Sustainable hydropower development, environmental protection and affordable electrification in Rwanda.

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***Abstract*-**The world is quickly turning into a global town because of the expanding day by day necessity of energy by all residents over the globe while the world in its structure can't change. The requirement for energy and its related services to fulfill human social and financial growth, welfare and wellbeing is expanding. Rwanda also is moving fast for its development in all sectors most especially energy sector which is a key in the development. Back to renewable in sustaining power as well as environmental protection and affordable electricity to all are an overwhelming approach in meeting energy demand of future generations. The study highlights the current status of hydropower development as renewable energy, environmental protection and accessible electricity in Rwanda.

Hydropower is an important renewable energy resource worldwide likewise in Rwanda too, since it is the largest generating power by 47% of all the total renewable energy in the country.

Even though the country has tried a tremendous job in sorting out the shortage of power but electricity is still scarce and unaffordable as shown in this article and environmental destruction as well, With the development of hydropower leads to sustainable power to overcome major issues like environmental destruction due to largely usage of biomass (charcoal and firewood), even access to electricity and its affordability is inevitably get solved. A sustainable hydropower project is achievable, yet requires appropriate planning and cautious system design to deal with difficulties. Fine planned hydropower projects can add to provide sustainable energy. A latest acquaintance is essential for energy planners, sponsors, and different partners to settle on educated choices concerning hydropower projects. This is essentially a review paper. Aside from utilizing professional information, the authors have additionally consulted widely from journals, reports and a few records to get secondary data regarding the topic. The study suggested various measures and policy recommendations which when regarded as would assist attain the aspiration of sustainable hydroelectricity thus to promote environmental protection and provide affordable electrification for the whole country.

***Key words*:** hydropower development, environmental sustainability, affordable electricity and clean energy**.**

I. INTRODUCTION

Hydropower or hydroelectricity is basically referred to as the conversion of energy from flowing water into electricity. It is viewed as a sustainable power source in light of the fact that the water cycle is continually restored by the sun [1]. The African mainland is portrayed by a low charge pace of simply above 40% and for each capita utilization of just 180 kWh in sub-Saharan Africa (barring South Africa), compared to the 2,674 kWh global average electricity consumption. Electricity is essential for economic and social development [2]**.**

Rwanda's hydroelectric power is the leading source of renewable energy with an average of 47% of the total renewable energy supplied in the whole country followed by thermal energy source with 27%. Rwanda's capacity part has become quickly over the previous decade, with power now available to the greater part of Rwandans in their homes, up from 10% in 2009, according to the World Bank Rwanda Economic Update, Lighting Rwanda. Blackouts have become shorter and less successive, the aftereffect of enormous interests in the area, the report says.

While Rwanda is on the right track for increasing access to electricity, the report indicates that the cost of electricity supply is among the highest in the region where by the electricity tariffs are ranging between US$0.12 and US$0.28 per kWh thus makes electricity unaffordable for most households and industry in general. It remains a constraint for the country's economic and industrial development. "Rwanda happened to be a leader in the push to give inexpensive, trustworthy and sustainable electric power to all residents in Africa," said Yasser El Gammal, Rwanda's World Bank Country Manager. "The challenge over the next five years will be to ensure that the electrification program remains affordable to the government". The Rwandan government perceives the basic job of power access in quickening monetary turn of events, just as improving wellbeing results and ways of life for residents. The National Strategy for Transformation plans to give all inclusive access to solid power by 2024.To that end, the report brings up that the legislature has executed a few changes changing the power organization into an industrially worked, state-possessed endeavor, and the private part has appeared as a strategic investment partner **[3].**

Around the world, about 3 billion individuals cook with biomass

on customary wasteful ovens. This practice has particularly harmful effects on health and environment. Firewood collection and charcoal production are worldwide significant contributors to forest degradation and to deforestation respectively, the carbon emissions from wood fires is responsible for an estimated 18% of the global warming process and the agricultural residues used as cooking fuel are not going back to soil for fertility anymore.

