An Evaluation and Development of the Potentials of Photovoltaic Systems for Water Pumping and Electricity Services in Rural Areas of Nigeria

Mobolaji Agbolade Onasanya

Institute of Energy and Sustainable Development
De Montfort University

Thesis submitted to De Montfort University in partial fulfillment of the requirements for the award of Doctor of Philosophy

May 2017

Abstract

Rural electrification has been a priority for many governmental and international donor organisations. Grid extension and various renewable energy technology (RET) options are recognised as viable means of providing enhanced energy and water services to isolated rural communities, and these have been successfully deployed in many regions across the world. In Nigeria, decentralized energy generation systems based on solar PV systems are often used to meet the low energy demands of rural areas and they have also been widely adopted for water pumping purposes in these places. However, the failure or underperformance of many of these installations is in stark contrast to their theoretical viabilities as asserted in many academic papers; this suggests deep underlying problems. Such failures have discouraged government and policy makers from supporting solar PV and, as an extension, other forms of RE projects as viable options for isolated rural locations, even when grid extensions to these places often remain economically and practically challenging. Hence, whereas a number solar PV projects have been implemented in rural communities in the country, appraisal of their success and failures has moved at a much slower pace. Evidence is needed, not only about the factors that contribute to the deployment of these RE installations, but also on issues that took place after such installations have been completed: if the technology fulfils people's needs and priorities, if the equipment remained in working order and for how long, and the particular and general decisions and actions that may have contributed to the success or failure of the installations.

The aim of this study is therefore two-fold. Firstly, to reveal and understand the fundamental issues and factors that mitigate against the proper deployment, diffusion and performance of solar PV installations in isolated rural locations in Nigeria and, secondly, to develop a framework and set of recommendations that could lead to improved deployment processes and better performance of such installations. In order to understand and address these fundamental issues, a systematic analysis of relevant literatures on renewable energy technologies and technology diffusion is initially undertaken. In addition, multiple methods including site visits, observation and physical evaluation of installations, interviews and discussions with stakeholders and key players, and seven exploratory studies of rural communities are utilised to collect primary data on the performance and effectiveness of solar PV installations. Thirty-Eight indicators across five core sustainability dimensions of Technical, Economical/Financial, Environmental Impact, Social-Ethical Development, and Institutional Development and Government Policies are used to assess and evaluate the study cases, revealing diverse and interconnected pre- and post-installation factors that contribute to both successful and failed installations. A main finding of the study is that involvement of private energy providers in the deployment and running of solar PV installations in rural communities in the country is more effective than the sole use of government agencies or contractors. It was also revealed that a number of factors including weak or absence of post-installation maintenance arrangements, non-existence of local representative authorities, failure to enlighten local residents on limitations of the installation and to train them on basic maintenance practices, weak implementation and low success of government policies, weak institutions and overlapping functions of government agencies impacted negatively on the performance of the installations. In addition, the study provides insights into the interrelationships between the factors; how the presence or absence of some can strengthen or weaken others. Finally, a framework and set of recommendations are generated that could support improved deployment procedures and enhanced performance of solar PV installations in rural communities. Although the study deals with the Nigerian situation, some of the findings can be readily extended to other developing countries with similar challenges in the provision of energy and water services to isolated rural communities.

Acknowledgement

Foremost, my deep appreciation goes to my supervisors, Dr Andrew Wright and Prof Mark Lemon, for their unwavering patience, understanding, and support towards making this study a rich and rewarding experience. I am indebted to them for their numerous suggestions and constructive criticisms that helped to chart the path for the study and, ultimately, led to defined outcomes. I also thank my local supervisor, Dr Peter Oluseyi for his guidance and encouragement. My gratitude goes to Dr Neil Brown who, though is not a member of my supervisory team, was available when required; and to the staff of the Institute of Energy and Sustainable Development (IESD) for creating an inspiring atmosphere during my study.

I acknowledge that this research has been made possible as a result of access to information provided by a number of organisations and people, especially during the fields work aspect. I am grateful to the staff of the Ministry off Rural Development and those of the Lagos State Electricity Board. I express my appreciation to all the participants, especially the numerous rural dwellers who willingly and enthusiastically provided valuable information during the study. I thank them for their time, and openness.

I thank the management of Yaba College of Technology for the permission to undertake this study and for the financial support given to me through the Tertiary Education Trust Fund (TETFUND). I am grateful to Mr Ariyo Salako who has always been there and has proven to be a father, a friend, and a source of inspiration. I thank Engr. Odunlade, Engr. Bejide, Engr. (Mrs) Alebiosu, and Dr. Aleburu for their encouragement and support. My sincere thanks goes to Prof Olatunboasun and Dr Fakolujo for the confidence bestowed on me during my stint at the University of Ibadan. I am also grateful Dr John Holmes, Dr Bernie Jones and all the people of the Smart Villages Initiative.

I wish to register my sincere appreciation to my fellow PhD scholars: Adegoke, Tobi, Taofeek, Seth and Sanusi for making settling down to the programme less tedious. In the same vein, I thank my colleagues: Joshua, Lateef, Adebakin, Osokoya, Adu, Busayo, and Edith for their encouragement.

To my wonderful Siblings: Aramide, Yetunde, Bolanle, and Lekan, I say a big ‘thank you’. I extend the same to my special friends: Sola, Yemi, Tunji, Tosin, Lekan, Sinbo, Patrick, and Gbenga who made ‘friendship’ have true meaning.

Lastly but very importantly, I say a big “Thank You” to my darling wife Elizabeth Oluwakemi for her unique understanding of my person and for managing the home front exceptionally well during the course of this programme, and at all times. To my lovely Children: Pleasant, David, and Grace, you remain highly beloved.

I give God the glory for, indeed unto me, He has done marvellously.

Dedication

During the course of this study, I discovered some of the diverse challenges involved in getting basic amenities such as sustainable energy solutions and water services to rural dwellers; especially those in isolated communities. Despite these challenges, a number of organisations and people are actively involved in non-profit programmes and projects to better the lot of such people, even though their efforts often appear neither noticed nor applauded.

This study is dedicated to all such organisations and people.

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CHAPTER 1 Introduction

1.1 Global Energy and Water Outlook

Whereas the availability of social amenities such as water and electricity are taken for granted in most urban cities worldwide, the absence, or acute shortage, of these amenities is prevalent in many rural isolated settlements, most of which are characterised by high level of poverty and underdevelopment. “Energy Poverty” and “Water Poverty” are concepts that have come to being used to explain the inability of a society to provide adequate energy and water access, respectively, to its people. Although governments of many countries have deployed various means to improve the access of rural people to enhanced energy and water provisions, these people still represent a large portion of those that lack such access (IEA, 2013); the provision of sustainable rural energy access has remained one of the significant political challenges for the governments of many developing countries (Mainali and Silveira, 2013). Although there is no distinct and unanimously accepted definition of “energy access” as it has always been used within a particular context such as the number of households supplied by electricity system to the total number households, or the number of household using improved and clean cooking facilities, around 1.2 billion people or 17% of the global population still lack access to electricity, while more than 2.7 billion people or 38% of the global population lack clean cooking facilities. The vast majority – 95% – of these people live in sub-Saharan Africa and developing areas of Asia, while 80% of them live in rural areas (IEA, “Energy Poverty”, 2016). Hence, sub-Saharan Africa and developing Asia have been regarded as the epicentre of the global challenge to overcome acute water and energy shortage (Sokona et al., 2012; IEA, 2015). As shown in Table 1.1, this presents a strong rural dimension to the problem: a feature which could be quite significant when decisions on choice of energy access approach or line of attack of this problem are being considered.

In sub-Sahara Africa, the severity of the problem can be appreciated when it is considered that the combined power generation of the 48 countries of the region is 68GW - no more than that of Spain (Eberhard et al, 2011). This becomes even more obvious when it is noted that South Africa generates 40GW of this total while the electricity generation by the remaining 47 countries is less than 30GW. This low energy availability in Sub-Saharan

Africa accounts largely for why the GDP in these countries are also among the lowest in the world (Karekezi, 2002).

Table 1.1: Numbers of people without access to electricity by region (million)

Region	Population Without Electricity "Millions"	Electrification Rate	Urban Electrification Rate	Rural Electrification Rate
Sub-Sahara Africa	**634**	**32%**	**59%**	**17%**
Developing Asia	**526**	**86%**	**96%**	**78%**
Latin America	22	95%	98%	84%
Middle East	17	92%	98%	78%
World	**1,201**	**83%**	**95%**	**70%**

Source: IEA, 2015

Although there is no unified definition of 'rural areas' as these can differ from one country to another depending on each country's statistical indexes, they possess typical features. Rural areas are generally scattered characterised by low population densities, difficult terrains/topography, lack of access to health care, infrastructure (roads, markets, information) and clean water supply, high illiteracy rate, gender inequality, and low economic features; with sources of income mainly from farming and fishing (Lahimer et al., 2013; Mainali and Silveira, 2013).

Similar to the energy situation, sub-Saharan Africa features some of the lowest rates of access to safe drinking water in the world, with over 37% of the 884 million people still using unimproved sources of water (WHO/UNICEF JMP 2010). The rural leaning of this is also seen in that a large percentage of this number – about 94 percent – resides in poor rural communities. Hence, a case of poverty entrapment is created whereby rural dwellers are poor due to absence of improved energy and water sources, and poverty, in turn, inhibits their ability to acquire such improved sources (Martin and Lemon, 2001). A UN report estimates that about 40 billion hours per year are lost in sub-Africa in the search for water; the same as a whole year's worth of labour by the entire workforce in France (UNDP, 2009).

