Pan African University
Institute of Water
and Energy Sciences

PAN-AFRICAN UNIVERSITY
INSTITUTE FOR WATER AND ENERGY SCIENCES
(including CLIMATE CHANGE)

Master Dissertation

Submitted in partial fulfillment of the requirements for the master's degree in

ENERGY POLICY TRACK

Presented by

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Contributions of Renewable Energy Sources to Sustainable Development in Africa: Case Study of Solar Energy Source in Rwanda

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Draft Submitted on 31 July 2019

Contributions of Renewable Energy to Sustainable Development in Africa: Case Study of Solar Energy in Rwanda

submitted by **Giselle Bamundekere**

A Research Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Energy Policy of Pan African University Institute of Water and Energy Science (including climate change) Tlemcen, Algeria.

Academic year 2018/ 2019

DECLARATION

I, **Giselle Bamundekere**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge and has never been presented for a degree in any other University. I also declare that all information, material and results from other works presented herein, have been fully cited and referenced in accordance with the academic rules and ethics.

Signature: Date: **2019**

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CERTIFICATION

This thesis has been submitted for examination with my approval as the university supervisor.

Signature **:** Date **: 2019**

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DEDICATION

This work is dedicated to the Almighty God for the unconditional love.

To my parents, siblings and friends who are always there for me, you are my rays of hope and without your support I would not be here.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the guidance and the help of several individuals who in one way or another contributed and extended their valuable assistance in the preparation and completion of this study.

First and foremost, I thank God for all his love, mercy, and the gift of life.

Deeply appreciation to the African Union Commission, which offered me this opportunity to do a Master of Science degree in Energy Policy at Pan African University in Algeria.

I wish to express my heartfelt appreciation to my supervisor, **Dr. Rosa Maria Fernandez** for her invaluable advice, her continuous availability, her assistance, guidance, support, and instructive comments, all that contributed to the smooth successful of this work. This work could not have appeared without her contributions; she was cordial to me in a unique way.

Deeply appreciation to Algeria Government, PAUWES Stakeholders, Tlemcen peoples and Algeria peoples in general for their support and their generosity which helped me along my studies.

I am also grateful to the Institute Director of PAUWES, Prof. Dr. Abdellatif Zerga and PAUWES staffs for their kind generosity and to provide the required assistance and enabling learning environment.

Warm appreciation to my classmate of Energy Policy 4th Cohort the time spent with you, was well spent.

Finally, my deep appreciation goes to my families, relatives and friends, all people who contributed to the completion of this project from near or far your support, and advices were extremely valuable to me during this studying journey. ***Thank you!***

List of Symbols, Acronyms, Abbreviations

AU: African Union

EAC: Eastern African Community

EARP: Electricity Access Rollout Program

EDPRS: Development and poverty Reduction Strategy

EDCL: Energy Development Corporation Ltd

ESSP: Rwanda Energy Sector Strategic Plan

EUCL: Energy Utility Corporation Limited

FONERWA: National Fund for Environment and Climate Change

GDP: Gross Domestic Product

GoR: Government of Rwanda

HV: High voltage

IEA: International Energy Agency

IPP: Independent Power Producer

IRENA: International Renewable Energy Agency

LV: low voltage

KWh: Kilowatt per hour

MINECOFIN: Ministry of Finance

MININFRA: Ministry of Infrastructure

MoU: Memorandum of Understand

MV: Medium voltage

MW: Mega Watt

NGO: Non- Governmental Organization

NISR: National Institute of Statistics of Rwanda

PAUWES: Pan African University Institute of Water and Energy Sciences

PPA: Power Purchase Agreement

PV: Photovoltaic Solar

RDB: Rwanda Development Board

REG: Rwanda Energy Group

REMA: Rwanda Environment Management Authority

REP: Rwanda Energy Policy

RETs : Renewable Technologies

Rwf : Rwandan Francs

RURA: Rwanda Utility Regulatory Authority

SD: Sustainable Development

SDGs: Sustainable development goals

SHS: Solar Home System

SwH: Solar water Heater

SME: Small and medium enterprises

SPSS: Statistical Package for Social Scientists

UN: United nations

USAID: United State Agency of International Development

USD: United state Dollars

%: percentage

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ABSTRACT

Acknowledging the role of energy in human development and considering the current global unsustainable consumption of a depleting and polluting source of energy, there is a need to advocating for sustainable sources energy. The renewable energies are considered as a way forward to achieve the sustainable development and meets the energy needs of the present generation without compromising the needs of the future generation. The objective of this study is to evaluate the contributions of solar energy to the dimensions of sustainable development (SD) in Rwanda with the hypothesis stating that the effective utilisation of solar energy would increase its contributions to the social, economic and environmental aspects of Rwandans.

Rwanda is a small and landlocked country with abundant renewable energy sources, and solar energy is one of the existing sources in abundance. Rwanda's energy mix is dominated by renewable energy mainly hydro and solar energy sources. We assessed the contributions of the existing solar energy projects to the sustainable development of Rwanda looking at the three dimensions of SD social, economic, and environmental. The triangular approach was used, and the data were collected using the mixed research methodology involving quantitative and qualitative research.

The major findings are that the solar home systems (SHSs) is the most used solar energy technology for electricity production and is frequent in rural areas. We found that the SHSs are contributing much on the social aspect (Health, Education, and Security), economically, SHSs contribute on jobs creation but is has some challenges first it is found to be expensive where it costs the 11.25 % end-user average monthly income second it has the limited capacity. Environmentally, SHSs are contributing to the preservation of natural resources, pollution reduction and to clean air and water this dimension is not fully known in the rural areas. The solar power plants in Rwanda are doing much better in impacting people's lives socially, economically, and environmentally but are much more expensive, and in a country with a high density of population the land could be a problem.

Solar energy is very much contributing to the sustainable development of the Rwandans is providing an alternative of electricity access to rural areas far from the grid, create job opportunities, giving Rwanda extra flow of money from trading carbon credit while preserving the environment and help the country to diversify its energy mix.

Key words: Sustainable development, Solar energy, Rwanda.

RÉSUMÉ

Reconnaissant le rôle de l'énergie dans le développement humain et les défis mondiaux actuels de l'épuisement des combustibles fossiles et de ses émissions de gaz à effet de serre, en tant que source d'énergie non durable la plus utilisée. Les énergies renouvelables sont considérées comme un moyen de parvenir au développement durable et de répondre aux besoins énergétiques de la génération actuelle sans compromettre les besoins de la génération future. L'objectif de cette étude est d'évaluer les contributions de l'énergie solaire aux dimensions du développement durable (DD) au Rwanda avec l'hypothèse affirmant que l'utilisation efficace de l'énergie solaire augmenterait ses contributions aux aspects sociaux, économiques et environnementaux des Rwandais.

Le Rwanda est un petit pays enclavé qui dispose de peu de ressources naturelles. Il dispose d'abondantes sources d'énergie renouvelable et l'énergie solaire est l'une des sources existantes en abondance. Le mix énergétique du Rwanda est dominé par les énergies renouvelables, principalement l'énergie hydraulique et solaire. Nous avons évalué les contributions des projets d'énergie solaire existants au développement durable du Rwanda en examinant les trois dimensions du développement durable, social, économique et environnemental. L'approche triangulaire a été utilisée et les données ont été recueillies à l'aide de la méthodologie de recherche mixte impliquant des recherches quantitatives et qualitatives.

Les principales conclusions sont que les systèmes solaires domestiques (SHS) sont la technologie d'énergie solaire la plus utilisée pour la production d'électricité et sont fréquents dans les zones rurales. Nous avons constaté que les SHS contribuent beaucoup à l'aspect social (santé, éducation et sécurité). Sur le plan économique, les SHS contribuent à la création d'emplois, mais présentent certains défis, mais s'avèrent être coûteux, alors que cela représente une moyenne de 11,25% par l'utilisateur final. Second, revenu mensuel, il a la capacité limitée. Sur le plan environnemental, les SHS contribuent à la préservation des ressources naturelles, à la réduction de la pollution et à l'assainissement de l'air et de l'eau. Cette dimension n'est pas pleinement connue dans les zones rurales. Les centrales solaires au Rwanda ont bien plus de répercussions sur la vie des gens sur les plans social, économique et environnemental, mais elles sont beaucoup plus chères et, dans un pays à forte densité de population, la terre pourrait poser des problèmes.

L'énergie solaire contribue beaucoup au développement durable des Rwandais en offrant une alternative d'accès à l'électricité pour les zones rurales éloignées du réseau ; créer des opportunités

d'emploi, en donnant au Rwanda un flux supplémentaire d'argent provenant du commerce des crédits de carbone, tout en préservant l'environnement et en aidant le pays à diversifier son bouquet énergétique et à réduire ses émissions de gaz à effet de serre.

Mots clés : développement durable, énergie solaire, Rwanda.

1. INTRODUCTION

1.1 Background

Globally, energy has been recognized as essential for humanity to develop and flourish. The United Nation in 2015 adopted the goal to ensure access to affordable, reliable, sustainable and modern energy for all by 2030, as part of the new United Nations Sustainable Development Goals (SDGs). This marked a new level of political recognition of the energy access (UN, 2015). Energy access is strongly interrelated with the other SDGs, including poverty reduction, water, improvements in health, infrastructure, climate change and so on. Energy is at the heart of all them (IEA, 2017).

Notwithstanding the role of energy being the lifeblood for human development, a big number of African populations remain without access to electricity. In spite of the progress in the last few years, the electrification rate in sub-Saharan Africa is currently just 43% (IRENA, 2013). According to the IEA report by 2030, roughly 600 million of the 674 million people without access to power will be in Sub-Saharan Africa, mostly in rural areas (IEA, 2017). Existing high growth of population and industrialization conduct to the exponential rising of energy demand and at the same time, to the high consumption of fossil fuel as a source of energy (Favretto, Dougill, Stringer, Afionis, & Quinn, 2018), which increases the green gas emission in the atmosphere and results into climate change hazards. Those climate hazards like floods and droughts present unsafe conditions to the African continent where the principal activities are highly dependent on good climate conditions. The existence of said hazards hinder the sustainable development (Favretto et al., 2018).

The achievement of the universal energy access goal by 2030 requires much effort globally, regionally, and locally. Hitherto the Renewable Energy Sources (RES) have been considered as a sustainable way to go, that can help to meet the present electricity demand without compromising the future needs and has the potential of limiting harmful emissions, and also promoting sustainable development purposes (Pereira da Silva, Cerqueira, & Wojolomi, 2018). Renewable Energy Sources have gained tremendous growth recently, principally stimulated by technological

developments, and their properties of being no depletable, non-pollutant and flexible (Ellabban, Haitham, & Blaabjerg, 2014).

The African continent presents a huge amount of Renewable Energy Sources (RES) potential such as solar, wind, biomass, geothermal, and hydropower dispersed across regions and mostly are still untapped (Pereira da Silva et al., 2018). Africa is often thought and referred as the "Sun Continent" or the continent where the Sun's influence is the greatest. According to the World Sunshine Map, Africa receives many more hours of bright sunshine during the whole year than any other continent of the Earth (World Map, 2019).

Despite the abundant energy resources of the continent, African countries are still lagging behind in the race of renewable energy growth though they are showing the willingness of adopting the use of renewable energy and enhancing the energy efficiency to ensure their energy security, dynamic economic development, environmental protection as well as combating climate change (Aguirre & Ibikunle, 2014). Despite the effort to develop and exploit the renewable energy sources to ensure a sustainable energy system and reduce the inequalities of electricity access between urban and rural areas, renewable energy distribution is still limited.

Rwanda is the African developing country located in East and Central Africa region, small and landlocked. The number of its population is around 12 million occupying an area of 26,338km^2 yet is the most densely populated country on the continent (482 inhabitants per Km^2), where 72% of its populations live in rural areas. The post-independence era of Rwanda was characterized by a stagnant economy, typically due to political instability, though a rapid socio-economic development followed that episode. Rwanda's GDP per capital was $695.69 in 2017 (World Bank, 2018). Rwanda has achieved 40.5% of electricity access rate which comprises 11% off-grid and 29.5% on-grid (RDB, 2017). Rwanda is aiming to achieve the universal energy access in 2024 to ensure social economic development, energy security, energy access and climate change mitigation (MININFRA, 2019). Rwanda uses a variety of technologies and natural resources, such as petroleum-based fuels, hydro, solar, methane gas, peat, geothermal, biomass, and waste contribute to the generation of electricity. Likewise, Rwandan energy sector scope goes beyond electricity and includes bio-products, such as wood fuel, charcoal, and biogas, as well as petroleum products, such as diesel, kerosene, Liquid Petroleum Gas and natural gas such as methane gas (Usengimana,

Ahmet, & Turgay, 2016). Biomass contributes 85% of primary energy consumed of which wood contributes a percentage of 57%, Charcoal 23%, Crop residues and peat of 5% (MININFRA, 2013; Vander Plas, 2009; Rema, 2013). Non-Biomass sources contribution is 14% of which Petroleum products equal to 11% and electricity contribution is approximately 4% (EWSA, 2013). The Rwandan electricity consumption per capita (30 kWh) is the lowest in the East African Community (EAC), when compared to Kenya (140 kWh), Tanzania (85 kWh), and Uganda (66 kWh); where about 25% of the imported petroleum products from neighbouring countries is used for electricity generation in the thermal power plants (Munyaneza , Wakeel, & Bin, 2016).

Rwandan power sector has very ambitious targets to achieve 512 MW installed power generation capacity, from its current 216 MW power generation and have universal access (100%) by 2023/24. It is also determined to achieve 52% on-grid connections and 48% off-grid connections by 2023/24 (Bimenyimana, Godwin, & Li, 2018; Power Africa, 2018).

Solar energy is among the most promising renewable energy resources in Rwanda. Its geographical location below the equator at 2° 0′ 0″ South and, 30° 0′ 0″ East makes it suitable enough for solar energy source potential, with the average daily global solar irradiation on the tilted surface being approximately 5.2 kWh/m^2 per day (Rutibabara & Mutabaruka, 2018; Safari& Gasore, 2009). Rwanda's total on-grid installed solar energy is around 12.08 MW originating from four solar power plants namely Jali power plant generating 0.25MW, Ndera power plant of 0.16MW, Rwamagana Gigawatt generating 8.5 MW and the Nasho Solar plant generating 3.3 MW (REG, 2018). Households far from the planned national grid coverage are advised to use standalone solar photovoltaic (Solar home System) to reduce the cost of access to electricity (MININFRA, 2019).

The aim of this study is to analyse in the African context the contributions of renewable energy to sustainable development. We will use the literature review to present different views of scholars and theory. Based on them we will come up with certain factors that prove the importance of renewable energy to economic, social and environmental aspects of sustainable development. Those proving factors will be used in a case study of Rwanda with the aim to evaluate the contributions of solar electricity to social, economic and environmental aspects of sustainable development in Rwanda through empirical research.

1.2. Problem statement

Considering the solar energy sources potential existing on the African continent, solar energy sources could contribute largely to sustainable development of the countries if it is well exploited (Pereira da Silva et al., 2018). Almost 600 million population of the continent does not have access to affordable, reliable sustainable and modern source of energy and this led to stagnant economy, environmental degradation, and sometimes dysfunctional society.

The Rwandan government have recognized the importance of energy access and aims to achieve its universal energy access by 2024. Energy policies, regulations, and strategies are in place with a continuous evaluation and monitoring. However, the access to energy is a still a serious challenge to Rwandans especially those who lives in rural area far from the grid. Their power purchase is still low which reflect the unaffordability of the systems they use, the limited systems impossible to be used for some income activities, as well as not being enough to meet their lighting needs.

The purpose of this study is to evaluate the importance of solar energy to socio-economic development and environmental preservation in Rwanda, as well as to find out how solar energy could contribute positively and efficiently to the wellbeing of the community in Rwanda. Though the solar energy role in Rwanda has been studied by different researchers, its contributions to the three aspects of sustainable development has not been fully addressed, which is the purpose of this study.

1.3. Objective

The aim of the thesis is to evaluate the contributions of renewable energy to sustainable development in Africa, with the ultimate objective of evaluating the impacts of solar electricity from existing projects to the three pillars of sustainable development: Economic, Social, and Environment. We will identify the principal challenges and barriers to the progression of Solar Energy for electricity production in Rwanda. Following is the research question of this study:
"*how can renewable energy contribute to sustainable development in Africa? And what are the contributions of solar electricity to sustainable development for Rwandans, in the economic, social, and environmental aspects?"*
Specific objectives are:

- To evaluate the development of solar energy in Rwanda.

- ❖ To assess the contribution of solar energy economically, socially, and environmentally in Rwanda.
- ❖ To identify the potential economic, Social and Environmental gains if the solar energy exploitation is increased.
- ❖ To highlight policy recommendations that should be adopted to overcome barriers and to improve the current situation.

The intention is for the thesis to contribute to development, which is sustainable in the Rwandan energy sector, with the expectation to ensure the improvement of decision making for energy policymakers and solar energy project developers.

1.4. Hypothesis

This research study will analyse the potentials of solar development in Rwanda under the hypothesis that an increased exploitation of solar energy source for electricity production will contribute positively to the three pillars of sustainable development: economic, social and environmental. Emphasis will be given to the importance of empowering all concerned stakeholders in the solar energy sector and the benefits of well-informed decision making.

1.5. Significance of the Study

The study will be of relevance to concerned Rwandese, and Advocacy groups in Rwandan energy sector.

- ✓ This study is expected to guide policymakers on enhancing the effectiveness and efficiency of solar energy projects by meeting social, economic and environmental aspects.
- ✓ Importance of involving different concerned stakeholders during a project feasibility phase and implementation phase.
- ✓ The area of opportunity that will be highlighted in the work is a significant input for solar energy market in Rwanda, and a guidance to Donors, and Investors.
- ✓ This work will be important to the researchers and academicians as it will be a useful guide for future researchers interested in sustainable development and sustainability of the energy system in Rwanda.

