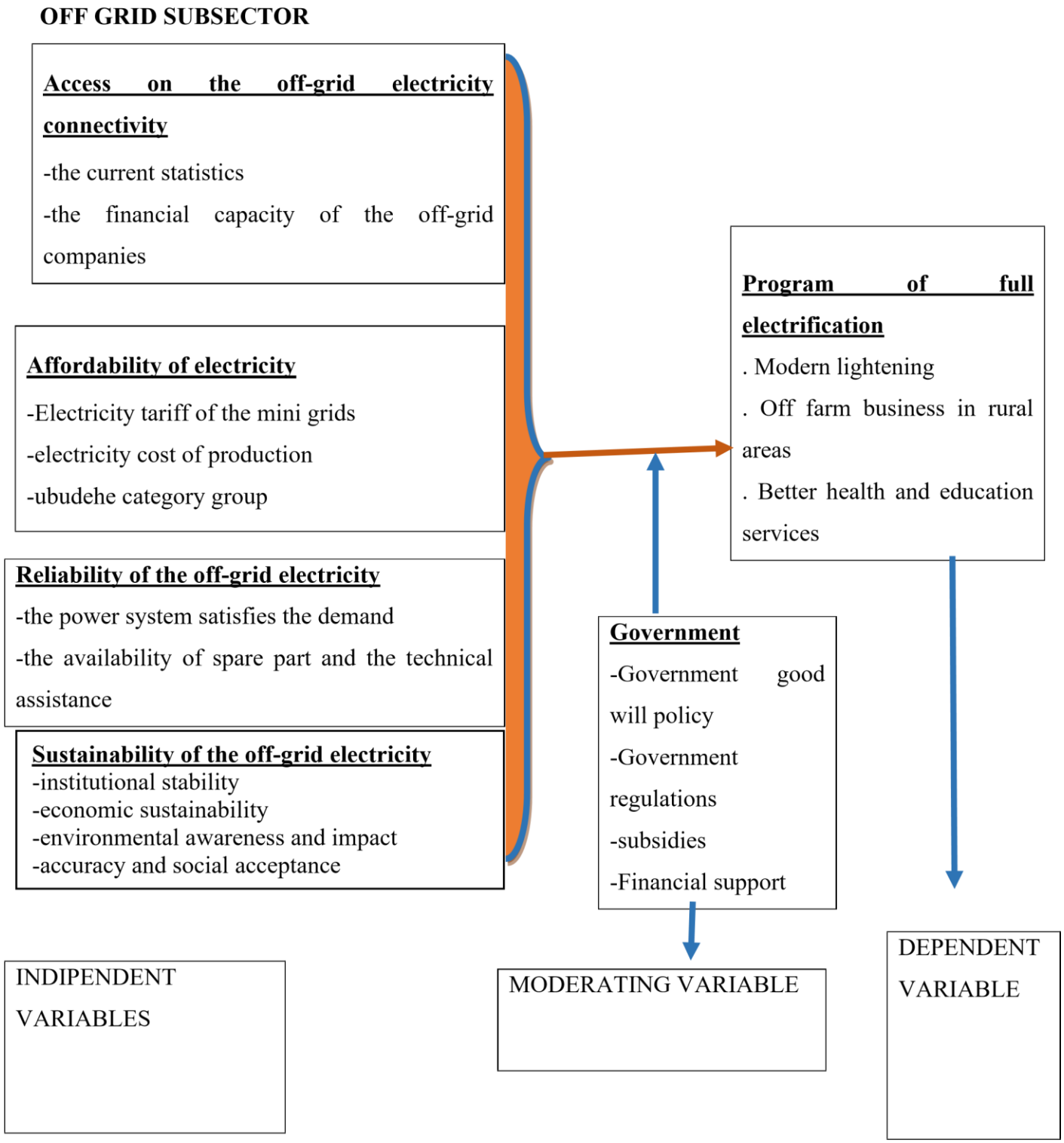
Different studies about the electricity status in general in Rwanda have been done(Bensch et al,2011).Off grid energy market access analysis in Rwanda have been done by Power Africa Off grid Project (PAOP, 2019) and it is mainly to show the available potential market off the off grid products to attract the investors however no known published work about the assessment of the contribution of the off grid sector to the national program of providing an affordable,reliable and sustainable electricity at 100% of the population by 2024.This study aims to analyse the efforts that have been

putted in the off grid sector and give the recommandations that can improve it, so that it gives the pretended contribution

2.4. Conceptual Framework

This is the figure that combine the research variables so as to provide the overview of the good image of how the variables are interlinked

Figure 1: Conceptual Framework



CHAPTER THREE: METHODOLOGY

3.1. Introduction

This chapter will give detailed presentation of the tools and techniques that will be used to investigate the research issues in the field. It included spelling out the area of study. It also highlights the study design, data source and the data collection tool, data processing and analysis and research limitation

3.2. Research Design

The research design is the precise implementations of the research applicability in a methodical manner. This is why we utilized a document analysis design and a quantitative research design in our research to better describe, explain, and comprehend the relationship between study variables: offgrid sector and full electrification program

3.3. Quantitative design

According to Kenneth (1978) said that the quantitative data analysis is carried out by numbering the attributes at the measures of research variables. In this research, the EICV's data have been cleaned and analyzed depending to the research objectives and other data from REG was analyzed using Microsoft Excel.

3.4. Qualitative design

The qualitative data analysis has been with great importance in order to assess the role of the offgrid subsector in program of full electrification in Rwanda. A qualitative document analysis for applied policy was applied (Ritchie et al, 2002). The off-grid electricity solutions reviewed in this study included solar home systems (SHS) for residential use and a micro-grid aimed at both residential and productive uses.