It could therefore be reasoned that the approach of making improved sources of energy and water accessible to these people should go beyond the concept of technology transfer or shallow attempts of merely ‘making the presence of government felt’, to an encompassing process that would positively permeate into the livelihood of these people and ease their poverty level.

A number of international organisations, including the UN and the WHO, have been at the forefront of efforts to increase access to electricity and safe drinking water to rural locations. Energy and its related issues - its provision, utilization and sustainable development - has been a central theme in many present global discussions. Driven by improved design of large-scale generation technologies such as hydro and steam turbines and the ability to convey large amounts of power over vast distances, the “top-down” centralized power generation and supply through grid extension has been the main approach to electrification in both developed and developing countries for some time (Rickerson et al., 2012). However, the cost of this approach can make it inappropriate in isolated or highly dispersed rural locations with low population densities (Deichmann et al., 2011; Blum et al., 2013). As an illustration, the average grid connection cost for a household in Kenya is about US$1900, while the more remote and sparsely populated communities that may be characterised with difficult physical terrains have much higher connection costs (Parshall et al., 2009). Decentralized solutions such as microgrids are therefore more cost effective solutions to delivering electricity to these areas (Blum et al., 2013). Hence, in such locations, the decentralised off-grid approach, where the generation of electricity is situated near the users, and focuses solely on meeting their local demands without any form of interaction with the grid, is often considered more practicable (Lahimer et al, 2013)

Nonetheless, while there are some success stories of electricity access improvement in countries such as China, Bangladesh, Brazil, and Nepal using the decentralized “bottom-up” off-grid installations to reach the people in such dispersed rural locations, many such installations in sub-Saharan African cease to function after a few years; killing the expectations of many rural dwellers with it. In spite of the large renewable energy potential in Africa, and despite the fact that this can be positively utilised at rural community levels, energy sources that could be used for the provision of electricity and water have remained under-developed.

1.2 Synopsis of the Nigerian situation

While sub-Saharan Africa is regarded as a region with a high concentration of people lacking access to improved sources of electricity and water as stated in section 1.1, Nigeria has the highest number of such people in the region. Out of her approximately 177.5 million people, the country has 98 million (Figure 1.1) and 57 million people that lack access to good quality electricity and water sources respectively, with many of these being rural dwellers (IEA, 2014; Word Bank, 2014). Furthermore, it is estimated that 53.1% of the Nigerian populace resides in rural areas (UN, 2014), while the country has the second highest concentration of people without access to electricity in the world, only behind India.

In a wide sense, electricity and water can be regarded to be intricately linked, even though this may not appear obvious in some instances. Water is often required in the production of electricity, and in the manufacture of electrical equipment/components. In the same vein, the processes of providing improved water access through pumping, treatment and transportation usually requires electricity. At a rural community level therefore, the availability or provision of electricity could make the delivery of improved water access a more achievable task.

As part of measures to improve on this situation, the federal, state and local governments in Nigeria have attempted to provide isolated rural communities with improved electricity and water services (or, in some instances, improved water access only) using solar PV technology, However, such efforts have not recorded much success; with many of the installations not functioning effectively beyond the first few months of being installed. The failure of these installations, which is in stark contrast to their successful applications in some other developing countries, suggests deep underlying problems. This has discouraged government and policy makers from further supporting solar PV and other forms of Renewable Energy (RE) as viable options for such locations even when grid extensions remain unfeasible. Hence, despite the abundance of solar resources, and government support for RE technologies to provide improved energy and water services to its rural populace, it is important to establish why the success rates of such installations have been low, and to develop means of achieving improved outcomes.

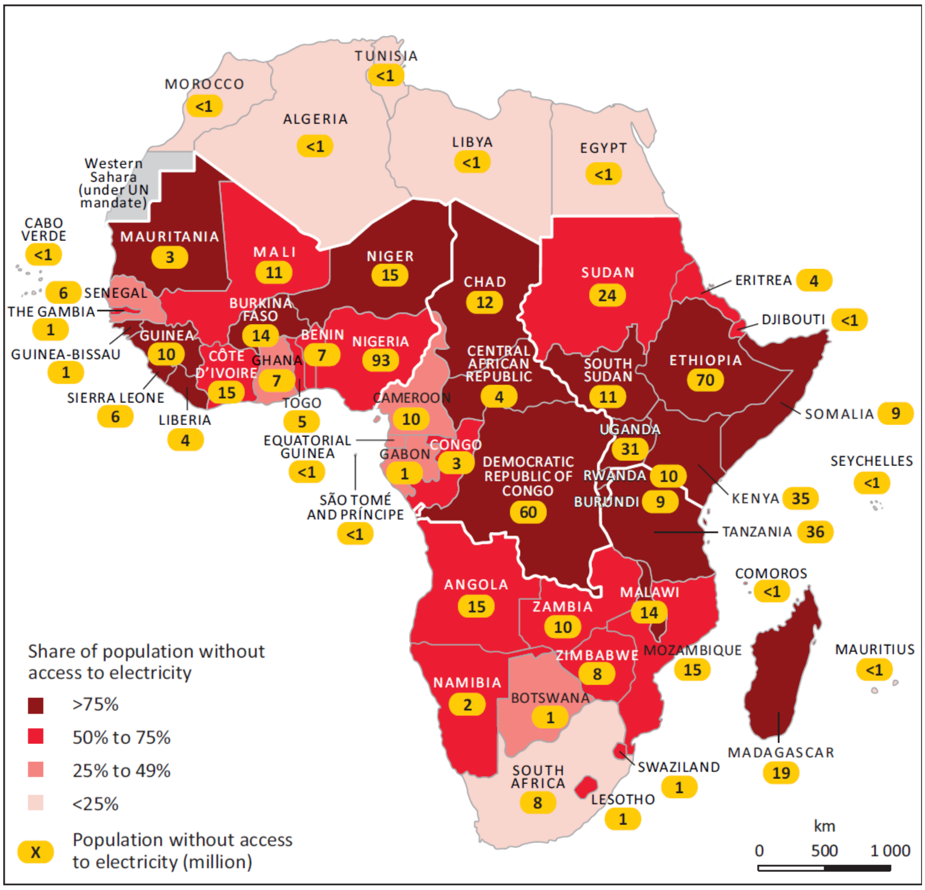

Figure 1.1: Number of people without access to electricity by country, 2012

Source: IEA, 2014

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1.3 Research Gaps

Many studies (Bugaje, 1999; Oparaku, 2003; Diad et al., 2011 Katti and Khedkar 2007; Kanase-Patil et al 2010) have been carried out on the appropriateness or otherwise of different types of renewable energy in rural locations both within and outside sub-Sahara Africa. In one such study, Sambo et al. (2010) utilised available, derived, and projected data to conclude Nigeria is endowed with appreciable RE sources of solar, wind, biomass, and hydro. Studies on the sustainability of RETs by Nfah et al (2007) and Mahmoud and Ibrik (2003) carried out for developing economies outside Nigeria were based on design guidelines and economic viability respectively. While Nfah et al (2007) modelled solar/diesel/battery hybrid power systems to produce electricity for typical rural households in remote locations in Cameroon, Mahmoud and Ibrik (2003) verified the reliability of solar PV electricity generation by matching the load with the state of battery charge in small rural villages in Palestine. Similar works that demonstrated the viabilities of RETs based on technical optimization and economic analysis were carried out by Shaahid and El-Amin (2009) and Lagorse et al (2009), while studies by Vera, (1992) and Mahmoud and Ibrik, (2003) only considered factors that are involved *before* the deployment and installation of RETs to demonstrate that solar PV technologies are reliable means of meeting the power demands in a rural location. In the same vein, in a survey of remote household energy use in rural Thailand, Yaungket and Tezuka (2013) used questionnaire as a tool to measure personal viewpoints, feelings, and dispositions of rural users to conclude that inadequate knowledge by users is the main cause of systems' breakdown. The study did not however include the opinions of other stakeholders.

Hence, while there appears to be a body of literatures that mirrors the theoretical viabilities of RETs in rural locations in developing countries such as Nigeria, studies based on the comprehensive evaluation of real systems and appraisal of their success and failures have moved at a much slower pace. It is noted that among rural electrification projects, only a small number are comprehensively observed and studied for sustainability after installation (Hong and Abe, 2012). A possible reason for this may be the associated difficulties involved in carrying out studies on evaluation of real systems than to do theoretical desk top studies. Therefore, despite particular interests to support and expand the implementation of RETs, especially solar PV in rural areas of developing countries, there has been many failed RETs projects with the minimal positive impacts.

Following these, evidence is needed, not only on the factors that contributed to the deployment of RE installations, but also on what took place after such installations have been completed and are being used by the beneficiaries. So, beyond appropriateness and viabilities of solar PV installations as established by many earlier works such as Mahmoud and Ibrik, (2003); Katti and Khedkar (2007); Lagorse et al (2009); and Kanase-Patil et al (2010) as referenced earlier, it is pertinent to know whether the technology fulfils people's needs and priorities, and whether the equipment has remained in working order and for how long. It is also necessary to know the relationship, if any, between successful and failed projects and the business models implemented. Furthermore, it would be beneficial to know whether the population has been trained to respond to technical challenges; how satisfied users are, and what, if any, are the local environmental consequences of implementing the new systems (Alazraque-Cherni, 2008). Similarly, Terrapon-Pfaff et al., (2014) states that “despite the large number of small-scale sustainable energy projects that have been implemented in developing countries, surprisingly little empirical evidence exists on their achievement or non-achievement of sustainability after the initial project activity was completed”. In Nigeria in particular, it is necessary to identify the factors responsible for the recurrent underperformance of many of the PV solar installations deployed to rural locations, and the kind of supports that are required to achieve sustainable installations.