1.6. Scope of the Study

In this study of solar energy development impacts evaluation, we will focus on electricity production from photovoltaic solar systems: on-grid and off-grid as both are solar energy electricity production technologies present in Rwanda. For on-grid data collection and analysis, we chose the Gigawatt solar power plant of 8.5MW located in Eastern Province of Rwanda, in Rwamagana District (MININFRA, 2019) which is the biggest solar power plant in the country. While for off-grid use the southern province of Rwanda is chosen in Kamonyi district and Runda sector because is one of the places where the off-grid through solar home system (SHS) technology is still low but with a high dissemination rate. The private companies like Mobisol Rwanda Ltd and Zola Rwanda are the involved companies in SHS private company will be interviewed while other policymakers and Government entities will be considered in this research because of the key role they play in solar energy sector in Rwanda. All research activities will be done according to the disposed resources with respect to all ethical considerations.

1.7. Limitation and Delimitation of the Study

During this study some limitations have come across, for instance, little knowledge about the questions asked during the data collection mainly due to lack of background knowledge and familiarity with technical terms. There were also translation challenges from English into Kinyarwanda the local spoken language, short time for research, rain season period, some household members who refused to provide full information originally and the remoteness of the area. Long process and delay in getting the permission to conduct the survey in the institutions and to talk with SHS end users.

To deal with these limitations different measures were taken, like explaining more the intention of the study and ensuring the confidentiality of the given information and restructuring the questions to make them easily understandable for the respondent. During the rainy season researcher worked hard during evening or night in order to reach everyone from the sample size on time.

2. Literature Review

2.1 Introduction

The ultimate purpose of this study is to assess the contributions of renewable energy to sustainable development in developing countries. This chapter help to understand sustainable development and how it is impacted by renewable energy deployment as well as its assessment and how it has been studied by different authors and their points of view with the help of literature review. Different theories and frameworks will be discussed, and the stand of this study will be shown with the purpose of highlighting the importance of solar energy to the three pillars of sustainable development in Rwanda.

2.2 Sustainable Development

2.1.1 Definition

Sustainable development has been defined in many ways, but the most frequently quoted definition is from **Our Common Future**, also known as the Brundtland Report: "Sustainable Development (SD) is development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Bruntland, 1987). Sustainable development is then a very broad concept that involves two words: Development and Sustainability.

However Loraima & Del Rio (2010) argue that the Brundtland definition is far from being an operative one which could define whether a given country or region is in a transition process towards sustainability or the extent to which a given development proposal is sustainable (Loraima & Del Rio, 2010). For a long time and till today at some degree, there are people who believe that sustainable development is not straightforward, they contest that, it is impossible to reach development without polluting (Velarde, 2011). Fortunately, there are other people who have proven that there is a way to reach economic development in a sustainable way (Muller-Steinhagen & Nitsch, 2005) Sustainability should be measured depending on the characteristics of the community and not forgetting the social, environmental and economic components. Sustainable development has to be the balance between the economic, environmental and social issues. Its

effectiveness depends on protecting and increasing the quality of economic activities, quality of using efficiently the available resources, and skills for the betterment of the community and the purpose of environmental preservation (Emas, 2015).

With current and emerging global challenges such as climate change, rapid urbanization, environmental degradation, increasing poverty, food insecurity, and financial crisis, the sustainable development that ensure social development, economic development and the preservation of environment is considered as a potential way forward (World Economic & Social Survey, 2013). The awareness and understanding of SD are necessary and urgent especially in developing countries for building resilient cities, reducing poverty and safeguarding the natural environment.

In trying to illustrate the need for harmony in balancing the economic, social and environmental aspects, Circular Ecology (2019) proposed the sustainability of Venn diagram that illustrate the Sustainable development (Circular Ecology, 2019).

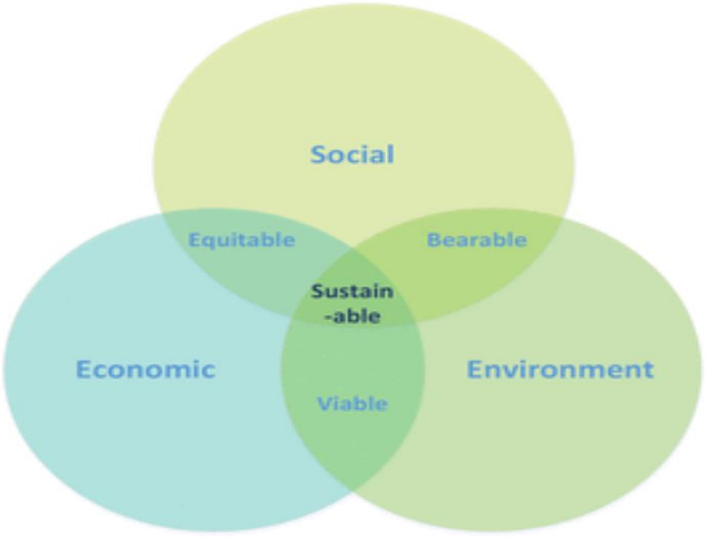

Figure 1. Sustainability Venn Diagram. Source: Circular Ecology (2019)

Other authors who advocated for the need of harmony are (Harris, 2003; Munasinghe, 2011; and Emas,2015). Confirming that ensuring sustainable development is the way to reach economic development without causing a harm or damage to the environment. Having that concept of sustainable development, we understand that pure economic development needs to have some limits because the achievement of sustainable development requires the integration of not only its economy, but also its environmental and social components at all levels. Those three pillars of sustainable development have experienced a growing recognition with time.

Economic: An economically sustainable system must be able to produce goods and services on a continuing basis by using its resources efficiently and responsibly, to maintain manageable levels of the raw materials and to avoid extreme sectoral imbalances which damage the environment (Munasinghe, 2011)

Environmental: An environmentally sustainable system must maintain a stable resource base, avoiding over-exploitation of renewable resource systems by promoting energy efficiency, and avoiding the depletion of non-renewable resources, in other words, is the ability of the environment to support a defined level of environmental quality and natural resource extraction rates indefinitely (Sathaye et al., 2011).

Social: A socially sustainable system must achieve fairness in distribution and opportunity, adequate provision of social services including health and education, gender equity, and political accountability and participation. Social sustainability ensures that the social wellbeing of a country, an organization, or a community can be maintained in the long-term (Harris, 2003; Sathaye et al., 2011).

Sustainable development has an economic dimension, because in any country, growth and income are important factors. It also has a social dimension with elements such as empowerment, governance and inclusion. The environmental dimension includes elements like natural resources and pollution. All those elements must be kept in balance integrated and harmonised (Munasinghe, 2002).

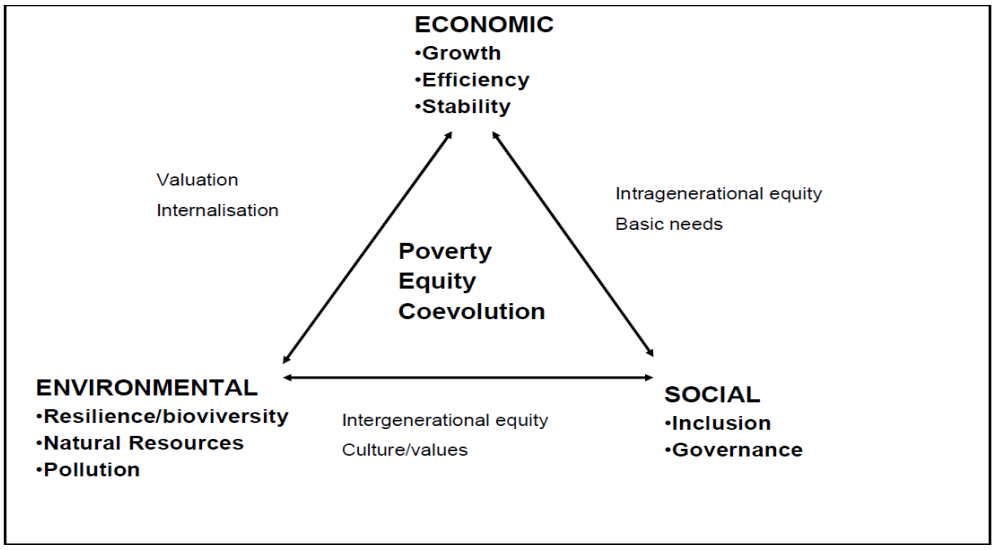

Figure 2. Dimensions of sustainability and their interrelation. Source: Del Rio & Burguillob,(2008)

2.1.2 Sustainable Energy Assessment

The concept of sustainable energy is derived from the attempts to implement the principles of sustainable development, “Sustainable development is the pathway to sustainability” (Circular Ecology, 2019). Access to energy is a key factor in the development of civilization of modern societies (Prandecki, 2014) . For this reason, the energy sector should be one of the first that will be transformed towards sustainable development. The three pillars of energy sustainability and bringing about sustainable development are the emerging fields, addressing energy needs by ensuring the access to modern energy, use of renewable energy and improving energy efficiency (World bank, 2010).

Sustainability is affected by diverse aspects of ecology, economy and social issues. Therefore, it is characterized as a complex and multi-dimensional construct. To process the complexity, adequate models, measures, and tools for capturing and assessing sustainability are necessary (Nessab, Urbel-Piirsalu, Anderberg & Olsson, 2007). The objective of a sustainability assessment is to provide decision makers with the necessary information and context required to support them in defining short- and long-term actions necessary for sustainable development (Pezhman, Noordin, Zameri, & Asadi, 2013). Economic development without changes in the coverage or the nature of energy flows is not possible, because energy is a basic unit of the physical world. For this reason, it is fundamental to the world, and each change in the flow involves environmental implications. It is because, all decisions relating to the acquisition of energy are associated with compromises (Prandecki, 2014), it is important to select the solution that will be associated with a greater development (e.g. by increasing efficiency) and smaller damage to the environment.

Sustainability is a complex and, at times, subjective field based on different perspectives. In order to process these characteristics, quantitative and qualitative indicators must be considered in sustainability assessments. Depending on their application and the availability of data, the indicators are generally based on theories, empirical analyses, pragmatism or intuition (Bitter et al., 2016). Sustainability indicators are either assessed separately or combined with one another. Indices are combined indicators that are based on the transformation and aggregation of sub-indicators with different units, to a single, dimensionless number (Pezhman et al., 2013).

Sustainability assessment generally involves a broad set of methodologies to evaluate social, economic and environmental impacts at the project, regional or national levels (Hacking & Guthrie, 2008; Mutatkar, 2016). Sustainability should be measured depending on the characteristics of the community and not forgetting the social, environmental and economic components.

There has been a natural progression of planning and assessment tools from allied industries including sustainable large-scale photovoltaic and solar thermal (Grágeda, Escudero, Fthenakis, Alavia, & Ushak, 2016).

Grageda and al. (2016) discussed the importance of solar energy to meet the electricity demand of Chile. They evaluated the existing solar energy projects based on multicriteria assessment for future sustainable energy.

Emphasized by (Loraima & Del Rio, 2010; and Sathaye et al., 2011) the territorial dimension of Sustainable development (SD) calls for the use of more operational approach to sustainability, which is adapted to the regional or local territorial contexts. In this regard, two major conceptual frameworks to assess the sustainability of specific development projects in specific territorial areas can be distinguished: substantive and procedural sustainability.

The first one considers how a specific project contributes to the improvement of the economic, social and environmental conditions of a specific territory, thus to the welfare of its population (Ghadimi et al., 2013). The literature on SD has tried to make this substantive approach operative through three major approaches: (1) Sustainability as the maintenance of the stock of capital (natural, man-made, human and socio-cultural) (Sathaye et al., 2011); (2) the triangular approach (Loraima & Del Rio, 2010), which considers the three interrelated dimensions of sustainability (economic, social and environmental) and; (3) the materials balance approach (Del Rio & Burguillob, 2008).

Regarding substantive sustainability, and for the purpose of this research arguing that the deployment of renewable energy projects may contribute to these three dimensions of local sustainability, the triangular approach is used to identify how a specific renewable energy project influences the economic, social and environmental dimensions of the sustainability of a given developing country (Janusz et al.,2016).

The triangular approach considers the three dimensions of SD (economic, social and environmental) and tries to assess the sustainability of a given development proposal, according to

them as they are shown in Figure 2 above. This approach continues to be highly influential. It forms the basis of the structure of the indicators of SD collected by key organizations all over the world, including the UN, the OECD and the European Commission (Pablo & Burguillob, 2008; Loraima & Pablo, 2010; UNECE, 2013).

Similarly, an acknowledgment of sustainable development, integrating social, economic and environmental dimensions specially to assess energy sustainability has been recognized and has been widely applied in furthering research in the field (Elkington,1998; Mutatkar, 2016).

Therefore, following this approach a sustainable local policy must tackle the three dimensions of sustainability with the aim to increase the standard of living of its citizens. Reducing unemployment and improving the quality of jobs (more permanent jobs), increasing regional cohesion and reducing poverty levels are key actions at local level to achieve social sustainability (Janusz et al., 2016). After all, a given project should not only be sustainable according to the three dimensions. It should also comply with the procedural sustainability approach. This is a participatory approach which considers the opinions and interests of all stakeholders (Del Rio & Burguillob, 2008; Sathaye et al., 2011).

The ‘‘procedural sustainability’’ stream of the literature argues that the analysis of the sustainability of a given development proposal (project) should not only focus on the impact of this proposal, but, also, on how this impact is perceived by the local population, how the benefits are distributed among the different actors and how this perception and distribution affect the acceptance of the project and, thus, its feasibility. Therefore, procedural sustainability is very relevant when considering a development project (Del Rıo & Burguillob, 2008). A wide array of stakeholders and their mutual relationship should be considered when implementing a project and this actor-network may either facilitate or discourage such implementation (Del Rio & Burguillob, 2008; Munasinghe, 2011). The interests, strategies, and behaviour of local agents with respect to the renewable energy project should be analysed. Thus, we will integrate this approach into our comprehensive theoretical framework. Therefore, a local SD strategy should combine a top-down (triangular sustainability) and a bottom-up (procedural sustainability) approach. It is argued that both approaches are crucial to analyse the contribution of RES to local and regional sustainability.

2.1.3 Indicators of sustainable development

Sustainable development is a multidimensional concept that ensure equally the environmental component in sustainable consumption of natural resources and protection of environment factors, that consider health care for the population which is the social side of equality, and quality of life and stop poverty which the economic side by increasing sustainability. Which makes sustainable development a connection between environmental, economic and social components (Teodorescu, 2012). Without indicators or a quantitative framework, sustainable development concept lacks a solid foundation on which to advance. An indicator is something that helps you understand where you are, which way you are going and how far you are from where you want to be (Sustainable measures, 2010) . Indicators of a sustainable community point to areas where the links between the economy, the environment and society are weak. They allow you to see where the problem areas are and help show the way to fix those problems. Sustainability indicators reflect the reality that the three different segments are very tightly interconnected (Sustainable measures, 2010), as shown in the figure3.

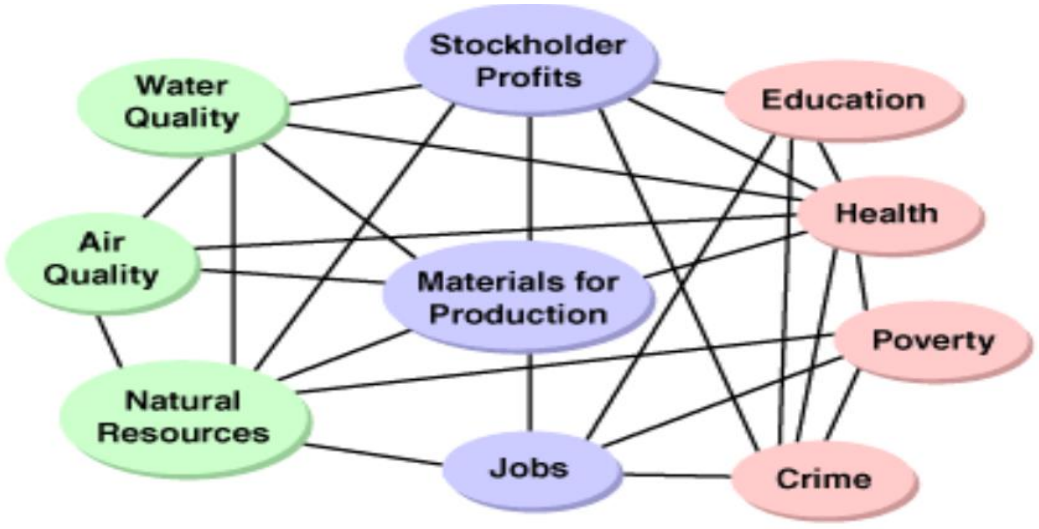

Figure 3. Communities are a web of interactions among the environment, the economy and society.
Source: **(Sustainable measures, 2010)**

The figure illustrates the interconnection between the different areas affecting sustainable development from which the indicators can be drawn, as the natural resource base provides the materials for production on which jobs and stockholder profits depend. Jobs affect the poverty rate and the poverty rate is related to crime. Air quality, water quality and materials used for production influence health. They may also influence on stockholder profits: if a process requires clean water

as an input, cleaning up poor quality water prior to processing is an extra expense, which reduces profits. Likewise, health problems, whether due to general air quality problems or exposure to toxic materials, have an effect on worker productivity and contribute to the rising costs of health insurance (Sustainable measures, 2010).

All these are equal parts of the sustainable development, consisted of three sides: the economic, social, and environmental area must be regarded as a whole, and any components should not be given importance than others. The figure below shows another way of looking at the interactions of the three dimensions that can be measured through different indicators, complex synergies and trade-offs among them.