3.5. Source of data

The source of data is the origin where information related to the research will be collected from. Normally, it is all about where we got information. The data four our research are mainly qualitative inputs and the EICV s data for some quantitative analyses have been considered.

3.6. Data collection and analysis techniques

The researcher aims to highlight the approaches employed in making the research richer, understandable, and clearly explained in this section, as well as the techniques utilized in data analysis.

Data source

Regulations, energy policies, and ex-post evaluation reports on electrification programs and projects, as well as the National Energy Agenda (previous and current versions), statistics from the Rwanda Energy Group (REG), and scientific works on related themes, were all used for the analysis. The other source of the data we use is the EICV s data related to the lightning source of fuel and the secondary data from REG website

Data processing

During the data processing the gathered data are translated into the useful information. For the EICV s and REG data we used, STATA 15 and Microsoft Excel helped for some computation and graph presentation

Data analysis

The set of indicators used in the table below were adapted from Feron et al. to qualitatively evaluate the affordability, reliability and the sustainability in general of the off grid rural electrification efforts in Rwanda.

Table 1:Indicators for the sustainability of off-grid electricity (adapted from Feron et al)

Institutional	Economic	Environmental	Socio-Cultural
Stability (durability) and long-term vision	Cost effectiveness	Environmental awareness	Accessibility (disparity, equity)
Regulation, standards and enforcement	Reliability	Environmental impact	Social acceptance
Decentralization and openness to participation	Funding (initial investment; operation and maintenance)	-	Accuracy
Expert know-how	Contribution to the income of users	-	Cultural justice
Adaptability (ability to meet future needs			

We were also able to identify and interview a group of key stakeholders by the help of the document analysis. In fact, we performed semi-structured interviews with important players in addition to document analysis. According to a widely used approach for assessing sustainability, such as the one employed by Hugé in his work on Conceptualizing the Effectiveness of Sustainability Assessment in Development Cooperation (Hugé et al ,2015), the interviewed stakeholders included experts from institutions and companies (REG, solar energy companies and hydropower mini grid). The stakeholders who were interviewed helped to validate the qualitative document analysis and to fill in information gaps. Interview and qualitative data questions were divided into four dimensions (institutional, economic, environmental, and socio-cultural)

Research limitation

The limitations for our research have been mainly the access on information: The covid 19 pandemic lockdowns have been constraint to meet some personnel for interview to overcome this constraint the researcher elaborated a kind of questionnaire in a google forms and it helped to gather some useful information. The other constraint faced is lack of Mini grid data for REG have focused on the SHS numbers of connections and the reports of the off-grid connections growth are based on those SHS distribution. Even though it has been a limitation for our research on the other hand it gave us the picture of the off-grid subsector in Rwanda

CHAPTER FOUR: DATA ANALYSIS AND RESULTS PRESENTATION

4.1. Introduction

It is challenging to develop renewable, stand-alone technologies for rural electrification since implementation necessitates trade-offs among various factors. Ilskog elaborated a holistic and multidimensional sustainability concept covering, economic, social, environmental, and institutional dimensions of sustainability (Ilskog,2008). In our research we adopted this approach to analyze the role of off grid subsector in the program of full electrification in Rwanda for it will help us to analyse our specific objectives of our research.

4.2. National off grid statistics

The off grid is a fast-growing sector in Rwanda. The table below show that in 2010/2011 the solar panel was only on the percentage of 0.33 of the lighting fuels used in Rwanda.

Table 2 : Lighting fuel distribution by households in EICV3 (2010/2011)

Primary source of lighting fuel	Freq.	Percent	Cum.
Electricity from national grid	1512	10.57	10.57
Oil lamp & gas	1374	9.60	20.17
Firewood	1269	8.87	29.04
Candle &lantern	5839	40.81	69.85
Solar panel	**47**	**0.33**	**70.18**
Battery & others	4267	29.82	100.00
Total	14308	100.00	

Source: Author's computation

From the table 4, the contribution of Off-grid solutions (solar panel) through electrification program was 0.33% while national grid connection was 10.57% for the purpose of Household lighting fuel in 2010/11.

Table 3: Lighting fuel distribution by households in EICV4 (2013/2014)

primary source of lighting fuel	Freq.	Percent	Cum.
Electricity from national grid	2594	17.99	17.99
Oil lamp & gas	733	5.08	23.07
Firewood	874	6.06	29.14
Candle & lantern	2973	20.62	49.75
Solar panel	**256**	**1.78**	**51.53**
Battery & others	6989	48.47	100.00
Total	14419	100.00	

Source: Author's computation

The table 5 presents the share of each lightning fuel in the year 2013/2014.the contribution of Offgrid solutions (solar panel) through electrification program was 1.78% and is the smallest compared to all other sources while national grid connection was 17.99%.

Table 4:Lighting fuel distribution by households in EICV5 (2016/2017)

primary source of lighting fuel	Freq.	Percent	Cum.
Electricity from national grid	3620	24.83	24.83
Oil lamp & gas	209	1.43	26.26
Firewood	591	4.05	30.32
Candle & lantern	1333	9.14	39.46
Solar panel	**1096**	**7.52**	**46.98**
Battery & others	7731	53.02	100.00
Total	14580	100.00	

Source: Author's computation

From the table 4, the contribution of Off-grid solutions (solar panel) through electrification program was 7.52% while national grid connection was 24.83% for the purpose of Household lighting fuel in 2016/2017. From EICVs (3,4 and 5), even though it was still on low level, the contribution of Offgrid solutions (solar panels) for the purpose of household lighting fuel was significantly increasing indicating the important contribution of Off-grid connection on full electrification.