Rwandan families go through as long as 6 hours out of each day gathering kindling and up to 33% of their revenues for their energy needs, worsening the cycle of poverty. National wide, About 79.9% of households use firewood as their primary cooking fuel and 93% of rural household utilize firewood as it is considered in most cases still abundantly accessible, in excess of a portion of the kindling stoves working across the nation are 3-stones stoves. Approximately 65% of households living in major urban areas like Kigali, Huye and Rwamagana use charcoal to meet most of their cooking needs through both traditional and improved cook stoves **[4].** The above factors affect the environment through deforestation leads to soil erosion, landslide, climate change and air pollution it is noted by world health organization that household air pollution is one of the leading causes of disease and premature death in the developing world **[5].** This can be mitigated by having availability of sustainable electricity nationwide.

II. METHODOLOGY

Methodology used to carry out this research is based on quantitative information and data attained from government documents, published research papers, authenticated websites, outlooks on sustainable hydroelectric power development and environmental protection, local and international organizations' reports and thesis. The international organizations include World Bank, International Renewable Energy Agency, and world health organizations. The emphasis is on the sustainable hydropower development, environmental protection as well as affordable electrification in Rwanda **[6],[7].**

III. HYDROPOWER DEVELOPMENT IN RWANDA.

A. Brief overview of energy generation

Rwanda's electric power supply is made up of home generation, imported power from neighboring nations and regional shared power plants. The electricity utilized in the country comes from the accompanying sources: hydropower plants, solar energy, methane gas, thermal power plants. So as to tackle the issue of power deficit known recently, the nation leased thermal power plants as temporary arrangement [8].

B. Hydropower development

Hydropower is regarded as the major source of Rwanda's electricity generation, over the last years, hydropower sector in Rwanda illustrated a remarkable improvement. Currently total installed capacity of power is about 226.7 MW, hydropower contributing 48.3% of it.The Involvement of private sector though investing in the energy field was the priority that marked the tangible achievements; Independent Power Producers (IPPs).

There are 35 hydropower plants that are grid connected with the supply capacity of 109.712MW. They incorporate shared and national power plants. Hydropower contributes about 48.3% of the whole installed capacity. Hydropower plants are freely possessed and managed by the government, rented to privately owned businesses, or IPP. The publicly possessed energy sources are supervised by the state utility Rwanda energy group (REG) under one of its two branches, energy utility corporation limited (EUCL). They incorporate bigger plants, for example, Mukungwa, Nyabarongo I and Ntaruka. 5 power plants (10 MW) are owned and operated IPP. Another 8 power plants with capacity of 13 MW are privately worked through renting concurrences with the Government of Rwanda.

Presently in Rwanda there exist a so called isolated networks totaling to 11 micro hydropower plants where initially started by the country and later gave it to private entities to expand the participation of private sector in power generation. Also there is pico hydropower plants ranging between 1 and 10 KW that are either government owned or managed and utilized by local communities or can even be completely private **[9].**

C. Impact of hydropower and other renewable energies.

- *Access to electricity*

In recent times, Rwanda has made an incredible effort throughout the Electricity Access Roll-out Program (EARP whereby access to electricity has raised in June 2012 from 364,000 households to 590,000 households (24% of the total) by June 2016. This continued to act as the power backbone, providing power to large users and driving economic growth. Illustrated in figure 1