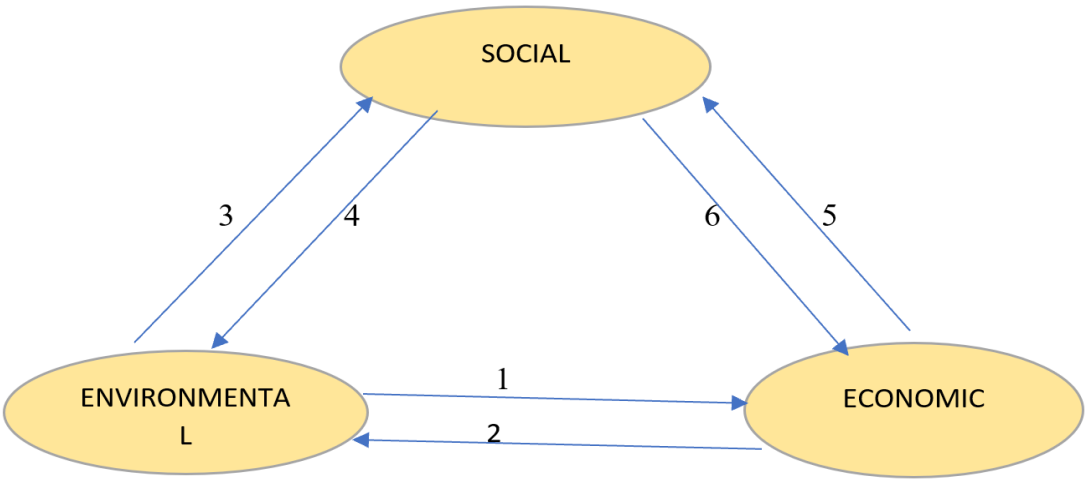

Figure 4. Interaction between economic, social and environmental.

Source: OECD (2005)

1. Environment-Economy: the economic costs of environmental, natural resources, sink functions.

2. Economy-Environment: pressure on environmental resources, environmental investment.

3. Environment - Social: human welfare, health care by maintaining a pure environment, access to resources and amenities.

4. Social - Environment: environmental responsibility, consumption patterns, demographic changes.

5. Economy - Social: providing jobs, at good living, income level and equity.

6. Social - Economy: quantity and quality of labour, institutional and legal frameworks and education and training (Candice, 2005; Teodokrescu, 2012).

Economy-environment: Growing pressures on the environment of economic activities as a result of population growth have led over time to damage the natural environment. The need for food was ensured by intensive agriculture. Consumer requirements have led to increasing energy intake used in all areas of production of goods and services (World Economic & Social Survey, 2013).

The aim of ensuring universal energy access should be considered with much attention. First, it is a primary necessity for economic to flourish, and neglecting the energy sustainability could cause hazards to the environment. Investment plays a necessary role in the economy-environment relationship, and environmental technologies should be applied to hold a clean, unpolluted environment especially in developing countries (Vitale, 2016).

Environment-economic relationship is determined by applying one of the basic principles of environmental policy where the polluter pays (Teodorescu, 2012). Teodorescu (2012) argues that imposing economic instruments of environmental policy in the form of environmental taxes is a way to launch the positive aspects of economic development and the environment and overcome the negative ones.

Environment- Social: The environment provides good quality of its factors (water, air, soil) depending on the pressure it receives from human activities and natural activities (Circular Ecology, 2019). The state of environment is closely related to pressures on it, thus good health, energy access and economic growth are conditioned by keeping pure environment, and biodiversity (Teodorescu, 2012; IPPC, 2014). Affirmed by (Munasinghe,2011) the objectives of sustainable development considered from the viewpoint environmental and social relationship are maintaining human health by reducing greenhouse gases responsible for global warming, access to clean energy, and waste management.

Social equity is one of the cornerstones of sustainable development involving a degree of equality with which energy is distributed, if the price of the power system is high the accessibility will be reduced, to ensure the availability and accessibility of the power systems right pricing is a must. (Munasinghe, 2002). Energy must be available to all at a fair price. Lack of or limited access to energy services marginalizes poor and limits their ability to improve their living conditions. Lack of electricity usually means, among other things, inadequate lighting, lacking clean energy for cooking and limited telecommunications (IPPC, 2014; Sathaye et al., 2011). At the household level,

accidents can happen in poor families caused by exposure to air pollution from the use of candles for lighting.

All sectors of the economy depend on safe and enough energy. Availability of jobs, industrial productivity, urban and rural development and all major economic activities are strongly affected by energy consumption (IPPC, 2014).

Social - environment: If the consumption growth remains unsustainable, negative environmental impacts would be felt through the adverse effects on health and therefore quality of life. Therefore, the aim to move to sustainable consumption should not be delayed and in terms of the relationship of the two pillars, social and environmental, human responsibility is essential (Munasinghe , 2002).

Economy-Social: One of the objectives of sustainable development is clearly providing jobs. The employment rate is the barometer of a country's economy and living standards as well as access to sufficient energy (Munasinghe , 2002).

Energy indicators related to the socio-economic dimension include two themes: model of production and security of supply. Energy use per capita reflects the global energy intensity of a society. Energy use per unit of GDP is a marker of the overall energy intensity of the economy (Prandecki, 2014). Addressing energy security is a key objective in the criteria of sustainable development of several countries (Sathaye et al., 2011). Energy supply disruption may cause financial losses and economic difficulties. To support sustainable development objectives, the power must be reliable, enough and affordable (Eggoh at al.,2011).

Socio-Economic: Human factors contribute to growth through their productivity and depend on job satisfaction, health status, and investment in human resources, which start from the time of enrolment in the school system (Teodorescu, 2012).

Sustainability requires this type of integrated view of the world and it requires multidimensional indicators that show the links among a community's economy, environment, and society.

2.3. Renewable energy

Renewable Energy (RE) is defined as energy that comes from resources which are naturally replenished on a human time scale (Vitale, 2016). It is defined also as “Energy obtained from natural and persistent flows of energy occurring in the immediate environment” (Twidel & Weir,

2006). An obvious example is solar (sunshine) energy, where its availability refers to the 24-hour major period. Such energy may also be called Green Energy or Sustainable Energy.

REs are well known for their properties of being clean and naturally replenished on a human timescale, with example such as sunlight, wind, rain, tides, waves, and geothermal heat (Vitale, 2016).

2.3.1 Contribution of renewable energy to sustainable development

The relationship between RE and sustainability can be watched as a hierarchy of goals and limitations that involve both global and regional or local considerations (Sathaye et al., 2011). The mitigation of dangerous anthropogenic climate change will be one strong driving force behind the increased use of RE technologies worldwide. In addition, the volatility of oil prices and the dependency on foreign energy sources are all contributing factors to the current interest in RE (Pereira da Silva, et al. , 2018).

RE is projected to play a central role in most Green Houses Gases (GHG) mitigation strategies, because of its technological developments, and its properties of not being depleted, and being no pollutant. Though it must be technically feasible and economically efficient, so that any cost burdens are minimized. Knowledge about technological capabilities and models for optimal mitigation pathways are therefore important.

Figure 5. The energy triangle—all essential requirements of a sustainable energy supply system can be fulfilled by renewables, already today or in the future.

Source: Muller-Steinhagen &Nitsch, (2005)

However, energy technologies, economic costs and benefits, and energy policies depend on the societies and natural environment within which they are embedded. Spatial and cultural variations

are therefore another important factor in coherently addressing Sustainable Development (Sathaye et al., 2011).

Sustainability challenges and solutions crucially depend on geographic location (e.g. Solar radiation), socioeconomic conditions (e.g. Inducing energy demand), inequalities within and across societies, fragmented institutions, and existing infrastructure (e.g. Electric grids) (Holling, 1997; NRC, 2010), but also on a varying normative understanding of the connotation of sustainability (Lele & Norgaard, 1996). These aspects underline the need to assess both the social and environmental impacts of RE technologies to ensure that RE deployment remains aligned with overall SD goals.

Aminrashti and Hezhabri (2012) contended that increasing fossil fuel prices, its scarcity, and the inevitable energy crises accentuate the importance and necessity of changing the current system of production and consumption of energy by replacing fossil fuels with RE resources to meet future global energy needs for survival, evolution, and development. They evaluated the impact of RE on SD, recognizing the status of renewable energies in electricity production and achieving SD, through using "a panel data -fixed effects" approach for a period of 7 years (2001-2007). "The findings of this study show that RE in terms of technical, environmental and economic benefits plays an important role in the world's future energy combination. So renewable energies are one of the most effective and influential ways on developing sustainable energy" (Aminrashti & Hezhabri, 2012). Energy should always be available, in enough quantities and at affordable prices, to support the goals of sustainable development. Interruptions of energy supply can cause serious financial, economic and social losses (Manso & Behmiri, 2013).

RE has strong synergy effects on the sustainable development for three main reasons. First, and most evidently, it provides energy, which provides the basis for making progress for all human development activities. In Africa, energy is currently a bottleneck to economic growth and thus for reducing poverty (Eggoh at al., 2011; Sahil at al., 2014). Energy has the potential to make agriculture more productive and thus contribute to food security.

Further, it has been shown to improve education and even to enhance gender equality (Sathaye et al., 2011). Since RE allow countries to become independent from fuel imports it also contributes to the goal of ensuring a reliable and sustainable form of energy (Aminrashti & Hezhabri, 2012).

Second, RE does not cause the local damage which some of the current energy sources like traditional biomass and coal, cause. It could thus contribute to the goal of ensuring healthy lives by replacing the source of indoor air pollution and by improving local air pollution from co-emitted air pollutants (West, et al., 2013). It could also improve the welfare of women as the burden of indoor air pollution is currently placed disproportionately on them (Sathaye et al., 2011).

In addition, it would promote the sustainable use of ecosystems, in particular, forests, by replacing the need to collect firewood.

Third, RE generates hardly any CO2 and thus hardly accelerates climate change. It (RE) has an influence on the long-term prospect of ensuring all aspects of sustainable development (IPPC, 2014).

Renewable energy RE offers the opportunity to improve access to modern energy services for the poorest members of society, which is crucial for the achievement of SD Goals and is a sustainable way forward for mitigating climate change which present the damage to agriculture activities as a direct threat to food security, but also to economic growth on the developing countries which are heavily relying on agriculture (Munasinghe, 2011).

Access to energy is a pre-requisite of economic and social development because virtually any productive activity needs energy as an input. Basic levels of electricity access (e.g. Lighting, communication, healthcare, and education) provide substantial benefits for communities and households. Providing a basic level of electricity access with renewable sources is increasingly economically feasible (Khobai, 2018).

Energy is a central key to achieve SD and poverty reduction as it affects the social, economic and environmental development aspects, including livelihoods, access to water, agricultural productivity, health, population levels, education, and sex-related issues. All those above facts asserted by (Loraima & Del Rio, 2010; Munasinghe, 2011; Eggoh, Bangake,et al.2011; Sathaye et al., 2011; Aminrashti & Hezhabri,2012; IPPC, 2014) underlie the understanding that a certain set of actions (e.g. Substitution of fossil fuels with RE sources) can accomplish all the development goals simultaneously implying that the development of RES should be a way forward to address different challenges to sustainable development in developing countries.

According to the IPPC report 2014 the exact contribution of RE to SD should be evaluated in a country-specific context, RE offers the opportunity to contribute to a number of important SD goals:

1. Social and economic development;
2. Energy access;
3. Energy security; and
4. Climate change mitigation and the reduction of environmental and health impacts. (IPPC, 2014).

Those renewable energy opportunities also have been studied by Owusu & Asumadu-Sarkodie, (2016). They reviewed the opportunities associated to renewable energy sources and concluded that Energy Security, Energy Access, Social and Economic development, Climate Change Mitigation, and reduction of environmental and health impacts ae the main benefits of renewable energy to sustainable development. According to their study despite these opportunities, they also highlighted some challenges that hinder the sustainability of renewable energy sources towards climate change mitigation in Africa. These challenges include Market failures, lack of information, access to raw materials for future renewable resource deployment, and our daily carbon footprint.

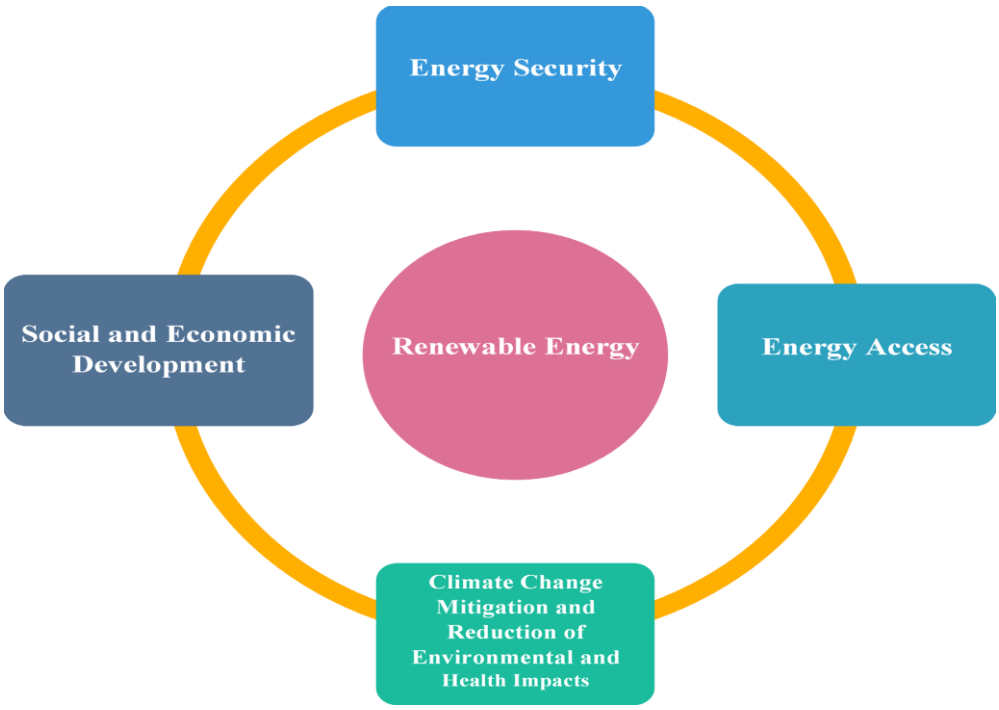

Figure 6.Contribution of Renewable Energy to Sustainable Development.

Source: Owusu & Asumadu-Sarkodie (2016)

Those renewable energy benefits are in line with the purpose of this work to identify the contribution of RES where our case study will focus on Solar Energy (SE) to achieve a sustainable development in Rwanda. Of course, from a triple sustainability perspective, there are other benefits of RES in a country, including reduction of emissions of pollutants (both local and GHG). From an economic and social point of view, RES has the potential to contribute to local development opportunities and jobs (Pereira da Silva, et al., 2018). The local community could be benefitted with their inclusion in the process of developing the RES and it could revitalize the economy of underdeveloped community areas. Economically, RES could deliver investments in remote areas, increase the local employment, and reduce the currency loss when importing conventional fuels. The money saved by the reduction of fossil fuel use would allow more financial resources to be allocated in other critical social and economic sectors and towards implementation of sustainable development policy (Loraima & Del Rio, 2010).

2.4 Rwandan Energy Sector Background

2.4.1 Introduction

Rwanda is an African country located in East and Central Africa region below the Equator at 1.9403^0 South and 29.8739^0 East, and its border countries are the Democratic Republic of Congo to the West, Uganda in the North, Tanzania in the East and Burundi in the South. The total surface area of Rwanda is 26.338 km square, and it is landlocked. Its population is around 12 million and 72% live in rural areas. The GDP per capita was $695.69 in 2017 (Power Africa, USAID, 2018).

Geography and climate

Rwanda is situated between 1° and 3° latitude south of the equator and has a subequatorial climate. The average annual temperature is 18° for the whole country. Recorded annual average rainfall is 989 mm. Rwanda has a temperate tropical highland climate, with lower temperatures that aare typical of equatorial countries due to its high elevation (SEI, 2009). There are some temperature variations across the country, and the mountainous west and northern areas are cooler than the lower-lying east.

Socio-economic indicators

Rwanda is a small but growing market, with a Gross Domestic Product (GDP) of USD 8.096 billion dollars in 2017 (RDB, 2018). Rwanda's economy is overwhelmingly rural and heavily dependent on agriculture; it contributes 33% of GDP through the production of coffee and tea, well-suited to the small farms, steep slopes, and cool climates of Rwanda (NISR, 2018). In addition to agriculture, other leading sector includes trade, hospitality, and financial services. Strong growth in the services sector, particularly construction and tourism, has contributed to overall economic growth (RDB, 2018).

Great progress has been made in attracting investment and encouraging entrepreneurship. Sustained economic growth is targeted in coming years, and overall national objectives are in place to achieve upper middle-income status by 2035 and high-income status by 2050 (RDB, 2018).

Environment

Rwanda undoubtedly is facing significant environmental challenges. The main problems to the environment in Rwanda are pressures from the growing population on the natural resources such as land, water, flora and fauna and other non-renewable resources (UN Rwanda, 2010). This is most evidenced in land degradation, soil erosion, a decline in soil fertility, deforestation, wetland degradation and loss of biodiversity (REMA, 2017).

Rwanda recognises the importance of sustainable development, environmental protection and reducing biodiversity loss. The protection of the environment and natural resources are seen as fundamental crosscutting issues of sustainable national development as stated in Economic Development Poverty Reduction Strategy (EDPRS1) and the second EDPRS2 and different strategies 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).

2.4.2 Electricity Production

The generation reports from Rwanda energy group (REG) show that hydropower occupies 46.8% of electricity generation in Rwanda. It is dominant because of its numerous sources scattered all

around the country, its longer plant life, higher capacity factor, and availability coupled with the upgrade and vigorous expansion programs (REG, 2017a). Besides hydropower, the energy resources in Rwanda include biomass, fossil fuels, and solar. Biomass resources in Rwanda include biogas, peat, wood, methane gas, and other organic wastes. The Table below shows each installed power generation capacity by technology employed in Rwanda between 2010 and 2017 (inclusive).