Current and forecasted share Off-grid solutions in full electrification

The table below gives numbers and percentages of the electricity access of the yearly targets from the 2018/2019 fiscal year up to 2023/2024 and the last column gives the off-grid access percentage.

Table 5: Expected Households connection and the reported off grid achieved from 2018 - 2024

Connections	**2018/2019**	**2019/2020**	**2020/2021**	**2021/2022**	**2022/2023**	**2023/2024**
Expected New On grid connections	163,914	148,201	160,466	173,624	187,472	202,734
Expected On-grid access	34.5%	38%	41.5%	45%	48.5%	52%
Expected New Off-grid connections	283,507	220,262	271,266	255,706	274,286	293,938
Expected Offgrid access	17%	23%	30%	36%	42%	48%

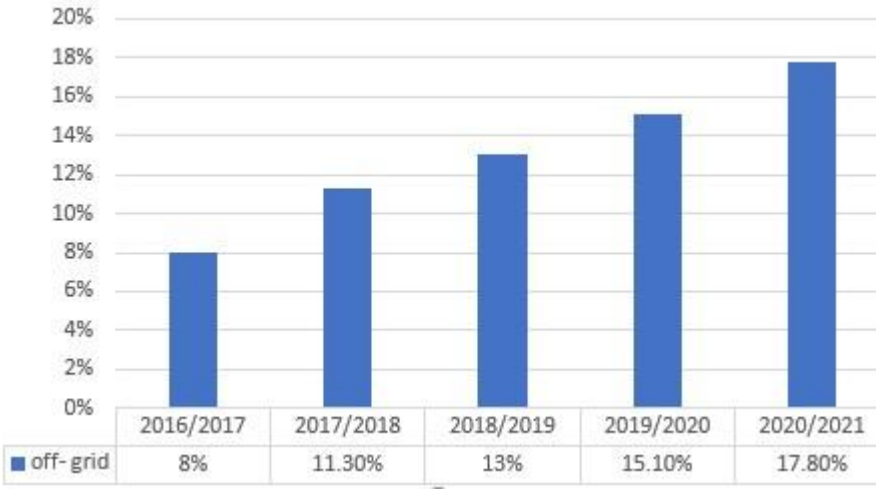
Expected Households connected (Millions)	1.5	1.8	2.3	2.7	3.2	3.7
Expected Households connected %	51.5%	61%	71.5%	81%	90.5%	100%
Real Off grid connections (%)	13%	15.1%	17.8%			
Total Electrification rate	37%	55.8%	65.9%			

Source: Author' s elaborated table from MININFRA and REG reports

According to table 7, it was predicted that in the year 2018/2019;163,914 households were to be freshly linked to the national grid, while 283,507 households were predicted to be newly connected through off-grid options., the contribution of off-grid solutions was 17 percent, while on-grid connection was 34.5 percent, resulting in an expected full electrification rate of 51.5 percent. 148,201 households were supposed to be newly connected to the national grid while 220,262 households were expected through Off-grid solutions. This results to the expectations that the contribution of National grid would have been 38% and 23% for Off-grid solutions in 2019/2020. 160,466 households would have been connected on national grid while 271,266 households would be connected through Off-grid solution with the contribution of 41.5% of National grid and 30% from Off-grid which would make 71.5% of full electrification in 2020/2021. It is expected that 173,624 households that would be connected to

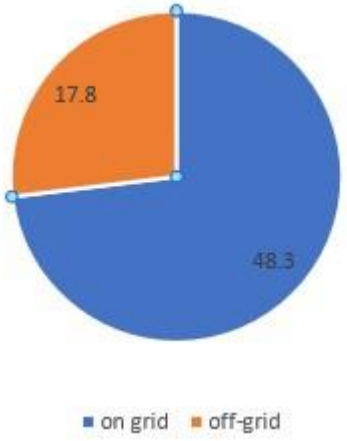
the national grid while 255,706 would be connected though Off-grid solutions with the contribution of 45% of national grid and 36% of Off-grid solutions which make the total 81% of full electrification in 2021/2022. For the year 2022/2023, 187,472 households are expected to be newly connected to the national grid while 274,286 households will be connected through Off-grid solutions with the contribution of 48.5% of National grid and 42% of Off-grid solutions and lasty the new connection of 202,734 households to the national grid, 293,938 new connections through Off-grid solutions will lead to The contribution of national grid will be 52% while the one of Off-grid solutions will be 48% which will make 100% of full electrification in 2023/2024.The achieved numbers of 13%, 15.1% and 17.8% of the off grid connections from 2018 up to2021 respectively and the achieved total connections of 37%,55.8% and 65.9% in the same respective years show that the gap between the expected and the achieved is getting bigger every year because the low rate of increase.

Figure 2:Off grid electricity access percentages



The chat above show that the off-grid electricity access is increasing over time (from 8.2 in 2016/2017 up to 17.8% in 2020/2021 fiscal year). its contribution towards the full electrification program is considerable for it occupy about a quarter of the current total electrification rate as it is shown on the chart below

Figure 3:The share of the off-grid electrification in 2020/2021



4.3. The analysis of the off-grid sustainability, reliability and affordability in Rwanda

4.3.1. Institutional Sustainability

Institutions are critical for long-term rural electrification, according to several studies. Institutions can be thought of as a set of norms that establish the ground rules for interactions. Institutional issues have been identified as a barrier to off-grid electrical systems' long-term viability in developing nations (Lyndrup et al,2012). Institutional faults include a lack of durability/stability and enforcement, inadequate regulations or standards, incomplete decentralization/participation, and a lack of adaptation

4.3.1.1. Stability/Durability

Strengthened and robust formal institutions are required for institutional sustainability. Stability (durability) and enforcement are two characteristics of strengthened formal institutions. While these two elements are typically low in many African developing countries (Levitsky, 2009), this poses a dilemma for the long-term viability of off-grid electrical systems. Rwanda has a promising story for since 1994 we notice the political stability, reformed governance, well-structured and strengthened institutions which has led to a remarkable economic development.