At the commencement of the study, technical factors were thought to be the main cause for the many underperforming/failed solar PV installations in rural communities in the country as this was a popularly held notion. Hence, the original aim of the study was to design and build a solar PV installation in a rural community that, presumably, would have improved performance, and could be used as a model in subsequent deployments. However, investigations carried out at the onset of the study revealed that technical factors act together with many other related and non-related factors in the underperformance and failure of these systems. It was therefore considered that developing a solar PV system with improved technical features, which, although, appears a reasonable undertaking, could suffer the same fate as previous installations due to the effects of other inhibiting factors such as maintenance, ownership and security issues that ought to be known and resolved alongside the technical factors. Consequently, a study using real case scenarios to reveal these diverse factors and their interconnections, and lead towards the development of framework and set of recommendations for improved deployment and performances of solar PV installations in rural communities, was considered as a more viable and robust research undertaking. This is believed to be crucial to the emergence of viable markets, correct adaptation, and improved operation and performance of such installations in the country, and such that could lead to improved enlightenment of consumers and policymakers such that negative perceptions and prejudices against solar PV technologies could be converted into sound decisions in its deployment to rural communities. Therefore, this study targets address the following knowledge gaps:

- the factors that contributed to the deployment of RE installations, and what took place after such installations have been completed and are being used by the beneficiaries
- how satisfied the users are
- the localized consequences of the deployment of solar PV installations to rural communities

- the relationship between successful and failed projects and the business models implemented
- how sustainable or otherwise are these installations and what factors contribute to such

1.4 Aim and Objectives

It is undeniable that the provision of improved electricity and water access is vital to poverty reduction, and improved social and economic well-being of rural communities. Nonetheless, while no form of energy may be considered as absolutely good or bad in itself, it is evident that the form of energy to be deployed to a rural community (either to be used directly at households level, or for the provision of some form of community services, e.g. pumping of water, should be based on a thorough considerations of the factors that could lead to best performances and wide-reaching positive effects. Since present indices in the deployment of solar PV installations to rural locations in Nigeria do not support such expected outcomes, this study aims

to develop a generic framework for the implementation and sustained performance of solar PV systems for water pumping and electricity services in rural areas of Nigeria.

This aim will be achieved through the following objectives:

i. To develop a systematic approach and associated indicators for analysing PV installations in isolated areas

ii. To undertake a review and evaluation of seven solar PV installations in Nigerian as case studies

iii. To obtain stakeholders' perceptions on various factors and issues regarding PV projects in Nigeria

iv. To integrate (i), (ii) and (iii) above to generate a framework for the improved deployment and performance of solar PV installations in rural locations.

1.5 Thesis Structure

This chapter introduces the global energy and water situation and the issues related to them; it focuses on electricity and water poverty in rural locations in developing economies, with attention to the sub-Sahara African region, and Nigeria in particular. Failure in the attempts of the Nigerian government to employ solar PV installations successfully towards achieving enhanced electricity and safe water access in rural locations is highlighted; from which the aim and objectives of the study are developed.

Chapter 2 gives a brief outline of alternative solar PV technology options as are often used for electricity services and water pumping in rural locations. It also reviews the technological, financial and business models for RE implementation and diffusion in rural locations, and a number of assessment and evaluation tools which enables the identification of key themes and indicators. The chapter further highlights barriers and drivers to diffusion of renewable energy systems, and ends with appraisals of examples of national rural electrification programmes. The status and issues relating to electricity and water access in Nigeria, along with organisational, regulatory and policy structures for their provision are presented in Chapter 3. Reviews and evaluation of efforts and experiences on various solar PV initiatives in the country are also carried out in this chapter, while lessons learnt from these are highlighted.

Chapter 4 outlines the methodologies available for a study of this nature and gives justification to the methodology choices adopted for the study. It further explains the rationale behind the selection of sites for the study. The instruments for data collection, method of data recording are explained in the chapter. The chapter ends with the development of framework for assessment and evaluation, and an explanation of the method of data presentation and analysis to implement in the conduct of the study.

In Chapter 5, the study procedures based on the methodology as produced in Chapter 4 are utilized to conduct interviews with relevant stakeholders and to analyse seven rural solar PV projects as study cases. These led to the identification of other relevant themes - in addition to the ones in chapter 2. In Chapter 6, a systematic analysis and integration of the outcome of the exercise is carried out based on discussions of key findings from review of documented cases, interview sessions and study cases, leading to the development of a final framework that can support mass implementation, and improved performance of solar PV technology in rural communities in Nigeria; thereby achieving the aim of the study. Finally, Chapter 7 gives the conclusions and recommendations: an appraisal of the contribution to knowledge and to what extent the aim of the study has been met. The Chapter rounds off with experiences and challenges encountered in the study, and suggestions on recommendations for further studies on the subject matter.

1.6 Limitation of Scope of the study

While Nigeria has a good solar radiation across all regions (see Figure 3.1), it has not been possible to carry out field cases evaluations of solar PV installations across all the regions. Nigeria has been subjected to terrorist and insurgents' activities lately. Although a level of calmness has returned to the South-South and South-Eastern states that were previously subjected to kidnappings and attacks on oil installations, the states in the Northern axis have remained under insurgent attacks mainly by the extremist Islamist group 'Boko Haram' which seeks to establish Islamic law in Nigeria. The group abhors all forms of western education and they have been responsible for several indiscriminate killings of civilians, and attacks on educational institutions, military establishments, and international organisations in the country. These have rendered it unsafe to carry out a study of this nature - which would involve visiting rural communities - in the northern part of the country. Hence, the field study is restricted to solar PV systems in the South West and South South regions of the country, where there is a relatively higher guarantee of safety, and a level of access to information is assured. However, it is expected that the findings from this study can readily be extended across to other regions in the country since they are largely governed by a similar set of socio-economic and cultural factors.

CHAPTER 2 Literature Review

2.1 Introduction

Rural electrification has been defined by Barnes, (1988) as "the availability of electricity for use by rural communities irrespective of the technologies, sources, and form of generation". Rural electrification has been a priority for many governmental and international donor organisations (Ilskog and Kjellstro, 2008; Pillai and Banerjee, 2009). However, despite sustained efforts, the outcomes have often not been encouraging; the global pace of rural electrification is still considered very low while the availability or authenticity of rural energy data has remained a major challenge in most developing countries (Paul, 2011; Pachauri and Cherp, 2011). According to a World Bank report in 2008 on the reassessment of the costs and benefits of the welfare impact of rural electrification, expected outcomes have not been achieved, as only 68% of electrification projects supported since 1995 have been ranked satisfactory; which is below the average rated assessment for all World Bank projects in general (World Bank, 2008).

Due to the absence of grid energy in many rural communities, the people mainly use traditional, lower quality energy sources such as candles, kerosene lanterns for lighting purposes, and batteries to power small radio sets. Gradl and Knobloch (2011) remarks that the poorest people in the world, such as those that dwell in rural areas and employ these traditional low quality energy sources, end up spending up to thirty percent of their household income on energy, which is relatively higher than the percentage of the income those living in urban areas spend on grid electricity. Therefore, in most cases, the immediate priority of dealing with rural energy poverty is to provide a minimum amount of energy to meet households' demands: these are typically characterised by low demands for lighting, charging of phones and small radio and television sets.

However, the success or otherwise of RE installations deployed to rural locations can be greatly influenced by various decisions and actions taken at both the pre and post deployment stages. For example, wrong decisions in the choice of technology to deploy to a location and the type of implementation model adopted, may influence the diffusion, overall performance and sustainability of the installation. In addition, beyond the choice of technology and the deployment model adopted, it is important to ensure the long term viability of installations in such places by taking local factors as may be necessary into consideration in the overall planning process. Such decisions regarding rural electrification could be premised on four considerations: the need: what is necessary; the environment: what is acceptable; the economy: what is affordable; the technology: what is feasible (Zomers, 2003). The aim of the subsequent sections therefore is to review literatures on models for technology transfer, implementation, diffusion, and assessment as they may relate to rural locations in order to bring out relevant key themes and indicators.

2.2 Energy Technologies for Rural Locations

As noted in section 1.1, the decentralized "top-down" approach often become impracticable to provide electricity to isolated or highly dispersed rural locations with low population densities. Hence for these locations, 'locally' available energy sources such as wind, biomass, solar and mini-hydro are often considered more realistic when used off the grid (Mainali and Silveira, 2011). As shown in Figure 2.1 off-grid (decentralized) electrification has majorly been on small-scale operations and they are mostly deployed using two approaches: local grid (or micro-grid) community systems and stand-alone household systems (Mandelli et al, 2016).