Table 1. Electricity supply. **Source*:* (Bimenyimana, Asemota, & Li, 2018)**

Electricity supply source	**Installed capacity MW (2010- 2017)**
Hydropower	100.34
Thermal	57.80
Methane	30.00
Peat deposit	15.00
Solar	12.08
Biomass	0.07
Geothermal	N/A
TOTAL	**216**

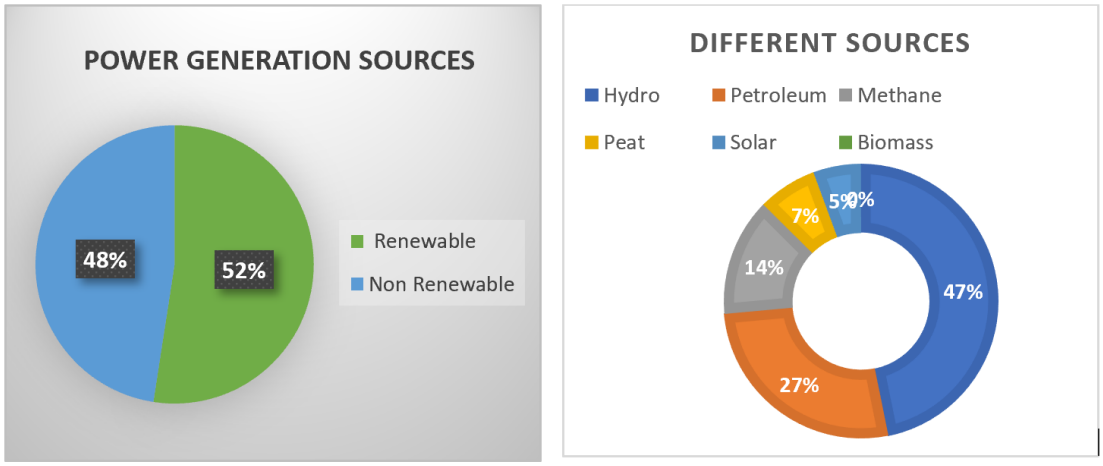

Figure 7. Power generation sources and their shares

Source: **(Bimenyimana, Asemota, & Li, 2018)**.

2.4.3 Transmission

Rwanda's transmission network includes three main voltage level: 70,110, and 220 kV. The power is transmitted from various points of generation across the country and this help to facilitate

regional interconnectivity of about 744.7 km of High Voltage (HV) transmission lines. The total network laid so far are 480.4 km (64.5%) of the 110 kV type and 264.3 km (35.5%) of the 220 kV types (Bimenyimana, Asemota, & Li, 2018). The lines of 70 kV were upgraded to 110 kV to improve network reliability and power supply stability amidst the country's changing power demand profile.

Energy Utility Corporation Limited (EUCL) is responsible of day-to-day operations of power generation, transmission, distribution and sales to final customers (MININFRA, 2015a). EUCL oversees and plans the transmission and distribution grid in areas already reached by electrification, promoting energy efficiency and demand-side management programs. The main challenge they face is lack of enough budget to improve the efficiency by reducing the losses of the existing transmission line and income per capita of customers is low for paying their electricity bills (REG, 2017a).

2.4.4 Consumption and Demand

Rwandan electricity consumption per capita is equal to 30 kWh, which is the lowest in the East African Community (EAC), when compared to Kenya (140 kWh), Tanzania (85 kWh), and Uganda (66 kWh). Here about 25% of the imported petroleum products in Rwanda is used for electricity generation in the thermal power plants (Munyaneza, Wakeel, & Chen, Overview of Rwanda energy sector: From energy shortage to sufficiency, 2016).

Petroleum fuelled thermal power plants were first introduced into the Rwanda electricity mix in 2005 when there were droughts (2000–2007) and the hydropower systems could not supply the nation with its electricity requirements. The high costs of fuel used to operate the thermal power plants have made the Government of Rwanda to subsidize domestic electricity tariffs (by about US$40 million annually) to make them comparable with the regional price range of between US$ 0.12 and US$ 0.18 (Bimenyimana, et al., 2018). At the end of the day, energy imports may have cost over half the value of total exports and the energy security is not one hundred percent guaranteed; such economies are unsustainable and an economic challenge to sustainable development.

2.4.5 Energy Sources Potential

Rwanda is rather well-endowed with domestic energy resources even though most of these resources remain untapped. Energy sources for electricity generation include hydropower, geothermal energy, methane gas, peat energy, solar energy, wind energy, and waste energy.

1. **Biomass resources.**

Rwandan biomass assets derived from forestry, wood, agricultural residues, organic components from municipalities, industrial wastes and wastes from landfills. Respectively, biomass resources contribute 85% and 5% of national energy consumption and GDP respectively. The following are biomass resources available in Rwanda (Ndayambaje & Mohren, 2011; Munyaneza, Wakeel & Chen, 2016).

Biogas

Biogas technology was developed in Rwanda as a solution to alleviate the hurdles of wood-based thermal needs for cooking and lighting in areas without access to electricity grid (Marge, 2009). Availability of manure supply across the country eased a rapid diffusion of this technology (Sinaruguriye & Hategekimana, 2013).

In Rwanda, biogas is produced either on a small scale by households with a biodigester 's volume ranging between 4 and 10m^3 , large scale by big communities and institutions with a biodigester's size approximately equal to 100 m^3 (Sinaruguriye & Hategekimana, 2013). The production technology in Rwanda is based on" Fixed dome model "which consists of a foundation in stones, round wall, dome, inlet and outlet made of bricks. The wastes from biogas production plants are piled then transported to the farms where they are utilized as crop fertilizers. This technology intends to reduce wood usage from over 90% to 50% by 2020. The reduced cooking energy cost in prisons of 50% and minimal biomass burning-induced pollution is remarkably advocating for the role of using biogas in Rwanda (MARGE, 2009; Sinaruguriye& Hategekimana, 2013).

Efforts should be applied through research & development and technology to improve the energy production from biomass. This will be an added value because biomass is among the best potential sources of energy available in Rwanda (MARGE, 2009). Its exploitation is still not yet well

developed as it can be used to produce energy for cooking and lighting in different forms (solid, liquid and gas) and be used in rural and urban areas.

Peat

Peat seems to be a promising alternative source of energy, as the dry peat reserves in Rwanda are estimated to be equal to155 million megatons extended to an area of 50,000 km^2. Their energy production capacity is equivalent to 700 MW that will be exploited in 30 years. The 7% of these reserves are located near Akanyaru and Nyabarongo rivers as well as in Rwabusoro plain. Power plants in Gishoma and Gisagara are respectively expected to generate 15MW and 80 MW (MININFRA, 2015). The Peat Energy Company (PEC) is an industrial scale company operating in the southwestern region of Rwanda, and it produces 13,000 tons per year with wet peat to be supplied to the Rwanda Cement Company (CIMERWA) in the region. The PEC initiated mechanical peat production in 2008; however, it is still vulnerable to its limited capacity to sustain large-scale peat production that could handle up to 50 MW of power (Hakizimana, Yoon, Kang, Kima, & Jeon, 2016).

Therefore, more investors are also needed in peat mining for use in electricity generation and under preliminary studies that endeavour to ascertain the feasibility as the operation needs a systematic and strategic planning due to hazardous effects the environment is subjected to.

Wood

Wood resources are the affordable energy source for cooking and heating for the majority of Rwandans. It is also an important source of income in Rwanda.

In 2007, the sector generated about 122 million US$ (5% of GDP) and it was nominated as one of rural development engines (Marge, 2009). Wood fuel is substantially consumed in Kigali city (20.7% of the national supply) either as raw wood or charcoal (Mazimpaka, 2013). This way of wood consumption is not efficient, and it contributes to indoor pollution, which can cause different health problems and diseases.

Methane gas

There are 59 billion dm^3 of methane gas dissolved in Kivu Lake, of which 29 billion dm^3 are extractable (UPEGAZ, 2004).

The gas originates from coupled processes which are fermentation of biogenic sediments and bacterial reduction of magmatic CO2. These reserves are expected to generate 700MW of electricity over a period of 55 years to be shared between Democratic Republic of Congo and Rwanda 350 MW each. The first extraction trial was installed in 1963 with a capacity to generate only 8000m^3 that were used to run boilers in BRALIRWA (brasserie et limonaderie du Rwanda) brewery, but thereafter in 2008, 1.8MW of electricity were generated and added to the national grid (Munyaneza, Wakeel, & Chen, 2016). Quite recently Kivu Watt project has launched its first extraction phase, which is adding 26 MW of electricity to the national grid (African Development Bank , 2010).

Hence, exploiting methane gas from Kivu Lake for electricity generation helps to avoid widespread catastrophes that could emanate from limnic (overturns) eruptions, which arise because of increasing and consequently, depressurized methane gas concentrations. Limnic reactions occurred in the Cameroon's Lakes Monoun (August 1984) and Nyos (August 1986), killing 37 people and more than 1,700 people, respectively (Rosen, 2015; Kling, 2016).

Others

Waste or power production is seen as a way of waste management evolved in order to handle the increasing amount of waste especially in Kigali city (450 tons of wastes per day) (Bimenyimana, Asemota, & Li, 2018). The other novel technology of biofuel production from Jatropha seeds emerged a few years ago after a study that revealed an estimated oil production of 25,000 tons per acre, which will increase clean fuel consumption and air quality. Both projects are nowadays in pre-assessment stage (Munyaneza, et,al. 2016; Wilson, 2010).

2. Fossil fuel resources

The conventional sources of energy are well known for its depletion with time and for greenhouse gas emission which result into climate change hazards.

Oil

Although recent studies suspected the occurrence of oil in the Nyungwe park (South-west), Rwanda does not have oil resources under exploitation and figures on the list of the least oil-consuming countries (6000bbper day) (Bimenyimana,et al., 2018). Most of the oil used in Rwanda is imported from Tanzania and Kenya.

Natural gas

Currently, there are no traces of indigenous reserves of natural gas in Rwanda. However, liquefied petroleum gas (LPG) which is imported is becoming a cooking energy alternative in urban areas (Mazimpaka, 2013). This is mainly due to minute emissions and cost-benefit facts associated with it.

3. Renewable energy resources

Energy known to be from sources that are naturally replenishing but flow limited (Janusz, et al., 2016). They are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time.

Geothermal energy

Geothermal power has the potential to provide a very suitable complement to Rwanda's other sources of energy. Geothermal power represents a stable and reliable source of supply that could also compensate for fluctuations in hydropower generation. Geothermal energy resources in Rwanda are allocated in northern and western provinces volcanic areas with energy generation capacities of 170MW and 320MW respectively (MININFRA, 2013). However, these resources are not yet exploited, their feasibility study is still being conducted.

Wind power

There are only two operating small-scale wind power generating turbines in Rwanda. One is installed in Gabiro (Eastern province) and serves for pumping water. Another one was installed at Kalisimbi summit for running FM (frequency modulation) transceiver antenna for radio and television (Munyaneza, et al., 2016). However, there is plenty of wind power regimes in the country and the government is involved in establishing an assessment with the target to identify the viable sites eligible for wind energy production (MININFRA, 2011).

Hydropower

Hydropower has generated the bulk of electricity in Rwanda since the 1960s. Hydropower is the most foreseeable renewable energy resource in Rwanda (Bimenyimana, et al., 2018). As per world's hydro atlas, 300 micro and pico-sites are present in the country even though their generation

capacity is only 26.74 MW and inefficiently serve solely 16% of the citizens. However due to floods and dryness, this resource is not stable and reliable.

Solar energy

The global solar radiation in Rwanda ranges between 4.8Kwh m^2day^{-1}minimum and 5.5KWh m^2 day^{-1} maximum given its geographic location (Rutibabara & Mutabaruka, 2018). This huge potential invoked the government to adopt solar energy as an alternative to illuminate remote areas, mostly located far from the electricity grids (EDCL, 2018a). Solar power technologies in Rwanda generate electricity by means of photovoltaic systems or heat engines. They are also used for water heating as solar water heating systems.

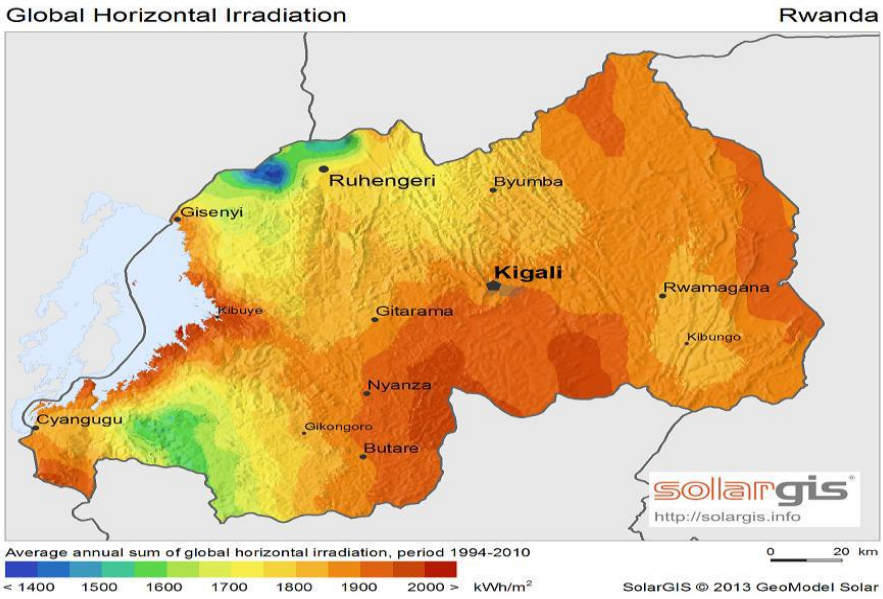

Figure 8. Global horizontal irradiation map of Rwanda. Source: Solargis Rwanda (2013)

Off grid: Households that are far away from the coverage of the planned national grid are persuaded to use standalone solar photovoltaic technology to reduce the cost of electricity access. The Rural Electrification Strategy in Rwanda approved in June 2016 outlines procedures through which every household in Rwanda could have access to electricity by the most cost effective means of developing schemes that will facilitate both the end user to access less expensive technologies and increase private sector participation in providing these solutions (MINIFRA,2019).

Mini grids are small distribution systems isolated from the national power system which include a source of power generation such as hydro or solar. These grid systems are likely to play a role in energy provision in Rwanda but, given the large investment costs of mini grid they represent 0.11% in the electricity production technology mix. From the study done for minigrid feasibility the cost of mini grid in Rwanda estimates around $1500 per connection which is higher than grid connection price (MININFRA, 2016). The government of Rwanda has committed to set up 100 solar PV mini grids in different rural areas as a solution to reduce the CO2 emission.

The mini-grid project aims to supply energy during power cuts, which are very common in the East Africa region. There are other companies working towards rural electrification in Rwanda such as Energy 4 Impact and Mesh Power. These companies have supplied 77,000 rural citizens with power solutions and created 7,000 jobs (Solar plaza, 2017). In developing countries including Rwanda, mini grids are progressively considered as an option to improve energy security, power quality and reliability, as well as to avoid power blackouts due to natural disasters (Kempener et al., 2015).

On grid

Rwanda's total on-grid installed solar energy is 12.08 MW (MININFRA, 2019).

Existing Projects

- Mount Jali in Kigali 250KWp Solar Plant. In 2006, the government of Rwanda signed an Memorandum of Understanding with German state Rhineland-Palatinate to construct, own and operate a 250 kWp grid connected solar plant and commissioning was done in 2007.It was funded by the German municipal power company Stadtwerke Mainz and installed by July 2008 (MININFRA, 2019). The plant was constructed on the top of Mount Jali in Kigali City. Since its commissioning date, the plant has been operating successfully.
- Rwamagana Solar Power Plant (8.5MW). Costed US23.7 million, the Rwamagana solar plant was built in collaboration with Gigawatt Global and is located near the Agahozo Shalom Youth Village in Rwamagana District. The electricity is being fed into the national grid under a 25 years power purchase agreement with Rwanda Energy Group Ltd (IPAD, 2015). This solar plant is composed of 28,360 photovoltaic panels and produces 8.5 MW of grid-connected power to power 15,000 homes. In February 5th, 2015, Rwanda's first utility-scale solar PV plant was inaugurated (Gigawatt, 2015).

- Nasho Solar (3.3 MW) power plant. The project was established and commissioned in 2017 to 3-megawatt solar energy to power-up the irrigation system and the surplus is used to light up homes in the area. The project was funded by the Howard G Buffett Foundation in collaboration with the Ministry of Agriculture (Tesvolt Rwanda, 2016).

Figure 9. Gigawatt Solar power plant in Rwamagana district.

Source: Gigawatt Global (2017)

Solar Energy contributes 2.2% of national energy consumption in year 2018 (RURA, 2018). It is used for heating and lighting by households, clinics, institutions, hotels, and hospitals as well as for irrigation. Solar energy is proactively alleviating the colossal electricity tariffs and high grid extension cost.

2.4.6 Rwandan Energy Policies, Regulations and Institutional Structure

1. Institution overview

A clear legal and regulatory framework for the energy sector plays a fundamental role in boosting confidence in Rwanda as an investment destination and attracting more private sector operators. The Rwandan energy policy will be well understood after having an overview of the key institutions who are contributing to the decision making, development and operation of the energy sector in Rwanda.

Ministry of Infrastructure (MININFRA): The Ministry of Infrastructure (MININFRA) is the lead Ministry responsible for developing energy policies and strategies, and for monitoring and evaluating projects and program implementation. It is in charge of setting an enabling policy and legal framework for the sector, including a suggested general approach to the optimal use of state subsidies in the sector, budget preparation, resource mobilization (MININFRA, 2015d).