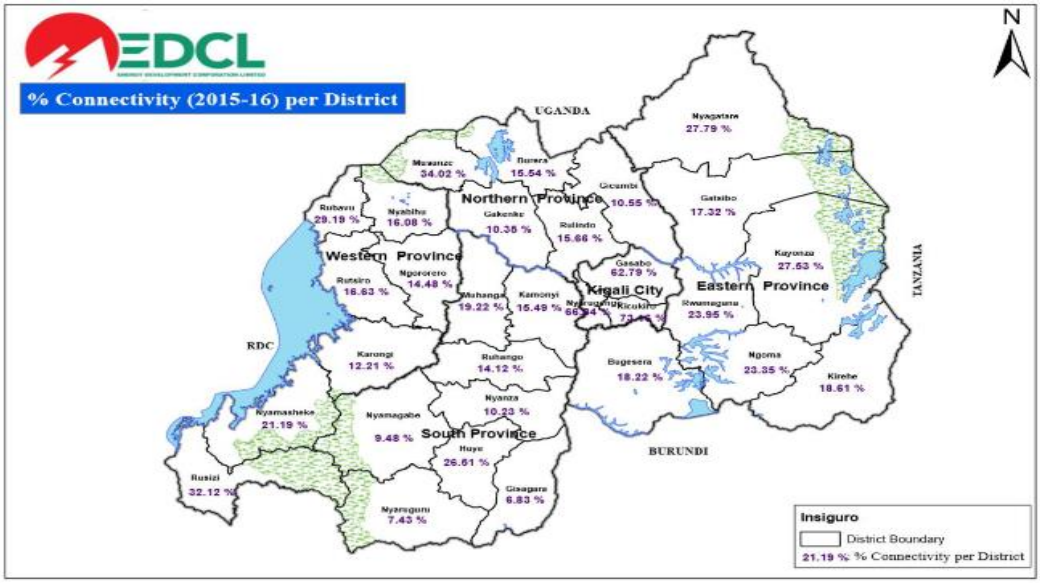

Figure1: electricity connectivity per district.

The figure above is dominated by urban areas unlike rural electrification was still a serious issue in general. Three major Primary objectives of the Rural Electrification Strategy was set

1. Ensure that by 2018, 70% of Rwandans have access to electricity and that by 2020, 100% of Rwandans have access to electricity. Many alternatives from unconnected solar systems through to isolated mini-grids and grid connection will be accessible.
2. The country will advise citizens to use the most suitable form of electricity regarding to their revenue levels and refer to their daily expenditures.
3. Customers will go on to be linked to the national power system through EARP and the target of connecting up the whole nation will continue. Government resources will be channeled to driving economic growth.

Figure 2, below, indicates the percentage of consumers connected under EARP by consumption level. The relatively low rates of consumption (almost half of consumers are currently using less than 20 kWh per month) [10].

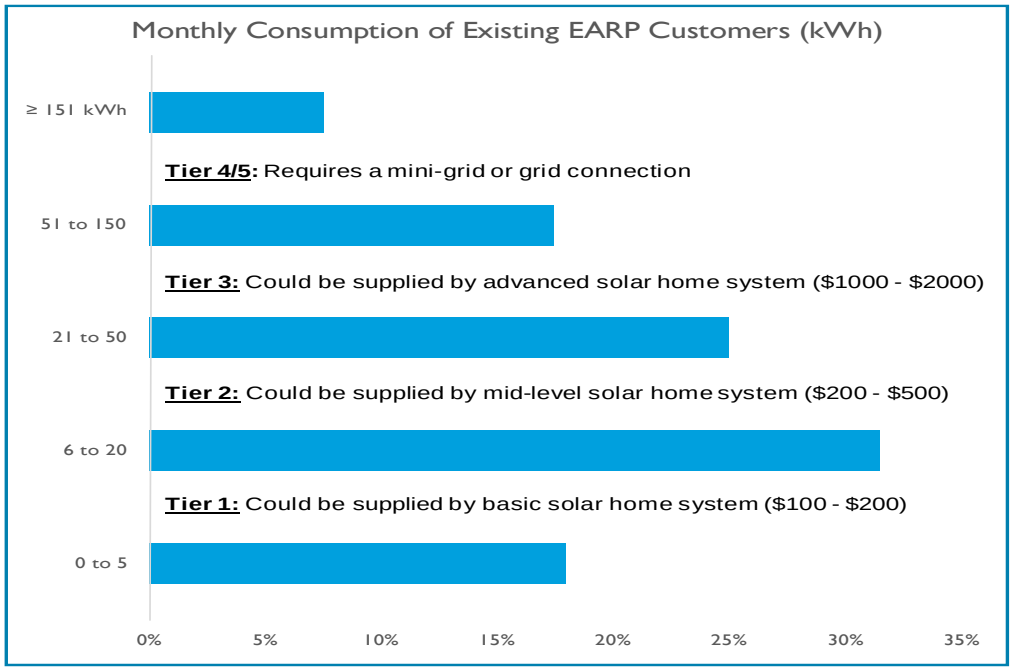

Figure 2: Levels of household consumption (Source EDPRS 2).