In energy sector there is a clear structure.

MININFRA

The Ministry of Infrastructure (MININFRA) is in responsibility of formulating energy policies and plans, as well as monitoring and evaluating the implementation of projects and programs. It is in responsibility of establishing an enabling regulatory and legislative environment for the business, as well as developing a general strategy for maximizing the use of state subsidies, budgeting, and resource mobilization (MININFRA, 2015d).

Rwanda Energy Group Ltd (REG Ltd):

REG Ltd is higher than EUCL and EDCL. It is responsible for overseeing and evaluating the operations and performance of the two companies, as well as providing senior leadership. The utility's top corporate entity is REG. (REG, 2018).

Energy Development Corporation Limited (EDCL):

EDCL is in charge of the development of both generation and transmission projects, as well as the exploration of new energy resources and putting in place a low-cost electricity development approach. Its main goal is to encourage the exploitation and use of domestic energy resources and investments. While it has autonomy in managing its affairs while pursuing this goal, it is required to report to MININFRA on a regular basis on progress toward established goals. (REG, 2018).

Energy Utility Corporation Limited (EUCL):

EUCL is in charge of power generation, transmission, distribution, and final customer sales on a day-to-day basis. EUCL is in charge of developing transmission and distribution networks in electrified regions, as well as promoting energy efficiency and demand-side management initiatives. EUCL's major objectives are cost savings, loss reductions both technological and non-technical, maximize customer satisfaction, and efficient generation dispatch to meet demand. (REG, 2018).

Rwanda Utilities Regulatory Authority (RURA):

RURA is in charge of regulation. Its responsibilities include licensing IPPs, approving electricity tariffs, authorizing Power Purchase Agreements (PPAs), and enforcing accepted technical requirements. (RURA, 2019).

While the Ministry of Infrastructure is primarily responsible for the energy sector, there are crucial policy inter-ministerial aspects. The Ministry of Natural Resources, for example, is in charge of natural resource extraction and environmental repercussions. (UN Rwanda, 2010), RDB gives instructions to the private developers, MINICOM optimize the business environment and the National Fund for Environment and Climate Change (FONERWA) is in charge of green growth and climate change implementation. (MININFRA, 2015d).

4.3.1.2. Regulations and Standards

Several studies have found that establishing a regulatory framework promotes the long-term viability of off-grid PV-based rural electrification programs (Mani,2012). It has also been demonstrated that having a regulatory agency has a good impact. (Stern et al ,2005). Rwanda's Rural Electrification Strategy, which was approved in June 2016, lays out plans for Rwandan population to gain access to electricity in the most cost-effective way possible by creating programs that would make it easier for end users to acquire lower-cost technology and for the private sector to participate in the delivery of these solutions. (MININFRA, RES, 2016)

In Rwanda, all off grid companies have first to sign a Memorandum of Understanding (MoUs) with EDCL in a campaign to enhance off-grid solar home system supply, improve the country's supply chain, and bring solar systems closer to clients across the country (REG,2019). This put a coherence between the constitution and the regulation. If a problem arises, the regulatory framework shows what steps to take and who to hold accountable.

In June,2019 the Government of Rwanda signed the international agreements for the Solar Home Systems installation and It sets both quality and service level requirements that guide the solar of grid

companies in the implementation of the electrification program. The following are the minimum service level requirements: 3 lamps working for at least 4 hours per day, a mobile phone charge supply for 2 hours per day, a radio charge supply for 5 hours per night, and provide the above for at least one day without input from the solar module) (Source: IEA/IRENA Renewables Policies Database Last updated: 19 March 2021)

4.3.1.3. Adaptability

Rural electrification necessitates the institutions' ability to respond to the country's changing conditions. The SHS have been found adaptable in Rwanda. Companies are willing to operate in all rural regions of the country but the issue of the insufficient solar radiation in some regions that make the SHS not marketable .Mini grids in our country face particular adaptability challenges namely the cost of Mini grid electricity, the regulatory difficulties, low rural energy demand, high payment default rates, and excessively optimistic demand predictions are all factors to consider that result to the higher the Mini grid cost and make the electricity tariff to exceed even the one of the on grid (Peters,2019)

4.3.1.4. Decentralization and Openness to Participation

Decentralization in Rwanda has been enforced since several years ago. The process of fiscal and financial decentralization in Rwanda began in 2001. It entails the transfer of financial resources, increased financial autonomy, and devolution of decision-making powers to local governments, enabling them to carry out the activities and obligations allocated to them. Rwanda's government has constructed a system of resource transfer from the national government to local governments to ensure that all citizens have access to high-quality basic services (NEW TIMES, 2009)

Through Umurenge SACCO s, the government provide the fund to allow people to have the loan for the SHS. REG, as a government entity, raises awareness in order to inform citizens and motivate them to use it. “We’ve already made tours in Districts explaining this to local leaders and seeking their support to raise awareness of citizens on this Government subsidy program to enable every Rwandan get electricity at a low cost”. Said Twesigye. (REG, 2021**)**

4.3.2. Economic Sustainability

4.3.2.1. Cost Effectiveness

A solution for electrification must be cost-effective in order to be sustainable. The cost of rural electrification is determined by a number of variables, including population density, local energy resources, distance from the nearest grid, and the quantity and quality of energy availability (Nerini et al,2016). The grid extension is expanding faster for now all sectors in Rwanda have access to electricity (REG,2021). This make the grid connection to be costly effective too