Rwanda Energy Group Ltd (REG Ltd):REG Ltd sits above EUCL and EDCL. It monitors and evaluates the operations and performance of the two subsidiaries and provides senior leadership. REG is the highest corporate entity of the utility (REG, 2018).

Energy Development Corporation Limited (EDCL): EDCL is responsible for developing both generation and transmission projects, exploiting new energy resources, and executing a least cost power development plan. Its core objective is to facilitate the development and exploitation of domestic energy resources and investments. In pursuing this objective, it has autonomy in managing its affairs, but regularly reports to MININFRA on progress towards set targets (REG, 2018).

Energy Utility Corporation Limited (EUCL): EUCL oversees day-to-day operations of power generation, transmission, distribution and sales to final customers. EUCL is responsible for planning the transmission and distribution grid in areas already reached by electrification and promoting energy efficiency and demand side management programs. Key objectives for EUCL include cost reductions, technical and non-technical loss reductions, improving customer satisfaction and the economic dispatch of generation to meet demand (REG, 2018).

Rwanda Utilities Regulatory Authority (RURA): regulates both the power and gas sectors; It is responsible for: Licensing Independent Power Producers (IPPs), Approving electricity tariffs, Approving Power Purchase Agreements (PPAs),and enforcing approved technical standards (RURA, 2019).

While political responsibility for the energy sector lies primarily with the Ministry of Infrastructure, there are important inter-ministerial aspects of policy. For example, the Ministry of Natural Resources leads on exploitation of natural resources and environmental impacts (UN Rwanda, 2010). The Rwanda Development Board acts as a gateway for private developers, the Ministry of

Trade and Industry is responsible for improving overall business environment, Ministry of Finance leads on resource mobilisation to support energy sector development, RURA is the sector regulator, National Fund for Environment and Climate Change (FONERWA) leads on the implementation for green growth and climate change, Rwanda Standards Bureau develops national technical standards, and Ministry of Local Government leads on promoting decentralised delivery of basic services including delivery of some of the modern energy resources (MININFRA, 2015d) .

2. Key Existing Policies

In March 2015, the Government of Rwanda formulated the Rwanda Energy Policy (REP) and the Energy Sector Strategic Plan (ESSP). The REP sets out the overall vision and policy framework, whilst the ESSP translates the policy directives and principles into concrete measures necessary to reach medium-term targets (MININFRA, 2015).

Rwanda Energy Policy (REP) (2015) is the high-level policy document which guides and influences decisions on the extraction, development and use of Rwanda's energy resources in a transparent and sustainable manner. It sets out governing laws and regulations, strategic directions and guiding principles that Rwandan institutions and partners shall adopt and adhere to, in subsequent implementation of actions.

The REP seeks to establish energy as one of Rwanda's most dynamic sectors and attractive investment destinations. It is founded upon three essential Government principles:

1. A resolve for transparent and effective sector governance

2. Easing doing business and reducing barriers to private investment

3. Enhancing institutional, organizational, and human capacities as well as the legal and regulatory framework (MININFRA, 2015).

The Rwandan energy policy is reinforced by the Energy Sector Strategic Plan (ESSP). The REP and ESSP are mutually reinforcing: the REP outlines a long-term vision, provides high-level goals, and recommends clear and coordinated approaches for achieving that vision; the ESSP outlines targets and an implementation framework against which to measure progress towards the realization of the policy. So far two Energy Sector Strategic Plan have been published, ESSP 2015 and ESSP 2018 (MININFRA, 2015).

Rural Electrification Strategy: 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 inequality between urban and rural areas the reason of rural electrification program. According to Rwandan Ministry of Infrastructure, the government has set the following strategies which are shown in four distinct programs (MININFRA, 2016)**:**

1. Setting up the facilities allowing low-income households to gain access to modern, clean, and sustainable energy services using basic solar power systems.

2. Creating a policy that facilitates the private sector and end users of solar power products to be more financially affordable.

3. To allow the private sector to develop and create mini-grids and the government will provide the help of sites identification and proper framework.

4. To keep extending the electricity network through Energy roll out programs.

Through the above program some remarkable strides have been made by the Electricity Access Roll-out Program (EARP), under which access to the grid has increased from 364,000 households in June 2012 to more than 700,000 households in 2017 (EDCL, 2018a). The solar Rwanda Program, was scheduled for a period of 4 years (2012–2015), and had the goal of installing 12,000 Solar Water Heaters (SWH) by the end of 2015 with a total yearly saving of 23.328 MWh after installing these SWHs, but, only 2,464 SWHs had been installed in different households across the country by the end of 2017 and the program is still under intense implementation (EDCL, 2018a).

Rwanda would benefit more by transitioning to a diversified renewable energy mix than relying heavily on hydro and fossil fuel. By adopting solar, Rwanda would create jobs for millions of Rwandans; this would also boost the economy, hence giving Rwanda extra flow of money from trading carbon credit while preserving the environment (RDB, 2018). This is very possible to achieve if new regulations were put in place to enforce this initiative.

3. METHODOLOGY

3.1. Introduction

This chapter highlights different research methodologies, state the research methodology we used in the thesis and explain why we chose that methodology for this work. It indicates how data were collected, analysed and interpreted in order to answer the research questions. It describes how the research objectives were reached and achieved for the purpose of this study, which is to evaluate the solar energy contributions to the three aspects of sustainable development: social, economic and environmental in Rwanda.

3.2 Research strategies

We will use the triangular approach of sustainable development, which has three dimensions of social, economic and environmental (Del Rio & Burguillob, 2008). The approach consists of demonstrating how those three aspects interact and interrelate to achieve sustainable development. The technology used for renewable energy electricity production will be assessed through a Sustainability Assessment Framework (social, economic and environmental dimension) for evaluation purpose.

That approach has been informed and used to assess renewable energy and sustainable development in different regions of the world (Del Rio & Burguillob, 2008; Loraima & Del Rio, 2010 ; Sathaye et al., 2011; Luong, Liu, & Robey, 2012).

3.3 Research method - Mixed methods research

Nowadays, numerous researchers have turned to mixed methods methodology as a way to address the critiques of quantitative and qualitative methods, claiming that when done correctly mixed methods have something for all readers, regardless of their philosophical worldview (Cresswell, 2015). It is also stated that mixed methods are more rigorous than quantitative and qualitative methods (Schulze, 2003; Creswell & Plano Clark, 2007; Courtney, 2017). Choosing mixed methods research combines the strengths of each methodology and minimizes the weaknesses by

providing more breadth, depth, and richness as compared with either quantitative or qualitative methods.

In order to satisfy the objective of the dissertation, of assessing the contributions of solar energy to social, economic, and environmental aspects of Rwandan's life by improving the energy access, energy security, socio-economic development as well as environmental protection a mixed research method of qualitative and quantitate research method was used.

Mixed research methodology recognizes the value of knowledge as constructed through qualitative means such as perceptions, as well as experience based on the factual aspects of the world in which people live. Another key characteristic of the mixed-method research approach is that it rejects the dualism that sets qualitative or fact-based and quantitative or subjectively based methodologies as having value only in exclusivity from each other (Lebednik, 2017).

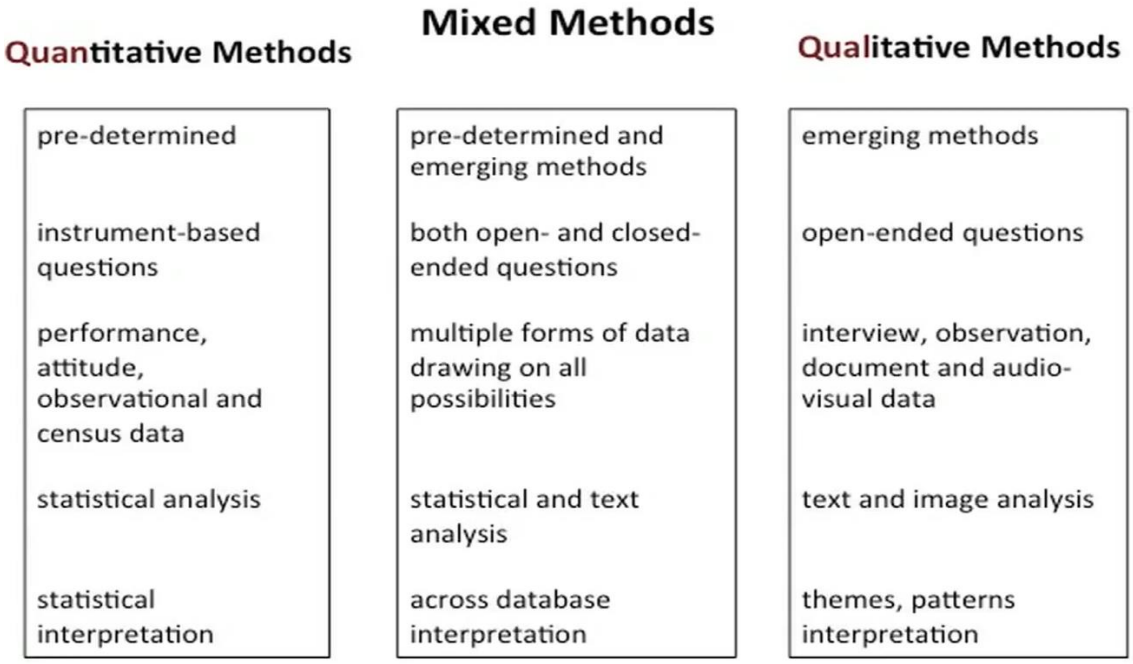

Figure 10. Comparing Quantitative, Qualitative methods versus Mixed method research
Source: Creswell & Plano Clark (2007)

The mixed method study is more complex than a purely quantitative or qualitative study because it requires ''knowledge of both,'' (Courtney, 2017). The main characteristic of qualitative research is that it is most appropriate for small samples, while its outcomes are not measurable and quantifiable. It offers also a complete description and analysis of a research subject, without

limiting the scope of the research and the nature of the participant's responses while the quantitative research focus on using numbers as its basis for making generalizations about a phenomenon. It is also concerned with analysing statistical, mathematical and numerical data through polls, questionnaires and surveys (Langkos, 2014).

The reasons for using the mixed method research approach was that it takes into account the context where qualitative and quantitative research methods are not sufficient to be used alone, because of the inherent weaknesses of each approach. For instance, quantitative research does not adequately investigate personal stories and meanings or deeply investigate the perspective of individuals. While qualitative research does not enable to generalize from a small group of people to a large population, it does not precisely measure what people in general feel (Cresswell, 2015). Which lead us to conclude that all research methods have both strengths and weaknesses and the combination of the strengths of both provide a good rationale for using mixed method.

3.4. Research approach design

In this study, numerical figures and descriptive information were obtained, giving it both a quantitative and qualitative research dimension. The study hence used both qualitative and quantitative approaches in data collection and analysis.

This mixed research methodology used involves qualitative and quantitative data collected and analysed concurrently to answer a certain research question beginning with specific observations which are used to produce generalized theories and conclusions (Creswell, 2013).

In this work, we need to understand the reasons behind the adoption of Solar Home Systems (SHS) for individual people and the country as a whole. This study will help us see the correlation between people's motives to adopt solar and the impact of solar in their daily life. We used both qualitative and quantitative research methods to know people's perspectives, stories, and feelings and to be able to quantify the importance of solar energy to Rwandans.

3.5 Study Area, Population, and sampling

Solar Photovoltaic is the most used technology to produce electricity from solar energy sources in Rwanda, whether on-grid or off-grid. The following are the studied areas, both non-probability and probability sampling techniques were used.

Study areas 1: For off-grid use, the Southern province, in Kamonyi district, Runda sector in Kanogo cell was chosen to be the off-grid study area because first the population are scattered and is one of the rural areas where the SHS dissemination is still low but growing rapidly (MININFRA, 2015). The total households who own the functioning SHS were 30 houses and we decided to interview all of them with the purpose to find out how their life is changing thanks to solar home system.

Study areas 2: The on-grid chosen site is a biggest solar power plant in Rwanda. It is in the Eastern province, Rwamagana district. The Gigawatt solar power plant has 8.5MW installed capacity. Situated at 02˚ 01' 36" S / 30˚ 22' 40" E, near the village of Agahazo, some 60 kilometres east of Kigali. The project is placed on a hillside (at an elevation of 1523m alms) and covers an area of some 20 ha.

Thanks to this solar plant more than 1500 households are using electricity from solar energy, its contribute almost 6% of electricity access in the country in 2017 (Gigawatt global, 2017). We chose this solar power plant to be in our case of study as an example of on-grid solar electricity production in rural area. At the solar power plant, we interviewed the manager of the power plant to understand the impact of this project to the economy, environment, and social aspects of the community near the solar power plant.

In this study we included also the private companies such Mobisol Rwanda Ltd, Zola Rwanda, and Off-grid box Ltd among the leading companies in SHS providing. They were interviewed to highlight and evaluate how they are changing the lives of Rwandans sustainably through SHS. In addition, to the policymakers and government bodies, some Non-government organizations were considered in this research because of the key role they play in the Rwandan solar energy sector.

3.6 Data collection method and tools

1. Survey

This was used to collect primary data from rural households who own photovoltaic solar home system, the survey involved the use of a semi-structured questionnaire indicated in Appendix7.1:A, in surveying a semi-structured questionnaire was considered appropriate since part of the questionnaire offers the house holds a choice of picking their answers from a given set of

alternatives while the other part of the questionnaire allows them to qualify their responses (Sherri, 2011).

2. Interview

This method involved the use of a semi-structured interview guide indicated in Appendix 7.1: B, has been used to collect primary data from supplier company's representative, policy makers and regulators, non-government organization, Gigawatt global solar power plant representative and Rwanda energy group (REG) off grid department.

3. Direct Observation

Direct observation was important, and it has proven to be helpful in this research area. Through direct observation different events and activities, people were engaged in and the way they are utilizing their system. Various behaviours were observed and captured, these were moreover helped in capturing different activities people doing during the night, the socialization levels in the villages in different ways were also observed. All these observations have driven further questions and the need of asking and understand from the people concerned.

4. Documentary Review

Various documents on rural electrification strategy through photovoltaic technology and other information about Rwanda were reviewed, some of them were obtained from the Ministry of infrastructure (MININFRA) and Rwanda energy group (REG), PV solar home system supplier offices, textbooks, journals, magazines, thesis, conference papers, newspaper articles, government reports, internet, and dissertations with literature relevant to the research topic were analysed as secondary sources of data to supplement primary data.

The whole process of data collection using mixed research method, the surveying and interviewing were in the form of semi-structured or in-depth interviews. Whose aim is to identify participants' emotions, feelings, and opinions. The main advantage of personal interviews is that they involve personal and direct contact between interviewers and interviewees, as well as eliminate non-response rates, but interviewers need to have developed the necessary skills to successfully carry an interview (Langkos, 2014). What is more, unstructured interviews offer flexibility in terms of the flow of the interview, thereby leaving room for the generation of conclusions that were not initially meant to be derived regarding a research subject (Sherri, 2011). However, there is the risk that the interview may deviate from the pre-specified research aims and objectives (Langkos,

2014). As long as the potential and relevant interviewees were analyzed we designed the questionnaire.

3.7 Data processing and analysis

Data were analysed both quantitatively and qualitatively, the data collected were carefully arranged, coded and analysed. The data analysis used both descriptive and inferential statistics in 23.0 versions the Statistical Package for Social Scientists (SPSS) and Microsoft Office excel 2010. The collected data were analysed according to the research question and thesis objectives.

The response got from the interview were coded into three part social, economic and environmental. Economically we looked at the following indicators: Standard of living, Wealth, and Employment; socially we considered the health, education, and security, while for environmentally we looked on the reduction of air pollution, clean air and water as well as usage of natural resources.

3.8 Ethical Considerations

The research process must ensure the participants' dignity, privacy and safety Scheyvens, (2003). In this study, social research ethics were assured. To be able to conduct this study, the permission and the introduction letter from the University were processed, after getting in the research area in Runda sector, self-introduction to the sector authorities were done and the introduction letter from the PAUWES was handed in. After identifying the households and the groups which were involved in the study, the information was sent prior the visiting house by house, the research participants were fully informed about the procedures involved in the research and were kindly asked to give their permission to participate, they were all assured of confidentiality, dignity. To ensure confidentiality, the participants were guaranteed that the identifying information would not be made available to anyone who was not involved in the study and it would remain confidential for the purposes it was intended for.

In the case of Gigawatt solar power plant, I requested the permission to visit and conducting interviews, I filled their visitor's form then pursued with the research.

In the case of private companies, public institutions, and non-government institutions, I wrote a letter requesting for the permission to conduct my research, and I attached the PAUWES introduction letter they were welcoming and willing to give the necessary information.

4. RESULT AND DISCUSSION

4.1 Introduction

This chapter highlight the result of the study, which realize the objective of this study of evaluating the contributions of solar energy to sustainable development looking at its three dimensions economic, social, and environmental in Rwanda. The primary and secondary data collected are emphasizing on photovoltaic (PV) technologies for electricity production whether on-grid and off-grid systems. PV technology is the most used solar energy technology in Rwanda, different stakeholders in the Rwandan energy sector were interviewed, including Solar home system (SHS) end users, policy makers and regulators, SHS companies, as well as non-governmental organization. Microsoft excel and Statistical package for social science (SPSS) were used for data analysis.

4.2 Result

The end users of solar energy source for the purpose of lighting and phone charging are mostly located in rural areas, where there is an absence of the national grid and other infrastructures. Most of the households are occupied by a big family with a low level of education, their income activities are agriculture, animal husbandry, and small business for subsistence, they earn a little monthly, and their power of purchase is very low.

1. General information

This study sought through data collected to find out the characteristics of the population who use Soral Home System and how SHS is impacting positively their lives. We recorded the information of the responders at each household or a shop using SHS for electricity purpose.