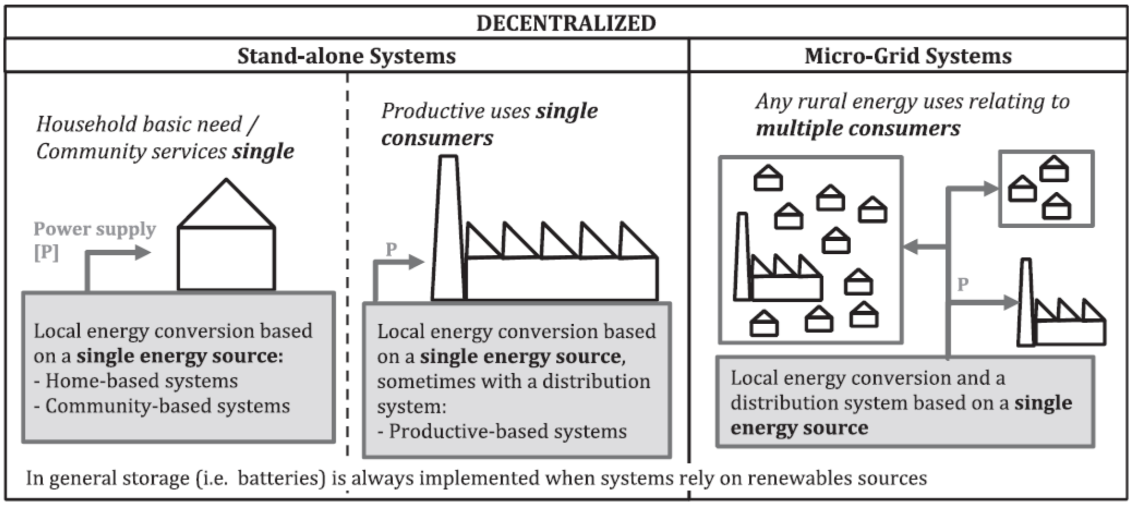

Figure 2.1: Representation of Off-Grid Electrical Systems

Source: Mandelli et al, (2016)

Local grid systems are mainly in form of small-scale hydro or diesel generating plants that generate and supply electricity to local areas where necessary distribution wiring have been provided. While the diesel-run plants are more common, they are often besieged with daunting operational and maintenance challenges. The purchase of diesel often imposes cost and logistic burdens, especially in local locations where it may not be easily available, and access roads could become particularly bad, especially during the rainy seasons. In addition, the price of the commodity is subject to sudden changes by factors that are not related to the location where it is being used. The Iraqi invasion of Kuwait that marked the beginning of the Gulf War in the early 1990s and the recent political turmoil, known as the "Arab Spring," in Egypt, Libya, Syria and some other middle east countries are notable examples of international events that affected the cost of oil and led to a level of scarcity. Beside these, non-availability of required spare parts or the inability to obtain such parts in time when needed for maintenance could prove problematic. On the other hand, while local hydro plants are characterised by low operational cost, they exhibit relatively higher capital cost. In addition, they have a 'site-specific' constraint since the availability of moving water in sufficient quantity in a proposed location is a pre-condition for their implementation.

Due to these constraints, off-grid energy generation systems based on solar PV technology, wind and biomass are often used to meet the low energy demands of rural areas. Since this study is based on already deployed solar PV electricity and/or water installations, the reviewed literatures are mainly on the technology; of which the basic constituent components are explained below.

2.2.1 PV System Components

The typical components in a PV system depend on the configuration adopted. The basic functions of these components are given below.

i. PV Array: A PV array is constituted of a number of PV modules that are electrically connected. PV modules are environmentally sealed collections of PV cells, which are the devices that convert sunlight to electricity. Usually, sets of four or more smaller modules are framed together to form a panel.

ii. Inverter: The dc-ac inverter is a device that collects the dc power generated by the PV array and converts it into standard ac power as can be used by home appliances. This device is not needed in dc systems as is often the case in installations used for water pumping only.

iii. Metering Devices: The metering devices are used to provide indication of the PV system's operation and performance. Such meters can indicate the output voltage and the power generated by the system.

iv. Balance of System (BOS) Equipment: The BOS equipment includes the wiring, protective, mounting, and any other system that are used to connect the PV system to the load while ensuring the safe and proper functioning of the installation. One of such components is the charge controller, which ensures that batteries in PV systems are not over-charged by disconnecting them from source whenever they are fully charged. The BOS equipment also provides ground-fault, and over-current protection for the solar modules.

v. Solar water pumps: Solar water pumps are designed to operate on low dc electric power produced by the photovoltaic panels. These pumps utilise positive displacement mechanisms that seal water in cavities and force it upward through an arrangement of diaphragm, vane, and piston pumps. Unlike conventional centrifugal pump, solar water pumps do not need to spin fast to work efficiently; hence they able to work even during low light conditions at reduced power, without stalling or overheating.

The deployment of PV installations to rural communities for electricity or water pumping purposes has been in the form of both the local grid community system and the stand-alone household configuration. These two configurations are briefly outlined below.

2.2.2 Local grid-based solar PV systems

In a local grid-based solar PV system, the PV installations serve the purpose of a central power station. It allows for a holistic generation and supply of electricity to cluster of homes in remote villages as well as identified loads in hospitals, schools etc. It can serve a local community or group of small communities through an interconnection of low-voltage transmission lines. Being majorly ac-systems, the requirements of a battery bank, dc-ac inverter and associated components are major features of this system. This increases the cost and complexities of the system, as well as introducing additional inefficiencies. The dc power generated by the systems is stored in batteries and converted to ac power for household and commercial use; hence, this configuration is commonly used to supply lighting and low power loads in rural locations. A schematic of such a system is shown in Figure 2.2.

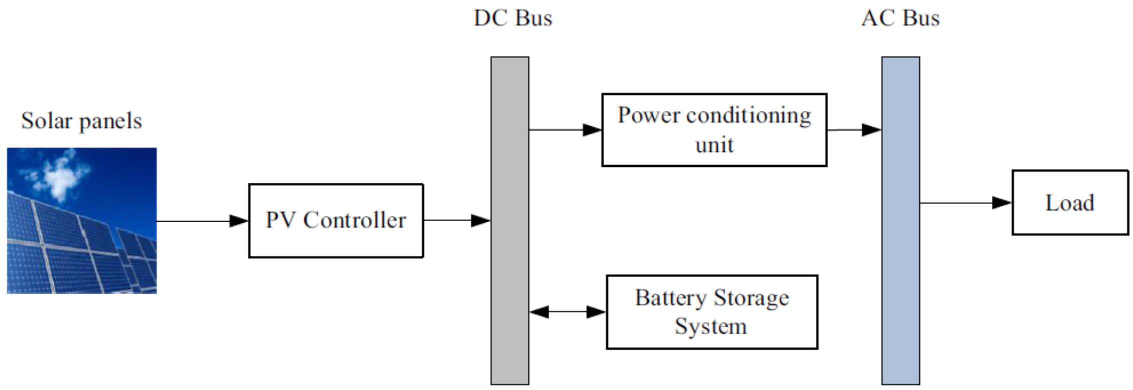

Figure 2.2: Local grid-base solar PV system

Source: Ghafoor and Munir (2015)

A simpler variation of the above is the dc PV system design in which the dc output of the system is directly used to power dc load directly, thereby cutting out the necessity of storage batteries and related accessories. This configuration is characterised by its simplicity, improved reliability and reduced financial cost (since it contains less components). However, since there are no storage batteries in the systems, the power is available only when there is sunlight. The design is ideal for charging batteries of small devices like phones, laptops etc. In addition, this configuration is often used for water pumping or irrigation systems in rural areas, and to supply the electrical requirements of telecommunication base stations in remote locations. A layout of such an arrangement for water pumping purpose is shown in Figure 2.3.

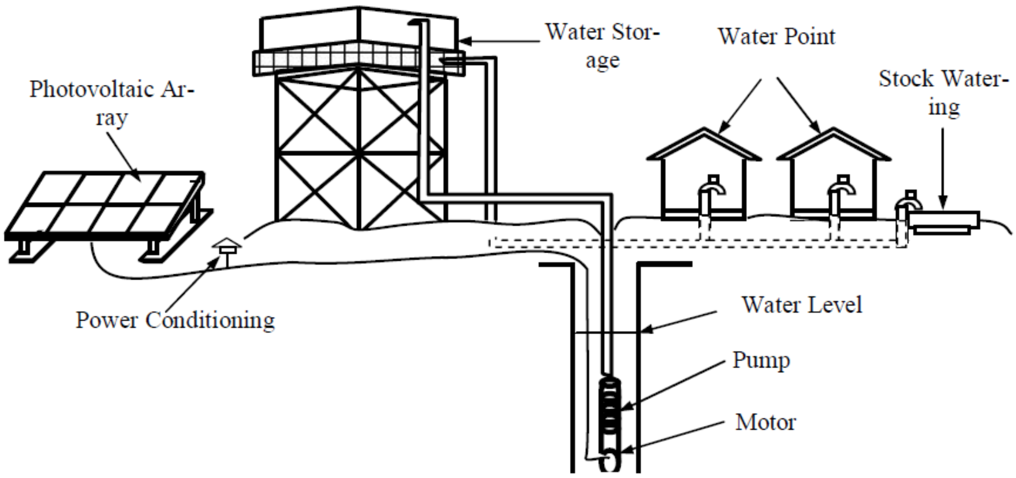

Figure 2.3: Layout of Solar-powered Water Supply
Source: Ramos and Ramos, 2009.

Another early applications of solar PV by government agencies both at the state and levels is in the implementation of solar street lighting systems in rural communities and urban areas where they were regarded as viable alternatives to power street lights due to the constant shortage of grid electricity. The common designs in many of the street light installations consist of the streetlight pole upon which the solar panels are mounted while the batteries are housed in a small metal box mounted just below the solar panel(s) on the streetlight pole as shown in Figure 2.4

Figure 2.4. However, most of these streetlights did not function beyond a few months due to a variety of reasons including poor design, lack of standardization of components utilised and inadequate maintenance (Akinboro, et al., 2012).

Figure 2.4: A Solar Street Light Installation

2.2.3 Stand-alone household systems

The stand-alone household PV system commonly referred to as the Solar Home System (SHS) is designed to provide electricity to individual homes especially if the communities/villages are sparsely populated and remotely located from the grid. It is used to provide energy for lighting and basic appliances such as Compact Fluorescent/Light Emitting Diode lamps, dc fans and television sets at individual household. A SHS typically consists of one or two PV modules, a battery bank and a charge controller. The modules charge a battery bank to supply DC electricity to the appliances, while the charge controller ensures the battery is neither fully depleted nor over-charged.