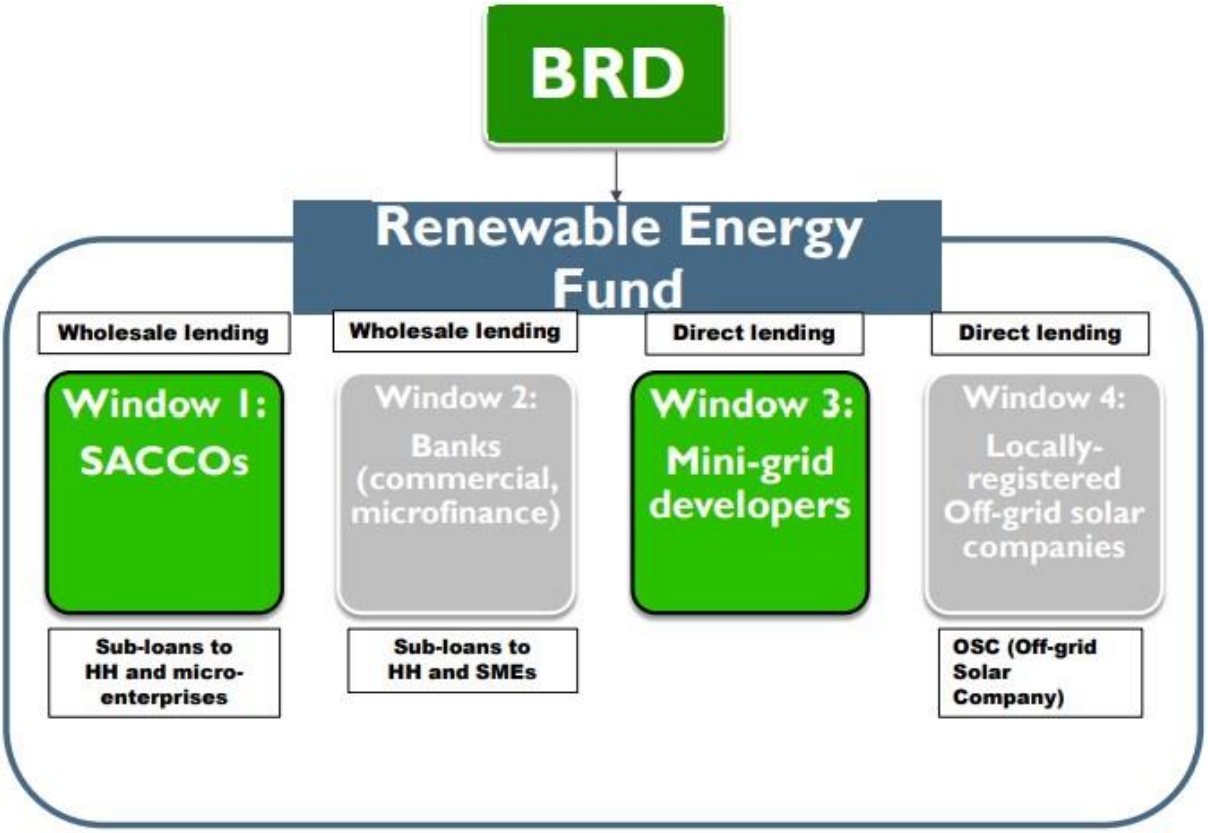
One among the challenges of the off-grid electricity market that have been mentioned by a customer services officer of one solar off grid company is the grid extension. Even though further research may be done on this, the quality of the grid electricity is better than the one of the SHS and this issue may create the competition that weaken the off-grid performance and thus a constraint to the economic sustainability

4.3.2.2. Initial Investment

In Rwanda the initial investment is made by the off-grid companies as it has mentioned by the manager of one solar off grid company:" *the Initial investment is made by the company*. *The government provide a loan facilitation through BRD and we thank that partnership*". The foreign companies for example BBOX and Mobisol occupy the big percentage of the off-grid market share in Rwanda that show the need of financial facilities to the companies in energy sector.

Through BRD the government of Rwanda provide different fund support to the off-grid sector in Rwanda and thus ensure the affordability of the off-grid electricity. As the chart below shows, window 4 if for the locally registered solar off grid companies and window 3 is the direct lent to the local mini grid companies. Window 1 and 2 is destinated to support households and SMEs to access on off grid electricity.

Figure 4:Renewable energy source funding



(BRD, 2019)

Recently BRD launched " window 5 Results based Financing (RBF)subsidy of 30 million US $ which has been called "Cana uhendukiwe"all for adressing the affordability constraints of the off grid electrification .It has be given by the World Bank and is expected to connect 370 000 households on the off grid electricity(BRD, 2021).

4.3.2.3. Reliability

In order to be reliable, the system have to be operational during its lifetime. That require the well organized and enough technicians to assist the clients. Operation and Maintenance (O&M) activities and costs covering have to be insured. The companies that deliver the off-grid services are the one who are in charge of those O&M activities. Although further research on field might be important, they affirm to have enough technicians and the quality of the service they give should be the best for they are the market-oriented companies

The impact research made within one of the solar off grid company in Rwanda called Azuri showed that even though the SHS are being adopted and appreciated by the people, out of 78 households using indigo SHS, 17 (22%) are using indigo SHS only, while 61 (78%) use other devices alongside indigo SHS (Simon et al, 2016). These numbers make the reliability of the SHS in our country to be questionable.