Table 2. SHS end user respondent's sex

			Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male		15	50,0	50,0	50,0
	Female		15	50,0	50,0	100,0
	Total		30	100,0	100,0	

The table 2 is representing the sex of responders in Runda sector, Kamonyi district who use solar home systems in their daily life for electricity purpose. We can see that the frequency percentage of female and male are equal to 50% for each sex.

Table 3. SHS end-user respondent s age

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	14-24	3	10,0	10,0	10,0
	25-35	11	36,7	36,7	46,7
	36-46	11	36,7	36,7	83,3
	47-57	3	10,0	10,0	93,3
	58+	2	6,7	6,7	100,0
	Total	30	100,0	100,0	

The respondents' age group shown in the table 3, are dominated by 25-35, and 36-46 with 36.7% for each group, and less headed respondent is in the age over 58 years .This shows that most of the respondents are youth generation they are in age of working and improve their well-being.

Table 4.SHS end-user respondent's level of education

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	never been to school	4	13,3	13,3	13,3
	primary	18	60,0	60,0	73,3
	secondary O' level	4	13,3	13,3	86,7
	secondary A 'level	4	13,3	13,3	100,0
	Total	30	100,0	100,0	

The level of education of someone means a lot on their social wellbeing and personal development, as we can see it clearly from the table 4 the end user's level of education is dominated by the primary school as the highest level of education.

Table 5. Occupants per household

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	3	10,0	10,0	10,0
	2-3	9	30,0	30,0	40,0
	4-7	16	53,3	53,3	93,3
	>7	2	6,7	6,7	100,0
	Total	30	100,0	100,0	

From the table 5 we can see that the highest frequency is for the group occupant of (4-7) with the 53,3% of frequency, this reflects a big family with many children and many of them are studying in primary school.

Table 6. Rooms per house

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	5	16,7	16,7	16,7
	2	4	13,3	13,3	30,0
	3	13	43,3	43,3	73,3
	4	6	20,0	20,0	93,3
	5	1	3,3	3,3	96,7
	7	1	3,3	3,3	100,0
	Total	30	100,0	100,0	

The rooftops of all the households are made from iron sheets, from the table 6 we can see that households with 3 rooms are the majority with the frequency of 43.3% and it is obvious that the households with many rooms are less frequent than the households with fewer, which reflect the small house occupied by big family.

Table 7. SHS end-user respondents' Income activities

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Agriculture	9	30,0	30,0	30,0
	Animal husbandry	5	16,7	16,7	46,7
	Small shop	12	40,0	40,0	86,7
	Part time employment	2	6,7	6,7	93,3
	No job	2	6,7	6,7	100,0
	Total	30	100,0	100,0	

Looking at the income activities from the table7 the small businesses is the frequent income activity because it was in the centre of the village, and they confirm that their business flourished after the usage of SHS, followed by the agriculture and animal husbandry.

Table 8. SHS end-user respondents' monthly income

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<100.000	29	72,5	96,7	96,7
	>100.000	1	2,5	3,3	100,0
	Total	30	75,0	100,0	

From the table 8 we can see clearly that almost all respondents earn monthly income which is less than 100.000 Rwandan francs, and it is possible to not even have any income during the whole month, because their income activities are seasonal.

2. PV home system information

This part of the system information looked at the most used solar home system and their usage, we found that the Solar Home Systems package available on the market are composed by the solar panel, battery, bulbs, and phone charger for the basic system some have the radio, television as well as lantern or torch.

Table 9. SHS used packages

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Basic SHS for lighting & phone charging	13	43,3	43,3	43,3
	SHS for lighting, phone charging with a television	10	33,3	33,3	76,7
	SHS for lighting, phone charging with a small radio	4	13,3	13,3	90,0
	SHS for lighting, phone charging, & small torch	3	10,0	10,0	100,0
	Total	30	100,0	100,0	

From the table 9 we can see that most of the solar home system are the basic one for lighting and phone charging with 43.3% of frequency, followed by a system with a television with 33.3% of frequency.

Table 10. SHS monthly cost

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	3,3	3,3	3,3
	4000-5000	14	46,7	46,7	50,0
	6000-10000	2	6,7	6,7	56,7
	11000-15000	7	23,3	23,3	80,0
	16000-20000	4	13,3	13,3	93,3
	26000-30000	1	3,3	3,3	96,7
	Retail	1	3,3	3,3	100,0
	Total	30	100,0	100,0	

SHS are priced variably depending on the components of the system, the capacity in watt as well as the servicing company, we can see clearly from the table10 that the frequent cost of the solar home system is for the group (4000-5000) Rwf ~ (5Usd) per month with the frequency of 46.7% mainly for the basic solar home system composed by a solar panel of 50W,1battery,3bulbs and 1 lantern.

Table 11. SHS owning duration

	Months	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1-12	20	66,7	66,7	66,7
	13-24	6	20,0	20,0	86,7
	25-36	4	13,3	13,3	100,0
	Total	30	100,0	100,0	

The study looked at the SHS monthly owning duration and we can see from the table 11 that the technology is still in the development stage, where the most frequent system owning duration is (1-12) with 66.7 % of the frequency.

The table 12, the study investigated on the distance between national grid and the household using PV solar home system and we found that majority are in the distance between 2-5 km with 60. %, followed by 1-2 km with 26.7%, less than 1 km with 10%, and in 500m with 3.3% respectively.

Table 12. Distance between the grid and the SHS household users

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	500m	1	3,3	3,3	3,3
	<1Km	3	10,0	10,0	13,3
	1-2 km	8	26,7	26,7	40,0
	2-5 km	18	60,0	60,0	100,0
	Total	30	100,0	100,0	

We can see clearly that the distance from the grid is not long but due to the limited budget of the government, Rwanda encouraged he private sector to provide the electricity access through SHS.

Table 13.Previous source of lighting

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Diesel	8	26,7	26,7	26,7
	candles	18	60,0	60,0	86,7
	piece of charcoal	1	3,3	3,3	90,0
	Torch	1	3,3	3,3	93,3
	NONE	2	6,7	6,7	100,0
	Total	30	100,0	100,0	

The study investigated means of lighting used before the solar energy and the result showed from the table13 that the candles were the most used with the frequency of 60% followed by diesel with 26.7 of the frequency. People were skeptical of using the candles because of its high probability of causing the burning accident, they went solar as an alternative for a short time believing the national grid is coming very soon. This cause some people also to not even border buying solar home system.

Table 14. Means of payment

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Self-payment	29	96,7	96,7	96,7
	government	1	3,3	3,3	100,0
	Total	30	100,0	100,0	

The study looked on how the household obtained the PV solar home system and the finding in the table 14 indicated that majority have paid the system themselves by a loan with 96.7% of the frequency and 3.3% got the system from the government aid. The ministry of health gives the PV solar system to the local health helpers.

Table 15. Main reasons of using SHS

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	less expensive	1	3,3	3,3	3,3
	far from the grid	29	96,7	96,7	100,0
	Total	30	100,0	100,0	

From the table 15, the study wanted to find out the reasons which lead people to use SHS and we find out that being far from the grid is the key reason with the frequency of 96.7% while the system being less expensive has the frequency of 3.3%.

Table 16. Challenges faced by SHS end-users

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	expensive	9	27,0	27,0	27,0
	intermittency	8	24,0	24,0	51,0
	battery capacity	4	12,0	12,0	63,0
	bad service	2	6,0	6,0	69,0
	Weak light	1	3,0	3,0	72,0
	Limited no income activities	2	6,0	6,0	78,0
	None	4	12,0	12,0	100,0
	Total	30	100,0	100,0	

The study sought for the main challenges of for the solar energy through solar home system and we found out that as it is shown in the table 16 that expensiveness has the highest frequency of, followed by intermittency and low battery life. This may result the discouragement of the solar technology end users.

Table 17. Suggested improvement

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Installations	1	3,3	3,3	3,3
	battery life	17	56,7	56,7	60,0
	flexibility	2	6,7	6,7	66,7
	price reduction	6	20,0	20,0	86,7
	more equipment to be allowed	2	6,7	6,7	93,3
	none	1	3,3	3,3	96,7
	None	1	3,3	3,3	100,0
	Total	30	100,0	100,0	

The study considered the SHS end user suggestions, the improvement of the battery life and reduce the SHS price are the two reasons highlighted by the SHS end users, the quality of the SHS should be enhanced and take into consideration the affordability of the system as well the possibility to plug on more utensil.

Table 18. SHS end-user satisfaction

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid					
	Yes, I am fine with the SHS	7	21,0	21,0	21,0
	No, the SHS need some improvement	10	30,0	30,0	51,0
	No Electricity from the grid would be better	13	39,0	39,0	100,0
	Total	30	100,0	100,0	

Looking at how how much people are satisfied by the services of SHS from the table18 we can see clearly that people prefer the electricity from the grid or much more improvement are needed for SHS to match its end-user's electricity needs.

3. Solar Energy contributions to the economic dimension

Keeping in mind the objective of this study of evaluating the solar energy contributions to the dimension of SD. In addition to 30 SHS end-users, we considered the 10 different views of stakeholders in the Rwandan energy sector aiming to find out how solar energy as one the existing abundant renewable energy potential can contribute to solve the problem of energy access shortage. The below table19 shows the types of the institutions we interviewed.

Table 19. interviewed institution & company

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	SHS company	4	40,0	40,0	40,0
	Solar power plant	1	10,0	10,0	50,0
	Government institution in charge of energy	3	30,0	30,0	80,0
	Non-government organization	2	20,0	20,0	100,0
	Total	10	100,0	100,0	

We interviewed solar energy provider through SHS company in off-grid technology and solar power plant manager in on-grid, government bodies and non-government organisation as it shown in the table 19. The Questionnaires were designed differently but had some questions in common (see Questionnaire in appendix).

To assess solar energy source contribution on economic aspects we measured how people feel about the contribution solar energy or how they perceive solar energy potential to contribute to the human flourishment the following scale were used: **5- Extremely 4- A lot 3- Moderate 2- Just a little 1-Not at all.** Interviewees responded based on how they feel about the contributions of solar energy to economic development. The findings are analyzed using the means, standard deviations. The respondents' views were variable depending on their experience for instance some of the SHS end-users do not consider this system to be very contributive economically they consider it as money taker even though it helps them to have the light.

Those who do small business they see solar home system as an alternative solution to have access to electricity even though it is limited.

Table 20. Solar energy contributions to economic dimension

	N	Mean	Std. Deviation
To work more hours than before SHS	40	3,38	1,170
Able to save money monthly	40	2,47	1,377
Feel more developed and capable	40	2,90	1,057
Started a new business thanks to SHS	40	2,57	1,196
Community have developed	40	3,22	1,050
Valid N (listwise)	40		

And from the table 20 we can see clearly how responder's responses varies, thanks to SHS people were able to work more hours than before with the mean of 3.38 and the standard deviation of 1.170 comparing this question with the one of SHS help people to save money the mean reduced and the standard deviation increases this reflects that the SHS does not really contribute much on the money saving for our interviewees.

4. Solar Energy contributions to the social dimension

In this part of the study we considered the opinions of all responders from SHS end user, SHS companies' provider, policy makers and regulators as well as non-governmental bodies. The questionnaires were designed in a way that someone will fill in according to the following scale of of 1-5 with **5 - Extremely a lot, 4- A lot, 3- Moderate, 2- Just a little, 1 Not at all**. How she/he feels about the impact of solar energy to social development.

Table 21. Solar energy contributions to social Dimension

	N	Mean	Std. Deviation
Children have time to do their Homework	40	3,25	1,316
Information &communication	40	3,40	1,008
Health& safety	40	3,45	1,085
Capacity building	40	2,80	,939
Security	40	3,20	,966
Valid N (listwise)	40		

We discovered that thanks to SHS children can use their evening time doing schoolwork and this has a keen importance to the responders with the mean of 3.25 and of course due to responder variability the standard deviation become 1.31. The fact that people can charge their phone, listen to the radio or watch tv without going miles in the search for these services got the mean of 3.40 and the standard deviation of 1.00. Good health and safety for everyone has a significant value for the responders no smoke from the solar home system and no high probability of burning accident in comparison with candles and diesel lamps this is reflected by the highest mean of 3.45 and the standard deviation of 1.08. People gained the new knowledge, emanating technicians for maintenance, innovations and other activities have enlarged with the mean of 2.80, with 0.93 of standard deviation.

well-being in the society is unthreaded when there is robbery or other insecurity resulted from living in the darkness, we discovered that having the bulb security for each house which use SHS have impacted the responders where the security questions resulted the mean of 3.20 and the standard deviation of 0.98.

5. Solar energy contributions to the environmental dimension

The study aimed to assess the said contributions of solar energy to environmental protection in the Rwandan case study by using the method of designing a questionnaire where the responders had the possibility to fill in how they feel about the contributions of solar energy to environmental preservation. The following scale was used **5 - Extremely a lot, 4- A lot, 3- Moderate, 2- Just a little, 1 Not at all.**

Table 22. Solar energy contributions to Environmental dimension

	N	Mean	Std. Deviation
Reduce Pollution	40	3,23	,862
Natural resources conservation	40	2,77	,800
Clean air& water	40	3,48	,784
Valid N (listwise)	40		

From the table 22, we can see clearly that having access to clean water and air count a lot with the mean of 3.48 and the standard deviation of 0.78, the responders value the importance of solar energy for not being pollutant and participating in production of clean water.

Reduction of pollution has the mean of 3.23 and the standard deviation of 0.86. natural resources conservation got the mean of 3.23 and the standard deviation of 0.80.

6. Awareness and SDGs Implementation

The study looked on the SDGs awareness and the challenges of solar energy progression on SHS as one of the objectives of the study.

Table 23. SDG's knowledge

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid		10	25,0	25,0	25,0
	No	30	75,0	75,0	100,0
	Total	40	100,0	100,0	

We realized that the SDGs awareness is very low. All SHS end users interviewed the do not know anything regarding the SGDs. This is reflecting the lack of awareness.

The other responders from the government bodies, non-governmental organisation, and SHS companies they have the general knowledge regarding the Sustainable development Goals. In order to increase the solar energy exploitation in Rwanda they recommend the empowerment of local players, to invest in research and development and capacity building, and to develop min-grid where it is shows a high profitability.

The main challenges of solar energy were discovered using the following scale where responders filled in how they feel about the **1.big- 2. Bigger and 3. Biggest** challenge of solar energy diffusion in Rwanda. The results are presented in the table below.

Table 24. Solar energy progression challenges

	N	Mean	Std. Deviation
Economic and financial barriers	10	2,40	,699
Regulatory barriers	10	1,20	,789
Community opposition	10	,90	,876
Cultural barriers	10	,40	,699
Capacity	10	1,70	,483
Valid N (listwise)	10		

The study sought to shed light on the main challenges of solar energy sources progression the information in the table 24 reflects what the private sector, public institutions and other key stakeholders in energy sector consider as the main challenges economic and financial barriers come first, followed by lack of capacity building and regulatory barriers.

4.3 Result discussion and interpretation

This part of the study gives the summary of the findings and the interpretation joined together the finding from the questionnaire, interviews and direct observation on the field and discussion. The findings are summarized alongside the objectives of the study and are discussed according to the relevance of the findings. Solar energy in Rwanda is used in urban area for water heating and in rural area for electricity purpose and irrigation. This particular study focused on the solar energy for electricity production which fall under the solar home system which is the most used solar technology and mainly found in rural areas.

The discussion is going to be focused on the three aspects of sustainable development economic, social, and environmental demonstrating how solar energy through its technology is contributing to those three aspects.

1. **Contributions of solar energy to economic development**

The importance of energy in economic development is recognized universally, and historical data verify that there is a strong relationship between the availability of energy and economic activity by (Kalogirou, 2004). Energy being the fuel of the economic development, the finding from the survey confirm that the fact of having access to solar energy source technology in rural areas has

helped them to increase economic activities one of solar energy beneficiaries who hold a small business said that It is safe to open his shop till 10 pm without any worry of being robbed and his clients are safer, which was not the case before having this solar home system. The other interviewee said that now it it easy to work for long hours at home they feel safer. The community seems to be developing people are starting new business and others are improving the existing ones.

On the other hand, the SHS companies are happy to be able to sell their products and also, are glad to help people to get access to electricity and contribute to people development. Many local jobs are being created through for sales agent, technician and so on.*" I am a happy man; I get my monthly salary payment and I am serving the right purpose. I am happy to wake up every morning and come to work because I know that someone out there is moving forward economically because of my work of technician"* one of the employees at the SHS company.

The public servants testify that the solar energy is so much contributing to the economic development of the population hence to the development of the country. The government has the responsibility to provide energy access to its population with the problem of the budget shortage the government opened the door and provide incentive to the private companies to invest in renewable energy to meet people's electricity demand. The solar companies are helping the government to provide energy access to people who stays in rural areas so far from the grid and contribute in the countries energy security not being so much depending on fossil fuel energy. One of the interviewee from the public institution said that " *I am working in the off-grid department and I am happy to see how many changes the SHS are bringing in for the development of our population, personally I bought a SHS for one of my family member who stay far from the grid he started a small business thank to this SHS and my nieces are able to study during the night"*

For easy interpretation and using the quantitative data, we chose the following three indicators which are linked directly to economic development and will help us to highlight the contributions of solar energy to economic development in Rwanda. We coded the the interviewees' responses into three categories matching each indicator.

Living standard: energy consumption at the household level is a key indicator of standard of living (Anderson, 2000). Modern, abundant energy can improve the living standards of billions of people and boost economic development and growth (Joyeux & Ripple, 2007). We chose this indicator in

the quest of finding out if the solar energy in rural areas is really participating in the increment of their living standard. Turyareeba, (2001) stated that the standard of living condition in rural locations is appalling and it is exacerbated by lack of modern energy. We measured the standard of living using the mean of certain questions in our questionnaire for instance how they think their life, and community have positively changed due to the SHS, we considered their income, as well as their power purchase.