After three years, currently, 51% Rwandan households have access to electricity, connected to the national grid (37%) or through off-grid systems (14%). As the target is 100% access to electricity, a national electrification plan has been elaborated to ensure that this target is reached

The national plan's approach on accessible electricity is that 52% of the entire population will be linked via grid extension whereas 48% will be linked via off-grid. Presently 14% is off-grid connected power **[8] .**

IV. AFFORDABILITY OF ELECTRICITY.

The population growth rate is highly increasing, currently the population is approximately 13 million and it is expected to almost double the population in 2050 indicated by Worldometer through population forecast as shown by the figure 3 **[11, 12].** While Rwanda is on the right track for increasing access to electricity the report indicates that the cost of electricity supply is among the highest in the region where by the electricity tariffs are ranging between US$0.12 and US$0.28 per kWh thus makes electricity unaffordable for most households and industry in general. It remains a constraint for the country's economic and industrial development **[3].** This simply means that a lot of work is required to be done in terms of power generation most especially in hydropower sector due to its simplicity, less expensive and long term serving project compared to the rest of power generations to be able to meet the market demand.

Table I: Rwandan population growth rate predictions from 2000 up to 2050.
(Source: www.Worldometers.info)

Year	Population	Yearly % Change	Yearly change	Migrants (net)	Medan Age	Fertility Rate	Density (P/Km²)	Urban Pop %	Urban Population	Country's Share of World Pop	World Population	Rwanda Global Rank
2020	**12,952,218**	2.64%	316,629	-9,000	20.0	4.10	525	17.6%	2,281,330	0.17%	7,794,798,739	76
2025	**14,576,985**	2.39%	324,953	-9,000	20.9	4.10	591	18.2%	2,659,944	0.18%	8,184,437,460	76
2030	**16,234,387**	2.18%	331,480	-9,000	22.1	4.10	658	19.4%	3,143,843	0.19%	8,548,487,400	76
2035	**17,921,521**	2.00%	337,427	-9,000	23.2	4.10	726	21.0%	3,768,985	0.20%	8,887,524,213	75
2040	**19,633,864**	1.84%	342,469	-9,000	24.4	4.10	796	23.2%	4,562,582	0.21%	9,198,847,240	76
2045	**21,357,199**	1.70%	344,667	-9,000	25.8	4.10	866	25.6%	5,477,407	0.23%	9,481,803,274	75
2050	**23,048,005**	1.54%	338,161		27.2	4.10	934	28.1%	6,483,462	0.24%	9,735,033,990	72

V. ENVIRONMENTAL PROTECTION.

According to the latest estimates by WHO, Household Air pollution(HAP) from cook stoves leads to over 4.3 million deaths per year worldwide, more than HIV,Malaria and tuberculosis combined. Children represent a significant proportion of such deaths. Carbon monoxide and particulates from the fires are responsible for severe respiratory diseases, perinatal mortality, low weight births, cancer, eye illness

including blindness and cardiovascular diseases. The expanding practice of catering with agricultural remains in regions where wood is scant prompts much higher introduction to destructive smokes.

Biomass is the most used source of power in Rwanda. Research done by the United Nations statistics division (UNSD), biomass ranked for 87% and 86% of major used energy in the years 2014 and 2015, respectively .Similarly, ministry of infrastructure in the energy sector strategic plan highlights biomass prevalence in the energy consumption as in figure below