4.3.2.4. Operation and Maintenance funding to ensure the reliability

The purchase of the SHS is subsidized by the Government for the people of categories 1 and 2 but the O&M costs are paid by the client after the guarantee period which is 3 years at maximum for some companies give 2. The population of category 3 for which the SHS have seen to be affordable ((Simon et al, 2016) the O&M cost may not seem a constraint. But the category 1 and 2 who receive the SHS on the subsidies of the Government (which pays 90% and the 10% is paid by the beneficiary) the Operation and Maintenance costs are surely an issue as the government don t provide the clear O&M support after the period of guarantee. The head of the off-grid department in REG argue: “we will not continue to help those categories 1 and 2 people…. they will not remain in those categories after some years they have to upgrade”. It is fine if they upgrade as it is wished otherwise the O&M costs would be the important constraint to those poor people to rely on the SHS.

4.3.2.5. Productive Use

The SHS available in our country are mainly of lightning and they may allow to charge phones and to use a radio. The solar water heaters that are mainly use in hotels and guest houses, solar irrigation pumps that help farmers are the productive profitable products that the off-grid companies distribute.

Even though the Mini grid are not with remarkable contribution on the national electrification program as the one of SHS, their productive use where they are, are with an unignorable impact. The quality of their power generations allows to the beneficiaries to develop some new business-like sewing machines, haircutting saloon and other business that need the use of fridge.

4.3.3. Environmental Sustainability

4.3.3.1. Environmental Awareness

Rwanda has signed the international renewable policies which are mainly for environmental purposes. For Photo Voltaic systems, A need for product labeling for system parts is included, as well as a requirement for battery chemicals. (IEA, 2021)

RDB set the requirements for energy projects and it is followed. Except for standalone solar home systems, all other energy projects, regardless of technology or size, require an EIA, which is contingent on the results of the project site visit. Small projects (under 100kW) are issued an EIA Clearance certificate (no study required), however those with a capacity greater than 100kW are required to perform an EIA study (RDB, 2017)

4.3.3.2. Environmental Impact

One of the reason the Renewable energy are being promoted worldwide is that they are environmentally friendly. The batterie of the SHS has been mentioned to be harmful if their disposal is not well carried and treated. The unproper use of the SHS and lack of training reduces the lifetime the battery and this last one is the weakest part of SHS. the study showed that in sub-Sahara Africa the battery troubles begin after only 3 working years (Narayan,2018)

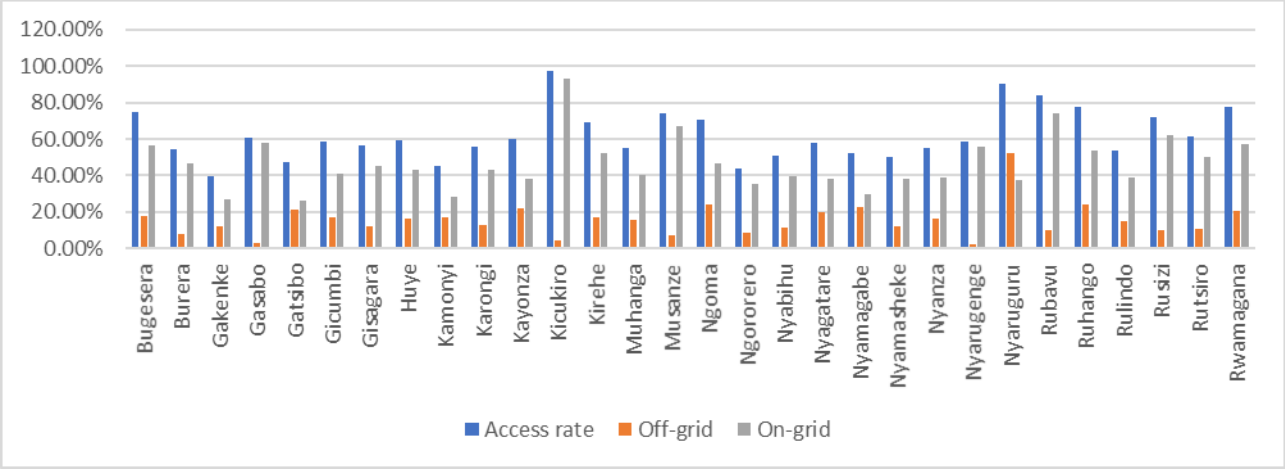
” The handling of the damaged batteries is challenging but those collected from the rural for replacement we took it to E-waste Enviro-save for recycling and use of new batteries or other materials needed. The major potential environmental concern arising from solar home systems is the improper disposal of the lead-acid storage battery used in SHS” said by the manager of Ignite solar company

4.3.4. Socio-Cultural Sustainability

4.3.4.1. Equity (Disparity)

The Equity of the electrification program in our country was the main reason behind the energy diversification policy. Those most vulnerable and hardly reached regions was the target of the SHS and Mini grid solutions.

Figure 5:District's electricity access rate by June2021



Source: Author's computation

The number above explain the equity in electricity access where the last in on grid access Nyamagabe(29%),Kamonyi(28%),Gakenke (27%) and Gatsibo (25%) all have the good number of off grid access:Nyamagabe(22%), Kamonyi(16%), Gakenke (12%) and Gatsibo (10%).all have at least 10% of off grid connection while the national off grid connection is 17.8%

4.3.4.2. Accuracy

The SHS is the appreciated energy solution especially in the rural area of African developing countries. According to a study conducted in Rwanda on According to a social shaping of technology research of appliance acceptability, information and communication technology (ICT), devices like cellphones and radios have the best chance of being adopted (Muza et al,2021). The SHS which are distributed

allow the phone charging and have the radio in the bouquet. This makes them to meet the Rwandan rural population need above the one of the clean lights.