Employment: we chose the employment as an indicator of economic development we wanted to identify how solar energy is contributing in jobs creation considering the link between economic development and employment proved by Melamed, Hartwig, & Grant, (2011) and Basnett & Sen, (2013). The mean values for job creation related questions were used to measure this indicator.

Wealth: Poverty reduction is the beginning of economic development and the creation of wealth (Lange, Wodo, & Carey, 2018). We chose to measure wealth as an economic development indicator, to find out if the SHS end users are increasing in their wealth thanks to SHS. in this measurement we considered the mean value of the amount of money saved per month, new business created or improved, and increased hours of working because now they have access to energy through solar home system.

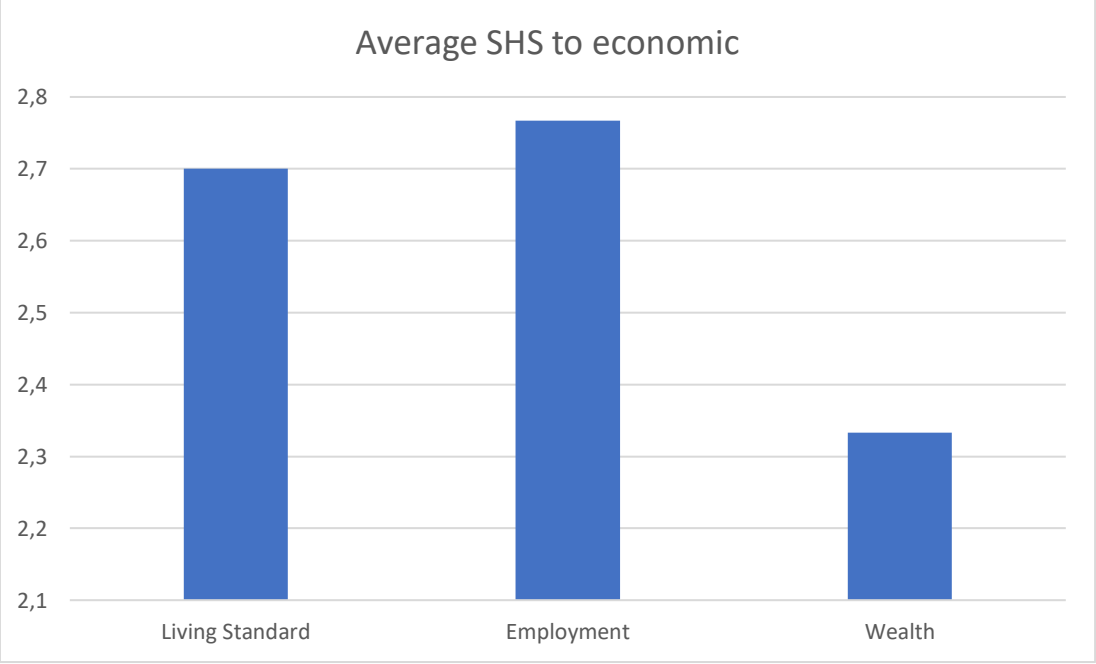

Figure 11. Contributions of solar energy to the economy. Source: Primary data,2019

We found out that the solar energy through the solar home system is contributing **2.7** on living standard, **2.75** on Job creation and **2.33** on wealth acquirement. All these indicators are falling under 3 scale which is moderate the main reasons of this, is lacking infrastructures like roads, and lack of capacity building as well as the low capacity of the available SHS which cannot be used for income activities. The contributions of solar energy to economic development is not high due to the lack of infrastructure and the solar systems used have the limited capacity because they cannot be used for some income activities which confirm what Paul cook(2011) discussed that electrifying remote rural areas has been slow in impacting people's lives economically due to lacking of the necessary infrastructures and other complementary service to support rural electrification.

The main rural economic activities are agriculture, husbandry, and other small businesses for subsistence. The average income from the people who use SHS system we interviewed is 40.000FRW~ 43 Usd, this monthly income is very low to pay for all household expenses, school fees for their children and the pay the SHS that cost in average 4.895 Usd which is around the 11..25% of their income. In addition, their incomes are seasonal this result to some people end up losing their system because they failed to pay.

However, RE can also contribute to increasing the reliability of energy services, in remote and rural areas that often suffer from insufficient grid access. The contributions of Solar energy on-grid technology in Rwanda were assessed using the secondary data from the biggest solar power in the country (8.5MW) which contribute economically in the increase in Economic Output (GDP): USD $9.27 million – $10.81 million per year (0.12% – 0.14% increase to estimate in 2015). Direct employment provided: 50 jobs for long-term maintenance and servicing and Indirect Increase in employment were about 4,900 – 5,800 jobs (0.11 – 0.13% increase to employment estimates) mostly for Rwandans nationality. This solar power plant is connected to the grid and it provides the electricity from solar energy to 15,000 – 18,000 households. The challenge with the on grid solar power plant require a huge land which could be a big problem for small countries like Rwanda.

We can see clearly that with the proper infrastructures in place and appropriate renewable energy technology people could experience the significance contributions of solar energy to their economic development and wellbeing. Stated that Energy is a prime agent in the generation of

wealth and a significant factor in economic development (Lange, Wodo, & Carey, 2018). No doubt the solar energy is contributing to the economic development of developing countries.

2. Contribution of solar energy to social development

Socially development is impacted by the energy consumption, the finding of this case study shows that thanks to electricity from solar energy source through Solar Home System student have time to study people can charge their phone and listen to the radio and be informed.

Most of the household w interviewed were families who have two to Three children who go to school, need security and good health. We found out that the reason that pushed them to buy the solar home system is for their children. One of the the responder said that" *It was very challenging for my one child to do her homework and revision during night and also challenging to her health and safety, she was always coughing because of the smoke from the diesel lamp, and I was constantly afraid that she will burn herself but now I feel more safe with this solar system, I make sure to pay on time I do not want to use again*"

The community enjoy the light from the SHS they confirm that security have increased no more robbery, because many people have the security bulb in front of their houses.

On the other hand of the government Solar energy sources are contributing much on social aspect where schools and hospitals have the electricity from the solar energy, the services have improved now.

The information collected informing the social aspect is interpreted using the three following indicators which are linked to social development, may response during the interview were coded to match these social indicators to shed the light on the contributions of solar energy to social development.

Health: Better health is central to human happiness and well-being. We chose this indicator taking into consideration the value means of the source of lighting people are using in comparison to time they were using diesel or candles. The consequences of using diesel lamps and candles are infant mortality, other breathing complications, and illness. People switching to SHS for lighting of course benefited their lives. We wanted to know at which level they value using SHS instead of those traditional means of lighting.

Education: Education is a powerful driver of development, there exists a high correlation between the attainment of education and social dimension of development at an individual level (Venkatraja & Indira, 2011). This reflects on the importance of education in influencing the social well-being of individuals. By choosing this indicator we considered the importance of having the light during the night so the student can have enough time to do revision and homeworks.

Security: we talk about society well-being when we have security no robbery or other insecurity resulted from living in the darkness, lack of the public light, and the vulnerability on burning accident due to candles. This indicator was chosen to identify the importance of using the SHS at the household level and in the community if it could contribute to robbery reduction or other insecurities due to the darkness. At which rate the SHS end user value it and how SHS is increasing the security in their home as well as in their community.

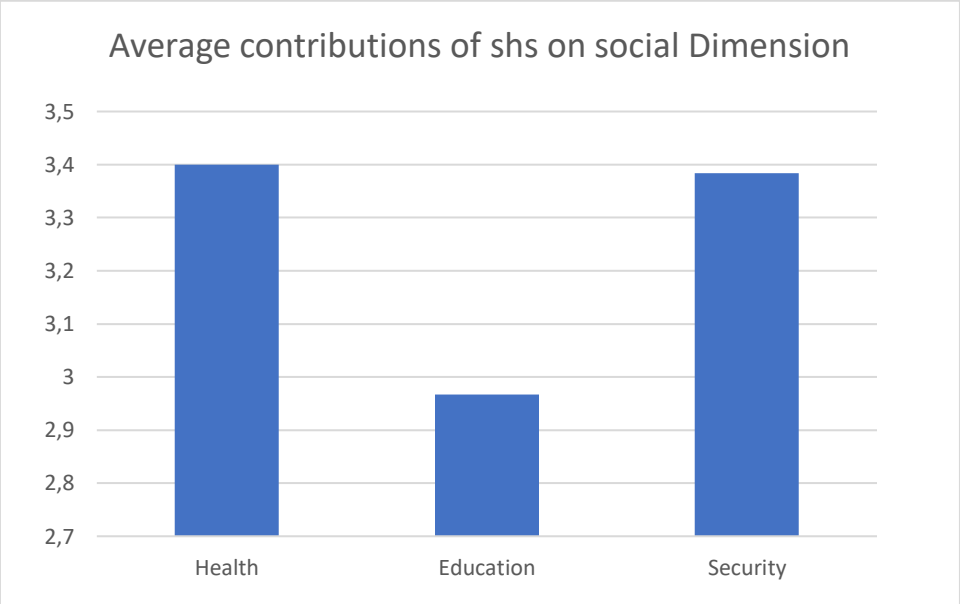

Figure 12. Contributions of solar energy to the social dimension.

Source: Primary data,2019

We can see very well that the health has the scale of **3.4** which is quite moderate but not as much as possible, people‘s life is still in danger because of using woods for cooking which cause air pollution and breathing difficulties, but at least inside the house, there is no smoke from diesel or candles.

Education got **2.98** which is moderate and the least score because mainly these SHS provide light during the night for few hours and cannot in the early morning when children want to do their homework and revision this cause frustration to the SHS end user parents. Another reason for this low score is because some families do not have someone who enrolled in school, and the score goes down. One of the responders said" *I am better now, I am no more worried about how my children will do their homework because I have an SHS on my house before when we were using the candles I was constantly afraid of my children being burned by the candles*." The only problem is the intermittency of the system that cannot provide the light for the whole day so that my children can study any time they wish to as it is the case for on grid electricity end users".

The security got **3.38** which is moderate people are happy to have the light on their house they can go out during the night without any problem or coming home late. Even though the community does not have the public light they feel more secure because most of them have the security bulb in front of their house which makes the whole community looks like having the public lighting. One of the responders narrated. "I was afraid at the beginning when I come here for the first time, the place where I was before the electricity was not a problem , I am a business woman wake up early in the morning leaving my child alone with candles, I was constantly anguished that it can burn my house and my child, coming home later in the evening it was a big challenge because of the darkness. The alternative of using SHS saved my life now I can go and come back home at any time without being terrified of any accident with candles."

Education, health and social protection systems provide people with an opportunity to develop from their own resources and live independently. More – education and health are human rights. Solar energy is contributing to the energy access through its technologies allows local communities to widen their energy choices. Provide supplementary health and education benefits.

The potential of access to energy to stimulate social development, was also informed by the study of Jaramillo-Nieves & del Río, (2010). They discussed how renewable energy could contribute to the social well being of islands. the result from our case showing that solar energy is positively impacting the wellbeing of the community and this is also informed by the IPCC report where they assessed the impact of renewable energy to social aspect and (Karekezi & McDade, 2012)that access to reliable, affordable and modern energy stimulate the social development.

3. Solar Energy contributions to the environmental dimension

Sustainable development (SD) should ensure environmental quality and prevent undue environmental harm, this SD's dimension seemed to be not well considered in the whole process especially for the SHS end users and even some have no idea of what it is or what it represents. The further explanations and examples were needed to make it clear.

We used the three key elements of environment which are the clean air and water, reduction of pollution as well as the natural resources preservation. The fact SHS does not pollute water and air was significant importance in the eyes of SHS end-user.

Solar home system companies are very glad to participate in the pollution reduction and natural resources preservation.

To interpret the contributions of solar energy to environmental aspect from the responder views. we used the following three indicators which are natural resources, pollution reduction and clean water and air to see the importance of these three to the specific conditions of the community beneficiaries of solar energy.

Natural resources: Well managed natural resources are the benefit of present and future generations. We cannot speak of environment protection and forget about natural resources conservation. In our quest of finding out how solar energy is contributing to natural resources management for this case study, during primary the data collection we realised that the natural resource is not a good indicator for this study because people in rural area do not understand what is it and this reflects the lack of awareness.

Pollution reduction: Pollution depends on energy consumption; renewable energy is known to be no pollutant the reason why we considered this indicator to measure the contribution of solar energy as one of the renewable energies to reduce the pollution. The pollution is not well known in rural areas.

Clean air and water: Polluted air and water it is a big danger to the human being and the whole ecosystem (Sathaye, 2011). Using solar energy contribute to the reduction of air and water pollution. We chose this indicator to find out at which rate people are aware of the importance of using non pollutant energy resources.

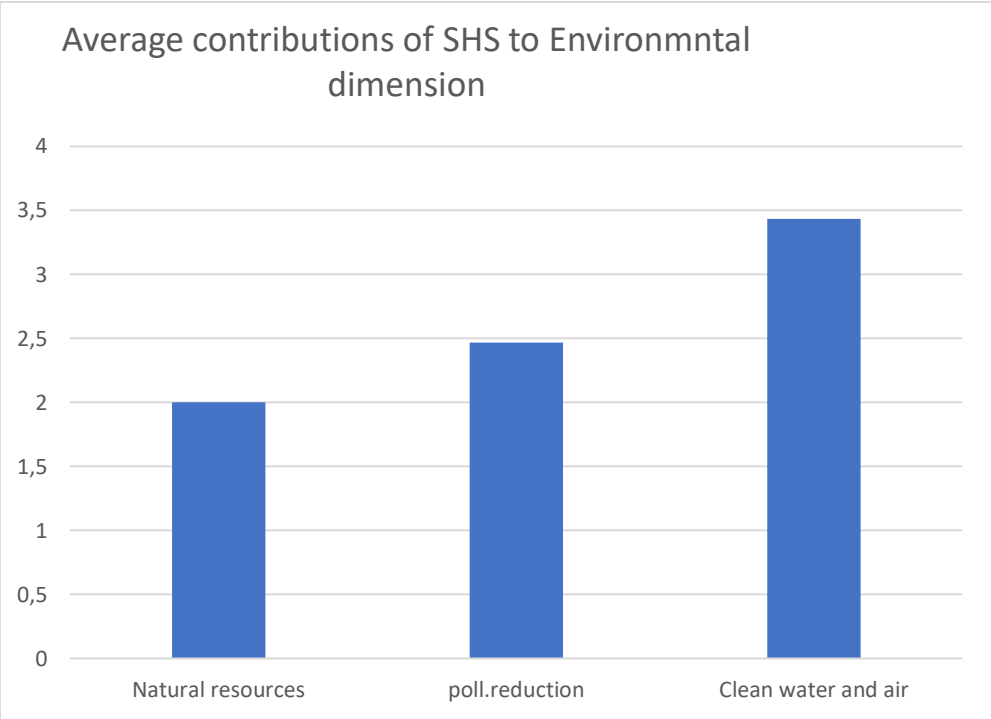

Figure 13. Solar energy contribution to the environmental dimension

Source: primary data,2019

Measuring those three indicators natural resources, pollution reduction, and clean air and water by using the following scale: **5- Extremely 4- A lot 3- Moderate 2- Just a little 1-Not at all.** We got the result below.

Natural resources got **2** which stand for just little contribution, pollution reduction got **2.5** which is between moderate and just a little, while clean water and air has **3.49** which is moderate. Clean water and air indicator were understandable enough. It could thus contribute to the goal of ensuring healthy lives by replacing the source of indoor air pollution and by improving local air pollution from co-emitted air pollutants (West, et al., 2013).

irst because they are familiar with the terms, and it is very important in daily life. In agreement by Solar energy is tremendously contributing to environmental aspects in Rwanda and also much are needed to be done because using renewable energy technology is a way forward to preserve our environment and mitigate the climate change (IPCC, 2014).

4. The Sustainable Development in this study context

To achieve the sustainable development (SD), we need to ensure the sustainability of energy system, which is reliable, affordable, sustainable and modern. The commitment of achieving the sustainable development in its three aspects economic, social and environmental in a balanced and integrated manner was established by UN in 2015. Energy has a central role to play in SD achievement as it affects the social, economic and environmental development aspects, including livelihoods, access to clean air and water, wealth, health, security, education, as well as pollution mitigation. Energy access is the golden thread that weaves together economic growth, social development, and environmental sustainability in harmony.

In our case study considering the triangular approach of those three aspects we calculated the contributions of solar on each one, the result is shown in the figure 14 below, representing the contributions of solar energy technology through SHS on the social, economic and environmental dimension in Rwanda.

From the finding presented in the figure below, it is shown that the contributions of solar energy to social development is the highest with the score of 9.75 resulting from the significance of the social indicators (health, education, and security) to the community we interviewed. The contributions of solar energy to environment indicators (natural resources preservation; reduction of pollution and clean air and water) is the next with the score of 8.99. Economically solar energy is contributing to living standard, employment, and wealth at the score of 8.9 which is the third.