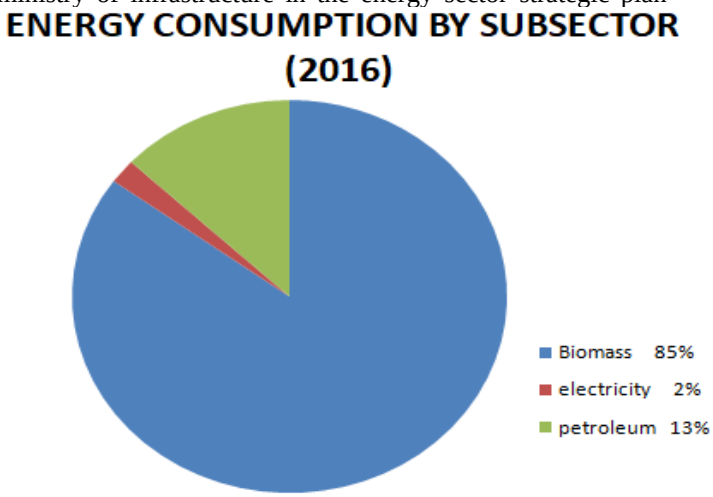

Figure3: contribution to total domestic energy consumption by subsector.

From the environmental standpoint, this extensive reliance on biomass for energy in the form of fuel-wood and charcoal - is no longer sustainable due to consumption being higher than production. Inefficiencies in the production and consumption of biomass for energy worsen the problem.

As a nation that tries to quick financial development, Rwanda has set a wide and comprehensive national objective, known as Vision 2020. The idea was to bring all Rwandans into the country's development journey, integrating green growth and climate resilience strategies Below are few points highlighting how Rwanda is regarded as one of the leading green growth on the continent.

i) Rwanda's mission to maintain a clean and healthy environment has been going since 2008 when it banned the use of non-biodegradable plastic bags and packaging materials. . Report by UN Habitat in 2008 announced Rwanda's capital, Kigali as one of the African cleanest cities.

ii) To achieve its goal of increasing forest cover to 30% of total land area by 2020, Rwanda has embarked on massive reforestation and tree-planting drive, and new measures like as forest management are being executed.

iii) Rwanda's commitment to conserve the environment has also been seen through the protection and restoration of degraded ecosystems such as wetlands, lakes and natural forests.

iv) As one of the most vulnerable nations to climate change, Rwanda is acutely aware of the challenges that lie ahead. Along these lines, to accomplish its vision of a low-carbon and atmosphere versatile economy by 2050, Rwanda has set up the Green Fund, a pivotal

v) speculation support, the biggest of its sort in Africa.

vi) For a country to achieve sustainable development, environmental sustainability must be taken into consideration. This applies to policies, legislation and programmes alike. Over the past years, the government has taken measures to ensure national development is in harmony with the protection of the environment **[4]**.

Rwanda, as a result of its topographical component and climatic profile is one of the sub-Sahara African nations inclined to debacles and particularly confined avalanches and floods.

Rwanda's ministry of disaster management and refugee affairs (MIDIMAR) reported that, within a period of ten months (Dec/2010-Sept 2011), disasters produced a complex web of impacts, which spans various sectors of the economy. During this equivalent period, Rwanda enlisted 43 misfortunes of lives and 73 individuals were harmed. Plus, 1854 houses were demolished, 29,899 Ha of yields were harmed and one hundred (100) school study halls were genuinely decimated. Therefore, the expense of the mediation exercises as far as calamity reaction and recuperation to help the casualties was

in excess of 515,520,000 Rwandan francs **.**

Different parts of the country are affected by landslide and floods differently due to many diverse reasons such as geo-aspects, soil type and other triggering factors etc. Most influenced Districts are Rutsiro Bugesera, Nyamagabe , Gicumbi, Kamonyi, Ngororero, Musanze, Rutsiro, Rubavu, Muhanga, Nyabihu and Burera and this is worsened by elevated level of weakness and Exposure. For other Districts, the level of vulnerability is not very high (figure5) . Clearly floods and avalanches are expanding because of various activating elements **[13].**