While off-grid solutions have shown to be a flexible approach to provide basic energy access, as people develop the demand upgrade and it can be challenging to reinforce and update the generation and storage capabilities associated with the old systems. As a result, localities may become relegated to the lower electricity services

4.3.4.3. Social Acceptance

The social acceptance level of the beneficiaries of any project influences its adoption and sustainability (Ruggiero et al, 2014). The Rwandan rural population is actively participated in SHS installation (Kizilcec et al,2021). Different advertising strategies about new facilitations pass on

Radio, television, small brochures, campaigns…all show that the government is aware of how the population involvement is with great value.

4.3.4.4. Social Justice

The Social justice is described as the equal access to wealth, opportunities and privileges within a society. The Government of Rwanda enforces the social justice in so many ways and different program have been put in place to ensure no group of people is left behind toward the sustainable development the example is Girinka program, the twelve years basic education program (Were et al,2011)

Within the electrification program also, the government provide subsidies on Solar Home Systems (SHS) to the vulnerable population (population of ubudehe categories 1 and 2) where it pays 90% of the price.

CHAPTER FIVE: CONCLUSION AND RECOMMANDATIONS

Introduction

This chapter present the summary of the findings of our study, the conclusion and the recommendations. Lastly the researcher suggests the area of further research that can complement this study

5.1. Summary of the findings

This study finds that the off-grid sector is a growing and important sector in the national electrification program. The EICV 3 data analysis showed that 0.33% of population were using solar panel as primary source of fuel for lightning in 2011 and it grew up to 7.52% in 2017 from the data of EICV 5. The very recent Data of 2021 from REG show that the off grid occupies about 1/4 of the electricity access. The institutional sustainability analysis shows that the institutions that works with the off grid sector are stable because of the good governance of our country, regulations and standards for the sector are in place and followed, while SHS are adaptable and appreciated, Mini grid are still having some adaptability issues like the cost of Mini grid electricity, the regulatory difficulties, low rural energy demand, high payment default rates and excessively optimistic demand predictions that result to the higher the Mini grid cost and make the electricity tariff to exceed even the one of the on grid. The decentralization and Openness to participation is one of the strengths of our government and it is applicable in the off-grid sector also. The affordability has been analyzed in the economic sustainability where the Cost effectiveness analysis showed that the off grid is cost effective where the national grid doesn't reach. The initial investment is done by the off-grid companies and this is good to the beneficiaries. Our government put much effort in funding by providing loans and subsidies to the category 1 and 2 of ubudehe program. This make the SHS affordable and strengthen the off grid. The operation and maintenance cost that is paid by the customers may be a challenge to the poorest household to gain from the use of the SHS. SHS that are used in our country are mainly for lightning and phone charging. They cannot be exploited in productive use and this is a constraint to their economic sustainability. The reliability on the SHS is still a challenge for a big percentage of their users use other sources of lightning beside them. The environmental awareness in our country is shown by that RDB set the requirements for energy projects and it is followed. The solar energy is

environmentally friendly, however the battery that are used in the SHS can harm. Measure to handle them are in place. About the social cultural sustainability, the SHS are distributed equitably in all district and the social justice is seen for even the most vulnerable household get subsidies to acquire the SHS. the off-grid solutions that are available nowadays are accurate for the allow to improve the wellbeing of the household that use them

5.3. Conclusion

The Rwandan policy of energy source diversification has much strengthened the off-grid sector and the off-grid subsector is growing considerably. All of these have been possible because the institutional sustainability of our country that is remarkable. Effort that has been used to make the off-grid electricity affordable (especially SHS) by providing subsidies and loans both to the households and the legally registered off grid companies gives hope that even the poorest household far from the grid will have the chance to upgrade its wellbeing by enjoying the modern and clean light. However, no matter what the government can do, the affordability will remain the constraint if the rural households don't improve their economic status. The renewable energy that is promoted in Rwanda (solar and hydro) is reliable in its nature for their source in not finite. However, the technology that is used or the Operation and Maintenance costs and activities may cause the end users to not rely on those sources of energy. In one study done about the SHS in Rwanda showed that a big percentage of their user utilize other source of light specially to increase the time and the O&M cost after a given guarantee may became a constraint to the poor people of category 1 and 2 who get SHS on the government subsidies. Different sectors of electrification sustainability namely institutional, economic, environmental and social sustainability show that our country is doing a great job even though there is still a journey ahead. Full electrification by 2024 is possible but the share of the off-grid sector is likely that it will be lower compared to the target of 48% for the grid is expanding faster than the rate of the SHS distribution.

5.4. Recommendations

From the findings of this study, the researcher recommends this

- To continue to strengthen the rural development strategies. The modern lightning is not a priority to the hungry households and even though those poor people will have a grid connection one day, they will not afford to buy a cash power
- To increase and enforce the awareness by all kind of advertisements in rural areas about the available different subsidies and loan schemes opportunities
- To put effort in the solar minigrids for they supply much energy compared to the SHS will lead to the sustain the reliability of the solar off grid electricity in a long run because as people develop their electricity demand increase. The SHS that occupy a big share of the offgrid electricity in our country are only the short run solutions for much are used in lightning and Phone charging only.
- to continue to search for technologies that ensure the reliability of the solar off grid electricity and make sure that they are affordable this will ensure the sustainability of the offgrid sector and it will be possible by the good collaboration and the high commitment of all institutions that are involved in the sector

5.3. Suggestion of additional research

The study we did might be complemented by the following area of research.