A smaller and 'lighting only' version of the SHS is the solar lantern. This is a portable LED lighting device that is housed in a plastic enclosure that contains a rechargeable battery. The rechargeable battery is charged using a PV module which is either integrated in the solar lamp itself, or is connected to the lamp by an electric plug-and-socket arrangement (Palit, 2013). Since solar lanterns and SHS offer lighting and limited access to electricity for household purposes respectively, their contribution to productive use of electricity is low (Ölz and Beerepoot, 2010).

2.2.4 Hybrid Energy System

A hybrid energy system is a combination of two or more different energy systems for optimal output configuration (Mohammed et al., 2014). While stand-alone renewable energy technologies can often meet the electricity needs of rural communities more cheaply, and have the potential to displace costly diesel-based power generation options, specific technologies have their inherent advantages and limitations (Kaygusuz, 2012). In some situations, due to existing limiting factors such as insufficient amount of an energy source, technical/ design limitations, or due to availability of prospects to exploit the inherent strength of more than one energy source to meet the energy demands of a locality, a hybrid system -is used. For example, the main limitation of solar and wind based renewable energy systems is that they provide electricity on intermittent basis (Khan and Iqbal, 2005), hence, a PV/wind hybrid system can guarantee a more continuous supply with less elaborate energy storage system than will be required if either was to be used independently. Most often though, diesel generators are more commonly used in conjunction with PV or wind systems in off grid-hybrid systems to achieve improved reliability of supply which could be used to meet varied energy needs such as lighting, or energy requirements for small equipment and cooking which may not be ideally met with one energy source only. A block diagram of the solar PV/ diesel generator design is shown in Figure 2.5.

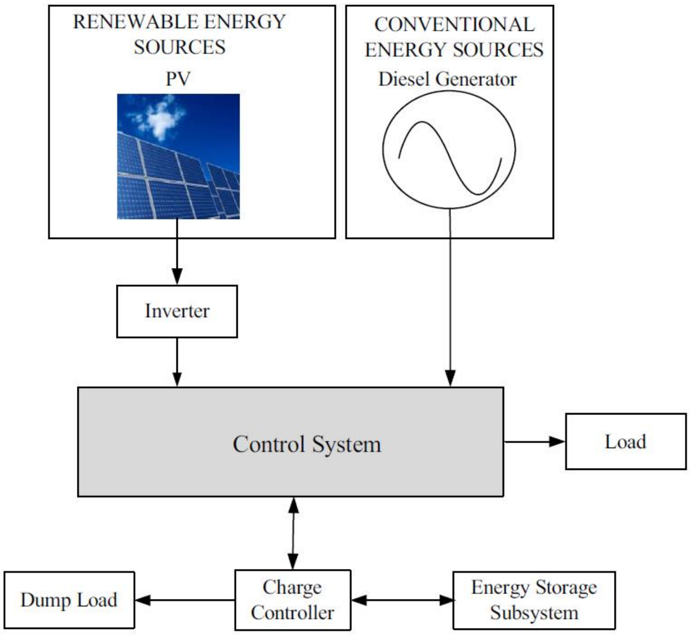

Figure 2.5: Solar PV/ diesel generator Hybrid System

However, as noted in section 2.1, the choice of the form of energy to be deployed to a rural location community is fundamental to the success or failure of such an exercise, and, therefore should be based on a thorough and scientific considerations of wide-ranging factors that could lead to best performances and wide-reaching positive effects. A number of analysis tools exists for project implementation and evaluation purposes.

2.3 Models for RE Implementation and Diffusion in Rural Locations

While a number of categories have been used to classify the use of energy in rural areas (Karekezi and Kithyoma, 2002; Kaygusuz, 2011), three main categories namely (i) energy for household basic needs, (ii) energy for community services and (iii) energy for productive and income generating activities are generally recognised (Mandelli et al., 2016). Electrification projects are majorly capital-intensive activities, hence, limited availability of financial resources is regarded as one of the major constraints to their implementation (Williams et al., 2015). The degree of penetration and acceptance of an energy solution to rural dwellers could then depend to a large extent on the implementation model and financial mechanism adopted. Several schools of thoughts exist on how best to achieve widespread penetration, especially of RE options, among rural dwellers. It has been suggested that it is essential the huge financial gap between the cost of electrification and the affordability by rural dwellers be bridged to enable a wide penetration of the technology in rural locations (Mainali and Silveira, 2011). Additionally, Pigaht and Robert (2009) submitted that the sustainability of any kind of off-grid rural electrification projects usually involves active local participation in their development and implementation. In addition, Cabraal et al., (1998) asserts that challenges associated with sustainability and replicability of business models, development of regulatory mechanisms for energy subsidies and incentives, and in integration of rural factors are major challenges confronting solar PV projects in many countries.

Efforts in rural electrification have traditionally been handled by governments through their agencies (Williams et al., 2015). However, due to financial constraints, their efforts have often been complemented by the private sector and international donor agencies. Nonetheless, the participation of private investors comes with its own challenges, as rural electrification projects are generally not considered commercially attractive, while the support of donor agencies often terminates after the completion and donation of such electrification projects. Globally, a number of financial mechanisms towards achieving improved affordability and increased penetration of RE technologies among rural users have been developed and implemented. These include subsidies, tax incentives/ import duty reduction, credit financing, low-interest and long-term loans, asset financing, private financing (Liming, 2009; Mainali and Silveira, 2011; Glemarec, 2012; etc.). In all, Mainali and Silveira (2011) assert that the identification of innovative mechanisms to attract capital and increase financing is critical to advancements in rural electrification that could ultimately lead to rural development. Some of these mechanisms are briefly discussed below.

2.3.1 Technology Diffusion Models

Rural electrification projects are often also categorised as demand pull or demand push. In the former, technology deployed is based on users' indexes such as assessment of willingness to pay, the desired products and system designs, availability of credit and after sales service, etc.). For the latter, the donor party - be it governmental or otherwise – solely decides on the technology to be deployed without any substantial contribution from the users. While demand-push projects (also known as donor-driven projects) may benefit users directly and also achieve technology transfer and capacity building initiatives, they are also known to have the tendency to distort market prices as the primary aim of the donor may be to 'sell' and achieve a wide spread of its technology without giving much consideration to the effect such donations could impact on local markets as experienced in Zimbabwe (Mulugetta et al., 2000). In addition, international donor bodies are known to often focus only on pushing particular technologies; the tendency being to opt for high profile, fast and large investment programmes, to work through competitive selection of technical assistance, and to identify projects through international business plan competitions and competitive calls for proposal rather than holistically utilizing energy services to improve standards of living and productivity, thereby risking investing their precious funds in actors and initiatives that can submit attractive paperwork but are often irrelevant to the real energy access and markets of the communities (Sovacool, 2013). Therefore, a sustainable energy electrification intervention by donor agencies should be based on multi-pronged and well-coordinated arrangements with clear and specific lines of actions beyond the immediate donor commitment period (Mulugetta et al., 2000). The technology options for off-grid rural electrification projects as adopted by the World Bank are shown in Figure 2.6.

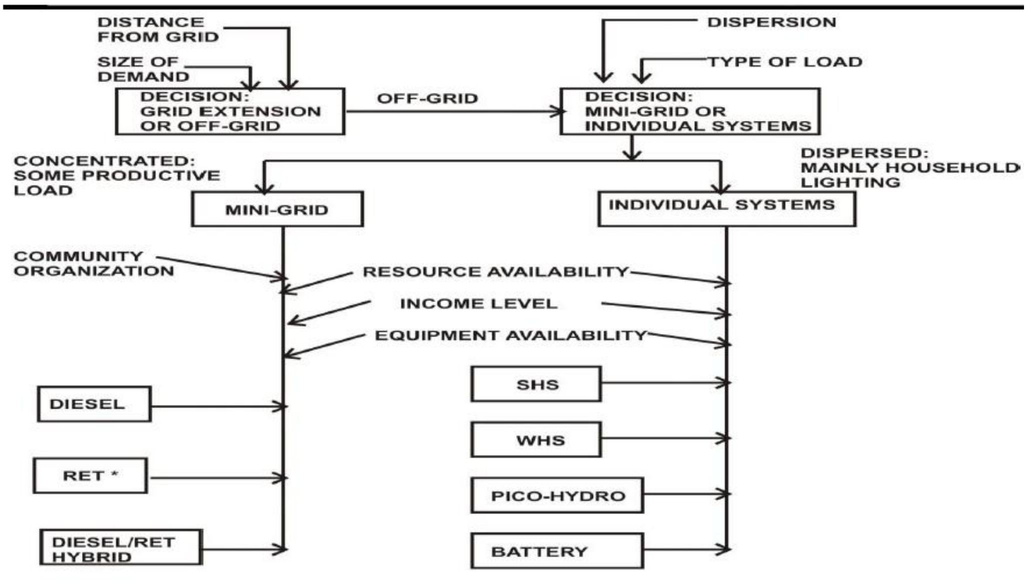

Figure 2.6: Technology Options for Off-Grid Electrification

Source: World Bank, 2008

Additionally, while a number of technology options exist for rural deployment, decision on which option to deploy should be based on holistic consideration of factors such as economic, technological, social, institutional, and ecological. As shown in Table 2.1, the estimated capital cost of gasoline generator is the lowest among the 3 energy options considered by Meah et al., (2008) for water pumping in remote locations. However, further consideration of the high operation cost, high maintenance requirement and low life span may negate against this option in such consideration.