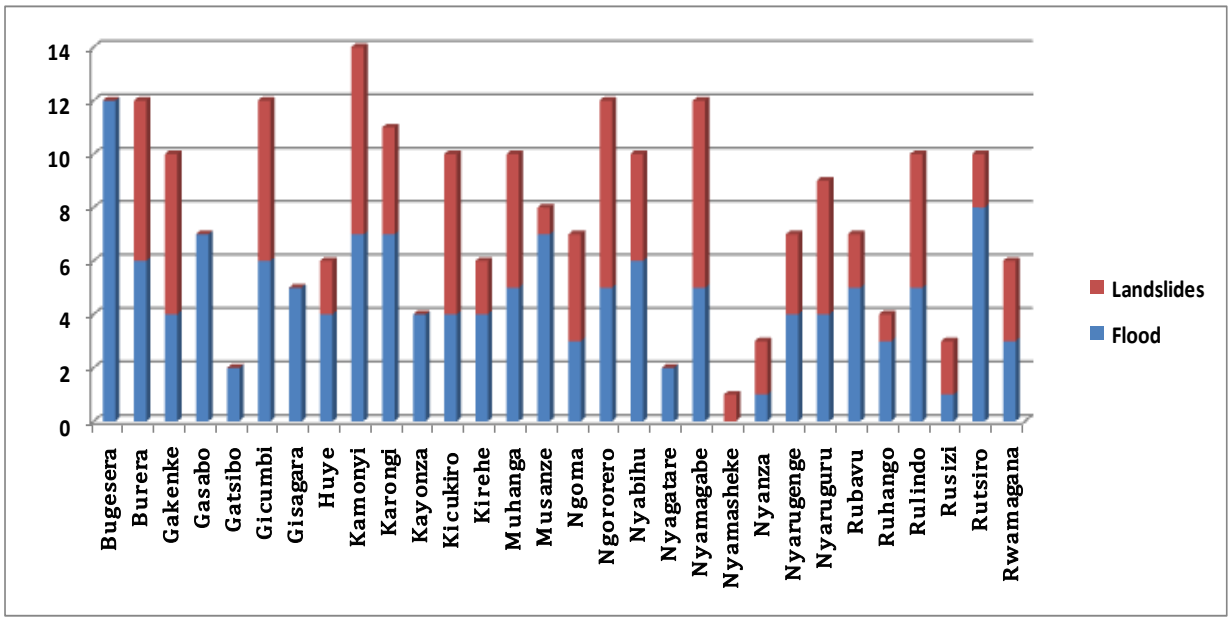

Figure4: Floods and landslides per District (in terms of affected sectors).

Other researchers have also made their contributions in elaborating the issues of landslides in Rwanda and highlighted some major landslide events and associated impacts and effects in different parts of the country (*table***1**) within different periods of time to confirm the severity of landslide hazards and disasters in the study area **[14].**

Landslides for the most part happen from March to May for a few reasons including high precipitation and other distinctive causal elements. This has become an incessant destroying marvel which needs genuine and specific consideration regarding limit every single related effect that overpower the individuals living in inclined zones and subvert advancement activities **[15].**

Table II**:** Latest main disasters caused by landslides in Rwanda.

Time	Place/Venue	Deaths and Injuries	Other Damages
April 2017	Muhanga/South	6 deaths and 27 injured	55 houses destroyed
May 2016	Gakenke/North	35 people killed and 26 injured	67 roads and 29 bridges
May 2016	Muhanga/South	8 people killed and 13 injured	5 roads damaged
May 2016	Rubavu/West	4 people killed and 5 injured	2 bridges destroyed
May 2016	Ngororero/West	13 deaths and 27 injuries	4 classrooms destroyed
April 2015	Ngororero/West	10 deaths and 13 injuries	24 houses destroyed
March 2013	Nyarugenge/Kigali	4 people killed and 3 injured	87 houses destroyed
April 2013	Gasabo/Kigali	3 people killed and 7 injured	56 houses destroyed
May 2013	Rulindo/North	12 people killed and 7 injured	79 houses destroyed
May 2013	Rutsiro/West	5 people killed and 2 injured	22 houses destroyed
May 2011	Nyabihu/West	14 people killed and 11 injured	300 houses destroyed

For Rwanda Country, it was affirmed that the precipitation parts of the nation differ to a great extent in space and in time (Figure 6) and this is brought about by various components including its geo-spatial restriction. Because of the ceaseless changes in precipitation designs, an expansion of genuine climate related risks including landslides that sway the nation at various scale, dissipated across the country is enrolled. This affirms the method of reasoning for landslide weakness planning. Also, the nation has a twofold climate establishment clarified by the marvel of the sun that crosses the equator around March, and the southern summer around September every year.