- Assessment of the impacts of covid -19 pandemic on the program of full electrification in Rwandan
- Assessment of the adaptability of the mini grid projects in Rwanda

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APPENDIX

Appendix 1: A serie of questions focused on during interview and data collection

DATA COLLECTION FOR OFF GRID SOLAR COMPANIES QUESTIONNAIRE

Dear Sir/Madam,

I am by names of **Bienvenue IRUMVA, a** Masters Student at African Centre of Excellence in Energy for Sustainable Development (ACE-ESD), University of Rwanda, College of Science & Technology (CST)

I am **conducting a survey** for my research Thesis which I would appreciate your input. The goal for my research is to find out **"the role of the off-grid subsector in the program of full electrification in Rwanda by 2024"**

This survey takes about 15-20 minutes to complete. Please answer each question truthfully and to the best of your ability as your opinion and experience are of great value to this study. The survey is divided in two parts: (1) a set of mandatory questions related to the verification and identification, and (2) a set of open questions which response depend on your field and your information.

The survey will be closed on the 8th of September 2021. We assure that all the information provided is treated with the highest degree of confidentiality for it is intended for the Thesis research Book only and will not be forwarded or made accessible to third parties.

Thank you for your help and input.

Kind regards,

Bienvenue IRUMVA

Section 1. identification of the respondent

A. The position in the company……

B. Working experience in the company……

C. Level of education…….

SECTION B: Open questions. Please try to explain for making the information more rich

1.What has been the role of your company for rural electrification in the past and the present?

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2.How is the rural electrification process put into practice?

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3.How many years of amortization you give to your clients on a PV system? does sometimes the client fail to pay in a due period?

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4.Do you provide a written instructions for use or a kind of briefing to your clients?

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5.How are the community members imbedded in the rural electrification projects?

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6. how is the compliance with the regulation assured? what are the specific regulation about the offgrid solar companies?

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7.Are there some bids of rural electrification that you find not interesting? If yes what may be the reason

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8.who is charged of the operation and maintenance (O&M) activities? (The off-grid company, the government or the client)?

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9.does he has enough trained and facilitated staff to ensure O&M services?

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10.Who pay for those O&M activities? (The off-grid company, the government or the client)?

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11.Who is paying for the initial investment costs? (The off-grid company, the government or the client)?

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12.What has the economic impact been on the user (e.g., energy for productive uses)?"

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13.How is battery disposal handled in rural electrification?"

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14.How would you describe the awareness on environmental issues on a political and social basis?" Are there any established norms about the battery disposal?

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15.To what extend (and how) are projects adjusted to local circumstances? does the service they get comply to their need?

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16.Do you provide different technological solutions to different communities?
If so, what are the criteria these decisions are based on?

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17.Do you remember any cases where PV systems were rejected by a community? what was the reason?

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18.are there the financial challenges for the sustainability of off grid solar electrification? Can you cite some?

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19.what re other challenges rather than financial that the sustainability of the solar electrification is facing?

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20.How do you see the feasibility of the Rwandan full electrification program by 2024? What are the challenges you see to the program?

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……

THANK YOU VERY MUCH!

DATA COLLECTION FOR MINI GRID COMPANIES QUESTIONNAIRE

Dear Sir/Madam,

I am by names of **Bienvenue IRUMVA, a** Masters Student at African Centre of Excellence in Energy for Sustainable Development (ACE-ESD), University of Rwanda, College of Science & Technology (CST)

I am **conducting a survey** for my research Thesis which I would appreciate your input. The goal for my research is to find out **"the role of the off-grid subsector in the program of full electrification in Rwanda by 2024"**

This survey takes about 15-20 minutes to complete. Please answer each question truthfully and to the best of your ability as your opinion and experience are of great value to this study. The survey is divided in two parts: (1) a set of mandatory questions related to the verification and identification, and (2) a set of open questions which response depend on your field and your information.

The survey will be closed on the 8th of September 2021. We assure that all the information provided is treated with the highest degree of confidentiality for it is intended for the Thesis research Book only and will not be forwarded or made accessible to third parties.

Thank you for your help and input.

Kind regards,

Bienvenue IRUMVA

Section 1. identification of the respondent

A. The position in the company……

B. Working experience in the company……

C. Level of education…….

SECTION B: Open questions. Please try to explain for making the information more rich

1.What has been the role of your company for rural electrification in the past and the present?

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2.How is the rural electrification process put into practice?

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3.How are the community members imbedded in the rural electrification projects?

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4. how is the compliance with the regulation assured? what are the specific regulation about the offgrid electricity companies?

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5.Are there some potential sites which you don t find interesting to you to develop the power plant for off grid electrification? What might be the reasons?

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6.who is charged of the operation and maintenance (O&M) activities? (The off-grid company, the government or the client)?

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7.does he has enough trained and facilitated staff to ensure O&M services?

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8.Who pay for those O&M activities? (The off-grid company, the government or the client)?

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9.Who is paying for the initial investment costs? (The off-grid company, the government or the client or other)?

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10.What has the economic impact been on the user (e.g., energy for productive uses)?"

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11.How would you describe the awareness on environmental issues on a political and social basis?" Are there some established environmental norms about the power plant?

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12.To what extend (and how) are projects adjusted to local circumstances? does the service they get comply to their need?

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13.Do you provide different technological solutions to different communities?
If so, what are the criteria these decisions are based on?

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14.Do you remember any case where the power plant off grid electricity power were rejected by a community? what was the reasons?

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15.what kind of financial challenges do you face while implementing your hydropower project?

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16.A part from the financials, what are other challenges for the sustainability of the off-grid hydropower plants projects?

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17.How do you see the feasibility of the Rwandan full electrification program by 2024? What are the challenges you see to the program?

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THANK YOU VERY MUCH!