Table 2.1: Comparison of Energy Options for Remote Water Pumping

Energy Source	Estimated Capital Cost	Operation Cost	Maintenance	Life Span (Years)
PV System	$6.8/Wp	None	Low	10-15
Electric Utility	$22/W	5-13 c/kWh	Low	N/A
Gasoline Generator	$2.5?W	$0.6/kWh	High	5-10

Source: Meah et al., (2008)

2.3.2 Financial Mechanisms

As stated earlier, the provision of rural energy services is often capital intensive and requires high upfront costs which government agencies cannot to bear alone. One of the greatest challenges remains financing for energy and the communities' ability and, sometimes, willingness to pay (Jones, 2016). A survey across 69 countries and over 140 organisations - including major multilateral, bilateral and financial organisations such as DFID (Department for International Development) and UNDP (United Nations Development Programme), showed that 'financial sustainability of projects' is the main parameter needed to assure long-term viability of electrification projects (Monroy and Hernández, 2005).

Even renewable energy services that appear to be modestly priced may be considered expensive by low-income consumers like rural dwellers who are more accustomed to purchasing energy in small units (Ballesteros et al., 2013). Hence, in order to expand rural energy services delivery especially in developing countries, a number of financial schemes have been implemented to mobilize financial resources within and beyond government quarters to supplement and overcome budgetary constraints. Such innovations serve to either enable easy financing by investors or to achieve easy affordability by users. Some of these as depicted by Ortiz et al., (2007) cited in Bhattacharyya, (2013) are shown in Figure 2.7 and further explained below.

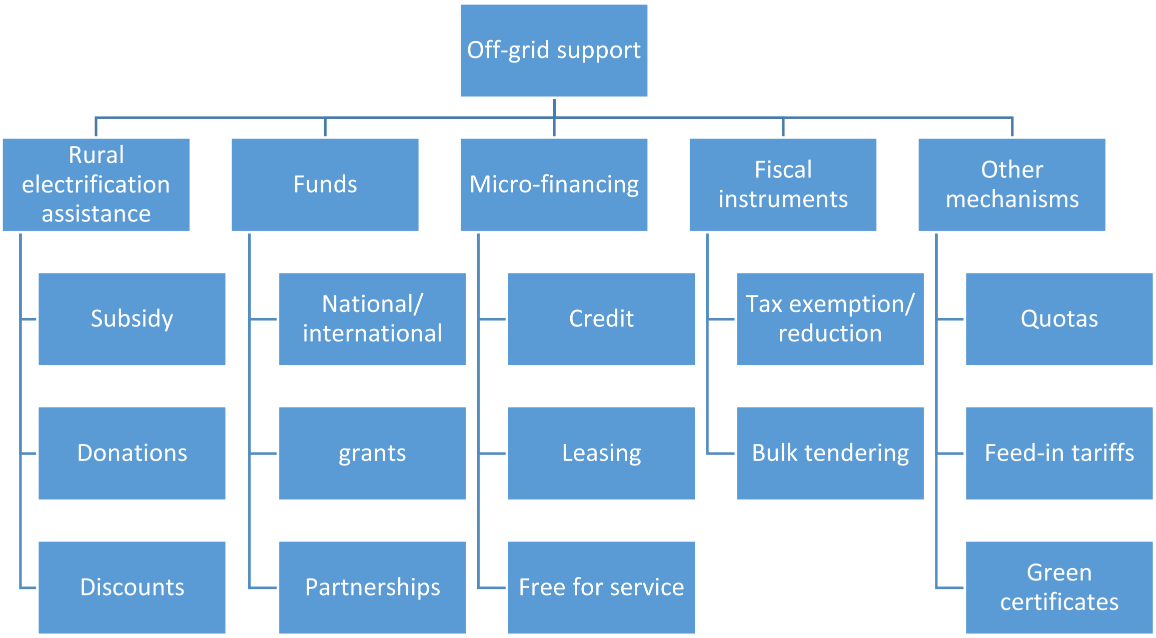

Figure 2.7: Financial instruments for off-grid electrification.

Source: Ortiz et al., (2007) cited in Bhattacharyya, (2013)

2.3.2.1 Public Private Partnership (PPP)

The phrase "public private partnership" (PPP) has been used to denote a range of different relationships among public and private organizations in the context of infrastructural and technological development (Sovacool, 2013). Other terms that have been loosely used to describe PPPs are "private sector participation," "liberalization," and "privatization." (Felsinger, 2010). The basic idea of PPP is to have governments and her agencies to partner with actors in the private sector implement projects together, thereby enabling the private sector entities to fulfil public policy goals as set out by the public sector. The most common division of responsibility in a PPP is to have the public partner set service standards and monitor performance, whereas the private partner raises capital and is responsible for building and operating the project (UN, 2005). Hence, it is seen as an alignment of policy goals of government with the profit objectives of the private partners.

With specific regards to PV diffusion in developing countries, Nieuwenhout, et al., (2001) found four types of PPP models: a donation delivery model, a cash model, a customer credit model, and a fee for service model, while Reinmu¨ller and Adib, (2002) broadly identified cash delivery, credit from companies and dealers, leases as common PPP mechanisms utilised. Some of these are briefly discussed below

2.3.2.2 Subsidies

Various schools of thought exist around the topic of subsidies for electrification projects. Energy subsidies have been defined by the International Energy Agency (IEA) as actions aimed at lowering the cost of energy provision either through incentives to energy generation or price reductions to consumers (IEA, 2009). It is often used as a tool for bridging the energy poor and those that have access to clean energy sources.

For rural electrification projects, two types of subsidies are usually considered: Capital Subsidy and Operating subsidy. While the former reduces the initial investment cost on project implementation, the latter is applied to reduce the running cost. However, on the basis of long-term sustainability, capital subsidy is often preferred as it tends to promote the use of capital-intensive generation technologies such as wind and solar which are characterised by high initial cost and low running costs (Rolland and Glania, 2011; Williams et al., 2015). Experience has however shown that full subsidization of capital costs of systems may encourage fiscal indiscipline and sharp practises among service providers such that the rural poor for which such subsidies were intended, may not fully benefit (Barnes and Halpern, 2000). Capital subsidies is also believed to negate the notion of community ownership as there are evidences that beneficiaries are more likely to take more proper care of projects fully financed by them (Sovacool, 2012). Hence, in some instances, the preferred model is the output based or performance based subsidies in which subsidies are tied to achieving pre-determined policy goals such as numbers of consumers connected (Shanker et al., 2003; Irwin, 2003). This model enforces performance on the service providers as projects must be financed, built, be in operation, and meet set-out milestones achieved before subsidies can be accessed. As mentioned earlier, operating subsidy, which is commonly used to reduce the cost of fuel are not often utilised when PV or wind technologies deployed since they do not run on fossil fuel and are thereby characterised by low running cost. However, such subsidy can be introduced in the form of direct subsidization of tariffs similar to grid-based electricity in developing countries where electricity is often sold to consumers at rates below the cost of production by virtue of public subsidies.

2.3.2.3 Credit financing

Since subsidies are finite resources that are often allocated from tight government/ private budgets, they mostly do not cover the total project cost. A number of credit mechanisms have been implemented in the promotion of rural electrification worldwide. Such include the fee-for-service, credit from local cooperatives, leasing of energy-generating products, credit from commercial banks based on the provision of some sort of collateral, and revolving funds (Gregory et al., 1997). In credit financing, dealers sell their products to rural clients on credit against collateral or personal guarantees, while payment is done in instalments. It is frequently applied to SHS and improved cook stoves distribution. However, the additional transaction costs associated with acquiring credit results in high installation cost. Furthermore, poor families often find it difficult to provide the required collateral. The more common challenges though resolve around the unavailability of microfinance institutions (MFIs) to serve the rural poor. A survey carried out in Tanzania, which is one country considered to have a roust microfinance sector for the poor, actually revealed that 60% of the rural population do not have access to any kind of financial service, only about 10% of them have access to a bank or MFI, and just 4% has a loan (Finscope, 2009). Similarly, in both Senegal and Mali, it was found that most MFIs operate in urban areas with less than 3% of the rural population having access to microfinance, and less than 1% obtaining actually micro-loan. It is therefore necessary that the existence of MFIs be married with specific objectives of achieving enhanced energy access through the provision of financial assistance to the rural poor via unambiguous arrangements.

The fee-for-service (fee-for-use) model is a financing mechanism where the Energy Services Companies supply and retain ownership of the energy equipment, and also provides the service and maintenance while the customer pays regular fees for using it (Bhattacharyya, 2013; Sovacool, 2013). The model is quite popular because it enables the up-front costs of RE installations to be spread over a long period thereby making it less financially burdensome for rural users. However, it is also believed that initial investment for the solar home systems remains mainly unaffordable to many of the rural users in developing countries (Lemaire, 2011). Nonetheless, the model enables the provision of long-term maintenance by the providers and also empowers the end-users to take more care of the equipment through information given to them by the providers. The approach has been implemented in a number of African countries including Senegal, South Africa, Zambia, Morocco and Namibia to promote a mix of solar and diesel systems (Lemaire, 2009; De Gouvello and Maigne, 2002. It has however been suggested that this model is only fit for high-volume rather than high-quality services. For example, a company with over 100,000 customers in East Africa used the model to offer small 8W solar home systems that power LED lights, a cell phone charger, and a radio to customers across a number of communities (Williams et at., 2015). Nonetheless, it is believed that the provision of these services can neither stimulate economic growth nor reduce poverty in the communities (Yadoo and Cruickshank, 2010).