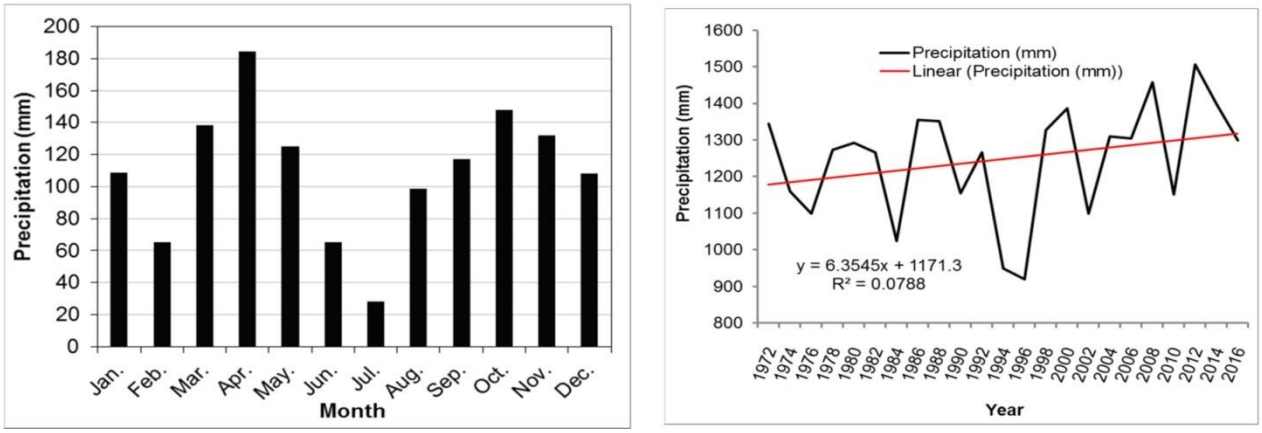

Figure 5**:** Monthly and yearly precipitation blueprint elements of Rwanda nation from 1972 to 2016.

The outlines in Figure 7 affirm the existence of landslide occasions in the examination zone, where they demolish various zones and harm a wide scope of properties including houses, streets, bridges, infrastructure facilities, crops and environment and, in most cases, families are left homeless **[14].**

Figure **6:** Regions influenced via landslides in the investigation region (Rwanda, January–September 2017).

It has been affirmed by past logical investigations that, for areas with uneven geographical nature, unsettling influences, for example, development of new streets, excavation activities and other distinctive man-made actions may cause Landslide exposure **[13, 16]**, and, in this manner, specialists made a decision about sensible to consider the good ways from fundamental streets as a landslide causal factor while carrying out susceptibility assessment studies.

The government of Rwanda (GoR) so far has done a

tremendous work in environmental preservation and protection through its long and short term set policies for instance in raising public awareness about reforestation, planting trees all over the country , banning the use of non-biodegradable plastic bags and packaging materials leads to the reduction of air pollution. In terms of rapid population growth rate the GoR emphasizes its citizens about family planning to produce whom they can afford to raise without being a burden to the government. Biomass usage is till at a high rate due to lack of enough and sustainable generated electric power, this is where this research comes in to highlight the inconveniences and with suggestions **[17].**

VI. RESULTS

Rwanda is a land locked country, its terrain is rugged with steep hills and deep valleys, rising in the north to the highest peak, Karisimbi (4,519 meters), which lies in a range of volcanoes. The country experiences shortage of water, electricity and apparently faces numerous disasters like droughts, floods, landslides, climate changes and as well rapid population growth rate, due to its geographical nature.