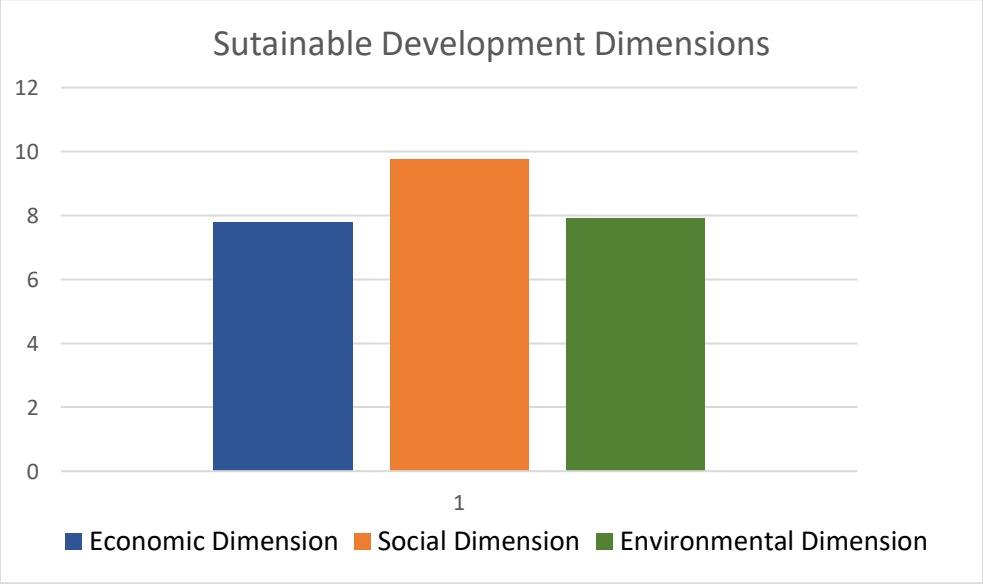

Figure 14. Contributions of solar energy to three dimensions of sustainable development

Source: primary data,2019

Socially, solar energy is helping Rwandan community in a rural areas to feel included in the race of the development, it is contributing in capacity building where it provide the opportunity to Rwandans technician to be trained on the technology of solar its functionality, assembling, and reparation. Rwandan technician students in Renewable energy get the opportunity to visit those places and some get the internship which help them to acquire the practical knowledge. One of the student who is doing the internship in the solar home system stated that" *This opportunity to be exposed in solar energy technologies help me to increase my knowledge and skills in practical work for example to understand the fabrication of solar panel, to know how the solar system work and to know different components of solar system and how to repair them*."

Security, Renewable energy sources through solar home system is contributing to provide the lighting in the community far from the national grid the security has increased, shop owners can work more hours during night without fearing to be robbed, the client can stay longer one of the people we interviewed said that "nothing better like to come home later in the night when there is light on your house you feel more secure." Thanks to solar energy, schools and hospitals now have the electricity the quality of service they provide have increased. Solar energy which is produced locally provided the electricity alternative which could have taken longer to wait for the national electricity grid. This is confirmed, the decentralized RE is competitive mostly in remote and rural areas, while grid-connected supply generally dominates denser areas where many households reside (Deichmann et al.,2011).

Economically, Solar energy for electricity production is not contributing that much because of its expensiveness the average cost of SHS per month is the 11.25 % of the average monthly income of SHS end-users interviewed , its intermittency, and low ability to be used for more and big economic activities which can generate the income. Comments from the interviewed people said that this solar home system is very limited "*I cannot use my fridge with this solar system, or other appliances and when there is no sun during the day it is hard even to light during the night or watch a tv which is not good for my business."* In addition the price of electricity from the gird because it is subsided by the government its price is lower than the price of solar home system and this is a burden to solar home system end users because most of them are low income household and their power purchase is very low.

Environmentally, solar energy is contributing a little and more efforts are needed especially in creating awareness among the population in rural area. It is very important to understand the importance of the SHS on the environment at a household level, regionally and globally this will also enhance the way we use the available natural resources. In rural area the main reason to go solar is because people are far from the grid not because they want to reduce the pollution and all of them, they prefer the electricity from the grid no matter how it is produced.

In the study of Jaramillo-Nieves and del Río (2010) confirmed that renewable energy sources (RES) have significant potential to contribute to the economic, social and environmental energy sustainability of small islands (Jaramillo-Nieves & del Río, 2010). RE improve access to energy for most of the population, they also reduce emissions of local and global pollutants and they may create local socioeconomic development opportunities.

Improving access to clean, affordable and reliable energy supply will therefore not only provide improved energy services, but it may also broadly increase productivity and avoid parallel investments in infrastructure, from small-scale generation equipment to parallel lighting and other economic activities that require the electricity. In this case study we found that before the usage of SHS the majority were using the candles and diesel lamps, which were not favourable for their health because of the smoke, it was hard for their small shops to flourish using the candles for lighting and also they were a high probability of burning accidents due to candles usage.

The contributions of solar energy to sustainable development in Rwanda It is obvious but more are needed to be done in order to ensure full achievement of the potential SD benefits from RE deployment, it is essential to put in place coherent, stable and supportive political and legal frameworks, suitable renewable energy technologies, and the appropriate tools for Investment should stipulate the development impact that in turn can empower communities, develop healthy societies, foster business growth, and improve African livelihoods.

A widespread access to energy in Africa is a precondition to unlock its potential for sustainable, inclusive, economic growth and make a difference in hundreds of millions of African lives.

The solar power plants in Rwanda are doing much better in impacting people's lives socially, economic, and environmentally but is much more expensive, and the fact that Rwanda is a small country with a high density of population the land could be a problem.

This study confirms the importance of solar energy to the sustainable development of Rwanda and this is in agreement with the study done by Sathaye, (2011) he discussed the role of renewable energy to sustainable development he found out that renewable energy deployment can contribute to the three sustainability dimensions at the regional level. Second, the existence of local participatory processes is crucial for the implementation of renewable energy projects because the acceptance of this project by the socioeconomic actors in a given territory facilitates its deployment (Sathaye et al., 2011).

5. CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the summary, conclusion, recommendation, and areas of future study on the topics related to the contributions of solar energy to sustainable development in Rwanda. The recommendations are addressed to all Rwandan energy stakeholders: policy makers, regulators, companies' suppliers, investors, households' members, and readers to achieve sustainably the universal energy access by 2024 considering the three dimensions of sustainable development.

5.2 Conclusion

The objective of this study is to evaluate the contributions of solar energy to the dimensions of sustainable development with the hypothesis of assuming that the effective exploitation of solar energy would increase its contributions to the social, economic and environmental aspects of Rwandans. It has been proven that renewable energy resources contribute to ensuring energy access, energy security, socioeconomic development, and environmental protection. Rwanda as a small and landlocked country with few natural resources has not been dormant to that importance of renewable energy has started to exploit its renewable energy potentials to meet the universal energy access. The electricity access in Rwanda has increased exponentially the current electricity access is 51% (37% On-grid and 14% off-grid) and solar energy contributes to 2.2% in the electricity production mix. Rwanda has the solar potential of solar radiation intensity approximately equal to 5kWh/m^2/day and peak sun hours of approximately 5 hours per day and this is significant potential to be exploited.

The approach used to assess the contributions of solar energy to sustainable development is the triangular approach looking at the economic, social, and environmental aspects which are interrelated. The data were collected using the mixed research methodology involving quantitative and qualitative research.

The major finding is that the solar home system is the most used solar energy technology for electricity production and is frequent in rural areas through solar home system, the system is composed by small solar panel, battery and bulbs television and radio are optional.

The frequent level of education is the primary school level, their daily activities are agriculture, small shops and animal keeping their monthly income is lower than 100.000 Rwf (<150$) which reveal the low power purchase the average monthly income of SHS end users is 40.000Rwf ~43$, at the end of the day SHS looks expensive and unaffordable because its average cost is 11.25% of the income.

Bearing in mind the purpose of this study we found out that the solar home systems are contributing much on the social aspect (Health, Education, and Security), economically solar home system has low contributions due to its expensiveness and limited capacity. SHS is expensive comparing to the electricity price from the grid this difference is due to the subsides from the government, in addition, SHS cannot be used for economic activities that require a lot of electricity, it does not meet the electricity needs fully more than lighting ad phone charging. Environmentally solar home system is contributing to the preservation of natural resources, pollution reduction and to clean lean air and water this dimension is not fully known in the rural area where they value the access to clean air water, the preservation of natural resources and reduction of pollution are not considered to be significant enough to them, and this is lack of awareness.

Solar energy is very much contributing to the sustainable development of the Rwandans especially in a rural area where people are far from the grid and waiting for the national grid could take longer. The solar energy gave another alternative to provide the electricity to people and help the country to diversify its electricity resources which contribute to ensuring the country's energy security.

This study agree also that the expansion exploitation of solar energy will contribute much but the suitable technology should be well investigated to avoid any competition with the agrarian land because there are many technologies out there of solar energy electricity production, for example, rooftop solar power plant which has more chance to succeed in Rwanda because of its geographical characteristic and its demographic people can produce their own electricity and sell to the grid once the measures of reducing the grid loss will be taken and implemented.

The expansion of renewable energy technologies is a supporting pillar of the energy revolution. Its goal is the sustainable transformation of the current energy system. Despite being positively acknowledged as low-emission technologies, some side effects such as fluctuating energy production, competing with agriculture on land use and effects on biodiversity challenge of solar energy in Rwanda.

5.3 Recommendations

The recommendations of this study are emphasizing on the three-points which are policy framework and regulations, Research and development on the suitable decentralized Renewable Energy technology, and Awareness.

- Adopting a renewable energy policy which aims to prioritize the increment of renewable energy in the energy mix, promote the participation of local players in the energy sector, avail the necessary infrastructure to stimulate the development, encourage the banks and other private sector to be involved in the achievement of the universal energy access to reliable, affordable sustainable ad modern.
- Research and development in energy (R&D) are the backbone of a good decision making and the development of a country, to enhance the impact of research will necessitate the partnership between government bodies, private sector, non-government organization and the universities(researchers) and a financial investment tools. This will stimulate researchers in the energy sector especially in the suitable technologies matching with Rwanda's conditions and situation. The huge investment will be needed for this initiative and the focus should be in decentralized electrification technologies, smart grid and smart metering, energy efficiency and innovation to achieve sustainable universal energy access in Rwanda.
- Awareness campaign and Education are the two important keys thing to do a successful implementation.

5.4 Area of further research

- Contextualization and Institutionalize the sustainable development concept in Rwandan energy sector.
- Assess the technical and financial feasibility of Mini grid technology in Rwanda to accelerate universal energy access.
- Evaluate the renewable policy adoption methods and assess the role of gender inclusion in the energy sector.

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7. APPENDIX

7.1 QUESTIONNAIRES

1. Questionnaire to household using SH System

Dear Respondent,

The researcher is a Master student in Energy Policy at Pan African University; Institute of water and energy science Include climate change located in Tlemcen Algeria. This is purely an academic study on a topic titled ‘‘Assessment of contributions of solar power to three aspects of sustainable social development, economic and environmental in Rwanda’’.

Runda sector in Kamonyi district has been selected to participate in this study because of relevant information on this topic. The information you provide is solely for academic purposes and will be treated with utmost confidentiality. Kindly spare some of your valuable time to answer these questions by giving your views. Indeed, your name may not be required.

Thank you for your time and cooperation

Section A: General Information/ (Please tick the appropriate option) Head of the family

1. Your sex: (a) Male (b) Female
2. Your age group: (a) 14 – 24 (b) 25 – 35 (c) 36 – 46 (d) 47 – 57 (e) 58 and above
3. What is your highest level of education?
   (a) Never been to school (b) Primary (c) Secondary (d) Post-secondary (e) University
4. i) How many people (occupants) live in this house?
   (a) 1 (b) 2-3 (c) 4-7 (d) More than 7
   ii) What is the level of education completed in the house?

- Number of people with primary studies or studying ☐
- Number of people with secondary studies or studying ☐
- Number of people with higher education or studying ☐

5. i) What is the materials from which the roof of your house is made from?
   (a) Tiles (b) Iron sheets (c) Thatched
   ii) How many rooms does the house have? ☐
6. i) Income activity…….

ii) What is the average monthly net income in Rwandan francs of the household?

(a) Less than 100.000 (b) Over 100, 001

7. System composition: Pv ☐ W battery ☐ AH Power controller ☐

Lamps☐ Phone charger☐ Television☐ Other…….

8. How have you got the PV system?

(a) Government / Ubudehe (b) self-payment

If yes (b) On average, how much do you pay for your system monthly?

(a) Less than Rwf 500 (b) Rwf 500-1000 (c) Rwf 1000-2000 (d) Over Rwf 2000

9. What were you using as a source of light Before this system?.....

Are you aware of climate change? Yes or no

If yes, what do you know about it

11. Reasons for buying the solar home system SHS is because it is: is expensive ☐

(b) Far from the grid ☐ or Not pollutant ☐ Other ☐

12. What is the distance between household and grid connected household (a) Less than 500metres (b) Less than 1 km but more than 500metres (c) 1-2km (d) 2-5km (e) More than 5km.

13. How long have you owned your system for?

Section B: Pv Solar Home System contribution to Social - Economic – Environmental

14. Do you think that this system has helped you financially Yes how? Or No
15. Do you think that you are saving money by using this system in comparison of before it?
16. What other benefits of this system to your family?
17. Do you know if someone in your community has/had a job thanks to SHS?
18. Is there any change observed in the community when people started to use SH system?
19. What are other benefits of SHS in your community according to you?
20. Using the scale below, rate how you feel about PV (SHS) has it really been helpful to you or your family member and your community?

5- Extremely a lot 4- A lot 3- Moderate 2- Just a little 1-Not at all

Social	5	4	3	2	1
My children are performing better in class because they have more time to revise at home and do their homework					
I have access to information now I can use my radio and charge my phone for communication					
Because of SHS my health and that of my family is better no smoke					
I feel more secure because I have a light on my house during the night					
I gained more knowledge and skills					
The security has increased in the community					
Economical					
I work more hours than before because of SHS					
I save money every month thanks to SHS					
I feel more developed and capable					
I started a new business thanks to SHS					
Our community is developing because of using SHS					
Environmental					
My house is clean, no more smoke					
Pollution has reduced					
Using efficiently the free source of energy					

Section C: Challenges and Sustainability

21. Have you ever heard of sustainable development goals? No or yes What do you know about it

…… ……...

……

22. Which company does it supply you the system?

……

……..……...

23. Are there any challenges faced in using PV?

……...…

……...……

24. Are there any improvements do you feel could be made to your system to be more sustainable?

…….....

……..

25. What are the services do you get after receiving the PV from system supply?

……

……

Thank you for taking time to respond to Questions

2. SHS Private company office worker and field agent

Dear Respondent,

The researcher is a Master student in Energy Policy at Pan African University; Institute of water and energy science Include climate change located in Tlemcen Algeria. This is purely an academic study on a topic titled ‘‘Assessment of contributions of solar power to three aspects of sustainable social development, economic and environmental in Rwanda’’.

Your company Mobisol Rwanda ltd has been selected to participate in this study because of relevant information on this topic. The information you provide is solely for academic purposes and will be treated with utmost confidentiality. Kindly spare some of your valuable time to answer these questions by giving your views. Indeed, your name may not be required.

Position:

Section A: General Information/ (Please tick the appropriate option)

1. Your sex: (a) Male (b) Female

Your age group: (a) 14 – 24 (b) 25 – 35 (c) 36 – 46 (d) 47 – 57 (e) 58 and above

2. What is your highest level of education?

(a) Never been to school (b) Primary (c) Secondary (d) Post-secondary (e) University

3. For how long you have been working in this sector Years ▭ Months ▭

4. Before working in an SHS company what was your occupation? In which sector

5. How could you describe your job? Have you been trained or attending regular training to do this job?

6. How many times you go to the field in a week?

7. Income activity…….

i) Are you doing another job apart from being a technician in this company?

ii)) What is the average monthly net income in Rwandan francs of the household?

(a) Less than 100.000 (b) Over 100, 001

8. What do you use for lighting in your house? Have you ever used another source of energy for lighting before?

9. Is anyone in your family member or neighborhood using an SHS at the house for lighting?

10. What do you think of sustainable development goals?

11. What do you think about energy sustainability?

12. What is the status of energy sustainability in Rwanda?

13. Do you think Rwanda could be powered entirely by renewable energy resources?

14. Why solar energy or SHS?

15. Using the scale below, rate how you feel about Solar Home System SHS energy contributions to sustainable development in Rwanda?

5- Extremely a lot 4- A lot 3- Moderate 2- Just a little 1-Not at all

Social	5	4	3	2	1
Solar energy is contributing to the wellbeing of a society					
S.E favorising good health and safety					
S.E is viable and reliable for a long time					
S.E contributes to the inclusiveness of the local players and to the welfare of its employees					
S.E contributes to offer access to information and help in capacity building of the community					

Economical					
S.E is an added value to stakeholders					
S.E increase income activities, hence the growth					
S.E increase profitability					
S.E favours the efficiency					
The community feels more empowered having solar power					
Environmental					
Efficient use of primary and other resources					
Help reduce pollution					
Waste handling and recycling					
Conserve water and land					

16. How Rwandans are they responding to the products and services you offer?
17. How many jobs does your company created for Rwandese?
18. When offering your product and services to your customers is the pollution reduction reason matter to your clients
19. How your company creates or participate in awareness of environmental conservation?
20. What are the main challenges do you facing when providing your products and services?
21. What do you believe could be a sustainable resolution to those challenges?
22. What do you believe will be the potential additions of solar energy progression to social, economic and environmental aspects in Rwanda?
23. According to you is off-grid system effective for your clients? What will be youe recommendations?
24. What do you think of empowering the local private sector in solar energy production?
25. Rate according to you from the 1-big 2-bigger 3-biggest challenges of solar power progression in Rwanda

    Economic/financial……

Regulatory barriers…….

Community opposition….

Cultural barriers….

Others… …….?

26. What do you propose that could be a sustainable solution to those challenges?
27. What are your recommendations or suggestions to increase the exploitation of solar energy in Rwanda?
28. Any plan for improving your products and services for them to be more sustainable and improve lives social, economic and environmental

7.2 PHOTO PLATE.

One of the converter At globalwatt solar power plant in Rwamagana district

7.3 BUGDET ALLOCATION

No	Description	Cost in DA	Cost in RFW	Cost in USD
1	International flight Local flight two ways Data collection transport	134487	 360,000	**1136,088$** **67.94$** **398,99$**
2	Internet monthly modem		225,000 95,000	**272.5$** **113.54$**
3	Digital recorder	13000		**109,81$**
4	Questionnaire printing, photocopy and translations		450,000	**503,60$**
5	Research fields assistant			**87.53$**
6	Thesis printing and binding Publication Poster			**100$** **150$** **60$**
	TOTAL			**3000$**