Another widely used model to enhance penetration of rural electrification schemes is the mixed finance model where the government offset the cost of the installation by providing fixed amounts of subsidy while the balance is borne by the villagers in the form of equity and credit from banks, and ownership resides either with private individuals or with the community (Mainali and Silveira, 2012). Although the provision of subsidy enhances the affordability of the model, yet it is characterized by high installation costs associated with its lengthy procedures and quality assurance system

In the donation models, the technology is deployed to the benefiting community as a gift often by an individual or a Non-governmental organisation (NGO) or international donor organisations Hence, while the donor has the exclusive prerogative on the choice of technology to donate, there may not be any constraint on the provision of post-installation maintenance mechanism prerogative which may add up to negate the success of such exercise.

2.3.2.4 Tax Incentives

Tax incentives are used as a way of indirectly subsidizing the capital cost of electrification projects as they can implemented in addition to, or in lieu of direct subsidies (Liming, 2009; Mainali and Silveira, 2011). They are often applied by governments in form of reduction or exemption from taxes payable as customs duties or other taxes payable on the importation and procurement of (rural) electrification projects’ equipment (Diouf et al., 2013).

Apart from the above, there are a number of other financial mechanisms in existence; the highlights of which are given in Table 2.2. While the positive features of each model may be exploited, the choice of model to implement varies from one country to another, and may even vary from one region of a country to another depending on the finances available and the prevailing local conditions. As noted by Limin (2009) in a study comparing rural renewable energy financing between China and India, "while conventional funding and financial instruments such as capital subsidies, donor grants, and tax rebates and similar fiscal incentives have been able to achieve a certain level of penetration, the large-scale use and commercialization of renewable energy products and technologies requires innovative approaches to the selection and delivery of financial instruments and channels". Hence, no model may qualify as a fix-it-all approach; innovative financial mechanism aligning existing local dynamics may be the bedrock of successful diffusion of RE electrification projects in rural locations.

Table 2.2: Summary of public micro-grid support interventions

	Description	Advantages	Disadvantages
Subsidies			
Capital Subsidies	Subsidization of capital costs for project realization.	Reduces capital burden and time to capital recovery. Promotes affordable tariffs to end-users.	Lack of public sector capital is a motivation for private sector subsidization but also a limitation on funding subsidies. Reduced incentive for fiscal discipline.
Operating subsidies	Subsidization of operating costs during operations. Includes fuel subsidies	Promotes affordable tariffs to end-users.	Exposes project to risk of subsidy discontinuation. Viewed as unsustainable and a continuous burden on public funds.
Output-based subsidies	Subsidization of capital and/or operating costs after project realization based on fulfillment performance of criteria	The subsidies to specific policy objectives such as connection rates.	Exposes developers to high cost at risk as subsidies are not paid until after project realization.
Direct tariff subsidies	Direct subsidization of consumers through instruments such as electricity vouchers or via sale of power to a subsidized 3rd party retailer.	Can be targeted to specific customer classes in the case of vouchers. Expands access to grid subsidies if sold to state owned retailer.	Essentially an operating subsidy with similar associated risks.
Guarantees and Preferential Lending			
Loan guarantees	Assists project in securing debt by assuming the debt obligation in event of default	Enables microgrid to secure debt finance or secure debt finance on more favourable terms. No upfront cost.	Transfers risk of project failure to guarantor. Cost is difficult to quantify.
Preferential lending	Direct lending on concessionary terms to projects	Provides access to debt finance at reduce interest rates and/or longer tenors.	Transfers risk of project failure to debtor.
Tax incentives Customs/duties exemptions	Reduction or exemption of microgrid equipment from customs and import duties	Reduces capital costs. No reduction in public revenue if project would not otherwise be realized	Reduces public tax revenue if the project would have been realized without incentive. Vulnerable to abuse if exempted equipment has multiple applications.
VAT/Sales Tax exemptions on equipment	Reduction or exemption of microgrid equipment from VAT/Sales Tax	Reduces capital costs. No reduction in public revenue if project would not otherwise be realized.	Reduces public tax revenue if the project would have been realized without incentive.
Income tax exemption/ reduction	Reduction of operating expenses through reduction in tax burden	Reduces operating costs. No reduction in public revenue if project would not otherwise be realized.	Reduces public tax revenue if the project would have been realized without incentive.

VAT/Sales tax exemptions on electricity sales	Reduction or exemption of electricity sales from VAT/sales tax.	Reduces electricity prices for consumers.	Reduces public tax revenue from taxes on substituted, unsubsidized forms of energy.
Concessions			
	Award of exclusive rights to service a geographic area for a fixed term with minimum service level obligation.	Protects microgrid investments from competition in medium to long-term. Often accompanied by subsidies.	Provides monopoly status to a single private sector operator. Proper regulation necessary to protect consumers.

Source: Adapted from Williams et at., 2009

2.3.3 Business Models

In addition to the various financial incentives, a number of business models exist, and the model being implemented may determine to a large extent the success or sustainability or rural electrification projects. In any case, *the bottom line* of any business model on rural projects is to financially empower rural users who, ordinarily, would have found it financially challenging to afford the cost of having access to improved energy services. Two of the more common business models are briefly discussed below.

2.3.3.1 One-Stop-Shop Model

The One-Stop-Shop or One-Stop-Source model is a business approach in which both the technical and financial services are provided by the same organisation. For this study, this could be a financial institution extending into the provision of energy products or energy access without a separate energy partner, or an energy organisation self-financing a commercial energy project without the direct involvement of a financial institution. A well-known example of the former is the highly successful arrangement in Bangladesh in which the Grameen Bank financially empowered a sister company the Grameen Shakti to facilitate the widespread uptake of SHS and solar lantern by rural dwellers in the country (Sovacool and Drupady, 2011).

2.3.3.2 Financial Institution and Energy Company Partnership

This model involves a financial institution providing loans to an energy company for the purpose of rural electrification. The financial institution manages and monitors the utilisation of such loans while the energy company deploys the installation. Usually, such loans enable affordable services to be provided to rural dwellers at terms that are mutually beneficial to the organisation involved. A main advantage of the arrangement is that it exploits the professional competencies of each organisation and therefore enable them to operate in their familiar terrains. This model has been implemented in the partnership between SEWA bank and Solar Electric Light Company in India (Palit, 2013).

A brief highlight of some existing business models are shown in Table 2.3.

Table 2.3: Highlights of different Business Models

Business Model	Advantages	Disadvantages
One-Stop-Shop	Ability to control where the energy end-user finance products are offered	Need to invest significant financial and human resources as this model depends upon adding a completely new core competency to the business that can affect all core operations.
Financial Institution Partnered with Energy Enterprise	Each partner is able to focus on core competencies, and also to pool resources for marketing, promotion, and improved services.	Requires significant communication and coordination with partner organisations beyond what is typical in dealing with suppliers, distributors, re-sellers, etc. Energy enterprises do not have control or influence on financing terms offered to end users
Umbrella Model	Energy enterprises are able to engage multiple village-level finance institutions with a single partnership, and lower cost to through bulk purchase agreements Village-level finance institutions typically serve rural and urban poor populations with high need for modern energy.	Larger number of partner institutions may be difficult to coordinate effectively. Energy enterprises will have low level of ability to conduct due diligence on village level finance institution partners Many levels of mark-ups could make end-user finance products too costly, potentially wiping out benefits of bulk purchase arrangements.
Brokering Model	Energy enterprises and finance institutions are able to increase access to energy end user finance with little to no investment Broker may be better positioned to market and promote energy end-user finance products	Business model has yet to be tested at a sufficient level to fully understand benefits and risks
Franchise/ Dealership Model	Ability to ensure steady supply of customers through franchises that may otherwise have cash flow problems	Could lead to cash flow issues if dealer/franchise credit is not managed properly

Source: Winiecki et al., 2009

2.4 Barriers and Drivers to diffusion of Renewable Energy Systems

Although the potentials of RETs to reduce CO_2 emissions and to alleviate poverty by extending energy access to remote areas are well documented (Mainali and Silveira, 2012; Shaaban and Petinrin, 2014; Ahlborg and Hammar, 2014 etc.), a number of barriers exists against them. These barriers can be defined as the varied factors, practices or phenomenon that work against the effective deployment, diffusion and performance of RET installations. While these factors may not necessarily result in total failure in the deployment or performance of these installations, they may considerably slow down or limit their output. In developing countries, apart from the obvious lack of capital to finance deployment locally and a lack of trade to accelerate diffusion with foreign capital, the barriers can include a deficient regulatory structure, a lack of clear legal framework, a lack of experience with incentivizing policies and a lack of local technological expertise to install (Müller et al., 2011).

The disappointing progress towards providing sufficient rural electricity has been partly attributed to the making of profit as the focal point in many of these projects, particularly where they are privately financed, and further ascribed to the failure to raise the incomes of rural households, failure to effectively design tariffs, and failure to adapt regulatory systems that can make electricity more affordable to poorer communities (Estache et al, 2001). In the same vein, Tupy (2009) notes that even if well-designed RETs support programmes are in place, onerous bureaucratic procedures and administrative obstacles can hinder rapid market development.

Six drivers were identified by the U.S. Trade Representative (2015) as necessary to stimulate foreign investments. These are: equal treatment of investors under the law; clear limits on expropriations and provision for compensation in the event of expropriation; transferability of investment related funds into and out of a host country without delay and using existing market rate of exchange; restrictions on the imposition of local performance requirements; freedom to choose management personnel regardless of nationality; and dispute settlement through international arbitration. The absence of some of these may be the reasons for the lack of interests by foreign investors in many sub-Sahara Africa countries where their participation in the energy sector is desired.