The GoR has introduced in place institutional framework to overcome the above mentioned challenges like Energy Sector Strategic Plan (ESSP) for 2018/19-2023/24 presents the current status of, and plans for, the energy sector, covering its three subsectors: electricity, biomass and petroleum, this is being monitored by the ministry of infrastructure under five years national policy priorities of Economic development and poverty reduction strategy (EPRS I) in line with long term national vision 2020 **[18].**

The government was expecting to achieve 100% access electricity by 2020, 100% access to much more cook stoves than currently used. Though a lot of work has been done in implementing national strategic plans in as far as hydropower development, environmental protection and accessible electricity are concerned but still there is a gap to fill in meeting the standard requirements of Rwandans, for instance in the capital city Kigali affordability of electricity is still an issue, landslides during rainy seasons leading to human destruction and displacement of people, charcoal is the most preferred fuel due to its long life storage and low cost transportation yet it is one of the main contributors to air pollution that leads to climate change which is currently a global issue , if these issues are still existing in the capital city simply shows how rural areas are experiencing more of it where there are places that don't have access to electricity at all and so on, this research highlights status of hydropower development, environmental protection and affordability of electricity and gives suggestions to support the existing ones **[19].**

VII. SUGGESTED MEASURES ON SUSTAINING HYDROPOWER, ENVIRONMENTAL PROTECTION AND AFFORDABLE ELECTRICITY NATIONAL WIDE.

To overcome the shortage of electricity, preserving the environment and having affordable electricity in Rwanda, proper measures and techniques need to be taken to guarantee sustainable development, in this article we suggest that due to the abundance of heavy rainfall a new technology of constructing dams in every areas of the country where the there is a high precipitation to collect all water that is regarded as a disaster to the country and later be used to produce power as hydroelectricity since Rwanda is favored by its geographical nature (hilly area). By adopting this technology even preserving the environment due to the available collected water by dams can also be used for irrigation, fishing and many other purposes.

This article also suggests to establishing strong research institutions where all developmental projects are being developed and produce home grown quality engineers that are ready to face the challenges exist in the country even beyond, rather than relying on the solutions from abroad. For instance, if there is a university specialized in hydropower engineering with qualified professors under the support of the government and responsible of the researches and projects planning and their implementation, with this strategy there is a guarantee solution to the existing issues in this field of hydropower engineering.

VIII. CONCLUSION AND RECOMMENDATION

Sustainable social and economic development of Rwanda to be attained, enough and accessible electricity has to be available through the entire country, as shown in its electrification targets of universal access to electricity for all households by 2023/24 **[10, 20, 21].** This article suggests the solution from the development of hydropower system, the combination of topology and hydrology make Rwanda an excellent place for hydropower generation. More emphasis is highly required by the government in encouraging local entrepreneurs to engage in this business of hydropower system by offering incentives such as lowering tax to the raw materials as a measure to attract more and build a competitive

environment amongst.

This research also proposes the GoR to attract more International investors with a condition to train the local citizens and learn from their experience targeting to be having skilled and experienced local people in near future.

Research institutions in Rwanda are still at the lowest level, the government of Rwanda through the ministry of education to promote strong research technology in the universities. Sustainable development goes with strong research institutions, learning from developed countries like china, most of china's big hydropower projects are done by universities. This is a solution not only in the development of hydropower sector but also boosting living standards of academicians or researchers at high level as well.

Rwanda experiences heavy rains that cause floods twice in a year with high annual precipitation. This article suggests the Construction of dams in all parts of the country to collect water to generate off /or on grid connected power, this is going to unravel rural electrification deficit and also it's an environmental protective measure from flooding.

Traditional Biomass fuel is largely used national wide which is a challenge to the environmental protection, conversion to modern biomass would minimize the impact of the cause but with available and accessible electricity especially hydropower, it is the safest strategy to protect the environment and ultimately fastest sustainable development.

Rwandan rapid population growth rate is increasingly leading to environmental degradation and demands much electricity; our suggestion to the government is strictly enforce law to oblige a fixed number of children per family with serious penalties to those disregarding the law.

We suggest the government to subsidizing electricity consumption for the citizens hence easily accessing the available electricity in the country and able to afford according to their financial ability.

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