Gujba et al, 2012 observe that many financing institutions in Africa do not have dedicated financing for energy. In addition, they consider lack of high-level technical skill as may be needed for low-carbon development projects, lack of awareness of the potential of the technology, high interest rates and unfavourable policy frameworks that do not negate high levels of taxations and inculcates low support for foreign direct investment as some notable barriers. A study by Mitchell et al., (2011) affirmed that there is often a lack of timely, appropriate, and truthful information in the reduction of transaction costs on RE installation projects which, for example, may be due to the reduction in the cost of major components (such as the reduction in the cost of solar panels used in solar installations). However, they further asserted that many renewable energy technologies remain economically uncompetitive at current energy market prices, making them financially unprofitable for investors.

In their study, Reddy and Painuly (2004) list the barriers as Awareness and Information, Financial and Economic, Technical, Market, Institutional and Regulatory, and Behavioural. In a similar study, Alphen et al (2008) note that the barriers that impede effective implementation and diffusion of RETs installations go beyond Technical factors to lack of information, insufficient capabilities, lack of understanding of local needs, business and institutional limitations, as well as political and economic constraints. Similarly, Jacobsson and Johnson (2000) list the factors leading to a new technology being rejected to include Actors and Markets (poorly articulated demand, established technology characterised by increasing returns, local search processes, market control by incumbents); Networks (poor connectivity, wrong guidance with respect to future markets); Institutions (legislative failures, failures in the educational system, skewed capital market, underdeveloped organisational and political power of new entrants).

In a report on the study of nontechnical barriers to solar energy use, Margolis and Zuboy (2006) identified the ten most common. While the report focused mainly on developed countries, some of the identified barriers also relate to developing economies. The barriers are given as:

- Lack of government policy supporting RE
- Lack of information dissemination and consumer awareness about energy and RE
- High cost of solar and other RE technologies compared with conventional energy
- Difficulty overcoming established energy systems
- Inadequate financing options for RE projects

- Failure to account for all costs and benefits of energy choices
- Inadequate workforce skills and training
- Lack of adequate codes, standards, and interconnection and net-metering guidelines
- Poor perception by public of renewable energy system aesthetics
- Lack of stakeholder/community participation in energy choices and RE projects.

Generally, the barriers are categorised as Technical, Economic and Financial, Market imperfection, Socio-cultural and Institution deficiencies. A summary of these barriers as adapted from Painuly (2001) is given in Table 2.4.

Table 2.4: Barriers to RETs Penetration

Barrier Category	Barriers	Remarks
Market Failure/ imperfection	Highly controlled energy sector	This may lead to lack of investments in RETs.
Market Distortions	Favour (such as subsidies) to conventional energy Taxes on RETs	This affects competitiveness of renewable energy adversely. Cost of energy from RETs increases.
Economic and Financial	Economically not viable High discount rates Lack of access to credit to consumers	Cost reduction in RETs needed. Incentives may be needed in the initial stages. It may reduce market size.
Institutional	Lack of a legal/regulatory framework	Renewable energy producers may face market/economic/financial barriers without this.
Technical	Lack of skilled personnel/training facilities Lack of operation & maintenance facilities	This can be a constraint for producers. This can affect product acceptance
Social, Cultural and Behavioural	Lack of consumer acceptance of the product	Market size becomes small.
Other Barriers	Uncertain governmental policies High risk perception for RETs.	It creates uncertainty and results in lack of confidence. May also increase cost of project. Environmental damages/pollution may be unacceptable.

Source: Adapted from Painuly (2001)

While the list of barriers as shown in Table 2.4 is not exhaustive, it is important to note that the identified barriers may not be present in every situation: some may be specific to a technology, site, area or region. In addition, the reasons for the drive towards the adoption of renewable may differ from country to country and this may determine the barrier(s) of relevance in a study. For example, since most developed countries have a high degree of grid electricity penetration, the concerns occasioned by global warming and climate change have been the main driver for the adoption of RETs such as solar PV as a viable mitigation against CO_2 emission from the fossil fuel-dependent sources in many of these places. Hence, while environmental consideration may be of priority in such situations and these may determine the barriers of relevance, this may not be so in developing countries where there is acute shortage of grid electricity. In such places, RETs are majorly being deployed to meet the energy requirements of people in locations where there is low possibility of grid extension in the immediate future.

Some of these barriers are discussed below.

- **Technical Barriers**

While most RETs are well proven and, hence, are apparently at low risk (Reddy and Painuly, 2004), technical barriers remain a major determinant to their effective deployment. Technical barriers relates to the challenges that that can hinder the performance of an installation by virtue of the technology adopted for it. Some of these are discussed in the next section.

Lack of skilled personnel/training

Lack of skilled personnel/training relates to insufficient numbers of skilled workers in the deployment and subsequent maintenance of RE installations. Karekezi and Kithyoma (2002) note that trained manpower that is capable of developing and manufacturing renewable energy technologies is a prerequisite for their successful dissemination. Design, preparation, deployment, and maintenance of RETs, especially at large scales, require a skilled workforce and expertise that are currently lacking in many developing countries. According to Margolis and Zuboy (2006), the main features of the technical barriers are the lack in the workforce of adequate scientific, technical, and manufacturing skills required for RE development; and lack of reliable installation, maintenance work force. Hence, in most cases, the technology or equipment is imported; spare and replacement parts when required may not be readily available especially in more remote locations (Umar et al., 2009). Lack of local skilled personnel/training may also result to inability to provide necessary repairs and maintenance as at when due.

Improper Design/Design Weakness and Poor Installation Procedures

Equally as important as the choice of the system is the proper design and monitoring of the support system adopted (Haars e al, 2004). Failures in RETs are known to have occurred due to bad design approaches that, in some instances, have imposed unrealistic expectations on the system, and through installation procedures that undermined the performance of such installations. Sambo et al (2014) list such factors related to improper design and poor installation procedures to include overestimation of irradiation figure, under-sizing of PV panels, insufficient battery capacity or wrong battery type selection, and underestimation of energy demand.

Sub-Standard products

RE systems are characterised by high capital costs compared with conventional energy. The intent to reduce these costs may encourage installers to seek cheaper but less effective products that do not eventually perform to expectations. In some cases, it is difficult to obtain quality spare parts for the installation (Dorji et al, 2012; Van Els et al, 2012). Furthermore, most developing countries lack standards, codes, and certification that could curtail the inflow of low-quality products and counter the negative perception about RETs.

Technological Complexities

RETs are not considered as simple enough to attract wide acceptance among the rural populace. For example, the necessity of additional hardware – batteries and inverters in the case of Solar PV systems – presents the technology as rather cumbersome and unattractive. This is further compounded by the limitation imposed on the ratings of the electrical load that can be supported by such RET installations. Additionally, interconnection and net-metering guidelines may be quite rigid where available (Margolis and Zuboy, 2006).

- ### Economic and Financial

Financial and economic considerations are major determinants in the viability of an energy system. The challenges posed by both the high initial up-front costs of most RE installations, and the low economic power of users is often compounded by an absence of adequate funding opportunities and financing products for renewable energy. This may also be in terms of difficulty in obtaining the necessary financing aids that may be required for the implementation of such projects. In addition, the absence or inability of users to access credit facilities could add to this challenge.

- **Highly Controlled Energy Sector**

In most developing economies, the electricity sector remains regulated and is under the sole auspices of the government. This discourages investment from the profit-driven private sector thereby negatively affecting the diffusion of RETs in these countries

- **Institutional Deficiencies**

Recently, a number of developed and developing countries have introduced major electricity sector reforms which significantly impacted on the market and institutional structure of the sector (Zhang, et al., 2008). For RETs to become more attractive to investors and acceptable to end users, strong institutions must be put in place by government. Such institutional structures for rural electrification as noted by Irwin (2003) will typically include government ministries for finance and energy regulators, private sector actors, non-governmental organizations, donors and community representatives. Meyers (1998) lists lack of legal and regulatory frameworks, limited institutional capacity and excessive bureaucratic procedures as major institutional deficiencies against the widespread of RETs, while Jacobsson and Johnson (2000) include institutions such as legislative, educational, capital market and political organisations. The absence of strong institutions could affect effective information dissemination, marketability, and provision of realistic financial incentives.

- **Lack of a legal/regulatory framework**

Deliberate and sustained measures need to be put in place to provide a level playing field, kick-start RET industry development, build up RET market capacities, make RET cost competitive without which RETs will be condemned to remain a small niche market (Tupy, 2009). Wang (2007) recognises a basic requirement to successful renewable energy development as the implementation of a comprehensive legal, policy, and regulatory framework that could attract large-scale investment. In the absence of legal framework, it may be difficult for private investors to invest in renewable energy facilities since big power utilities control a monopoly of power generation and distribution in most developing countries (Beck and Martinot, 2004).

- **Uncertain governmental policies**

Uncertainty policies relate to bad policy design, policy discontinuity and/or insufficient transparency of policies and legislation (Müller et al., 2011). Investors are attracted to government policies that are stable; and as such will not change with successive government. The full benefits of trade liberalization will be realized only if investors perceive reforms as credible and subject to reversal (Asiedu, 2002). Such policies would include legally laid down RETs support schemes with effective long-term investment security, infrastructures and political will (Tupy, 2009). Ironically, many developing countries are characterised by political turbulence with unpredictable change of government that are inimical to infrastructural growth, discourages foreign investment and jeopardizes returns on investment (Dupasquier and Osakwe, 2006; Morrissey and Udomkerdmongkol, 2012). Nigeria, as a case in point, is presently characterised by high risk of political instability and terrorism, threats to political stability, and risks of Islamic insurgency in the North and militancy in the Niger Delta region which can harm investors' confidence (Gara et al., 2014).

- **Non- involvement of stakeholders**

RETs need to gain the confidence of stakeholders including developers, customers, planners and financiers and end users. It is necessary to dissipate general information and increase public awareness in respect to new RETs. This will enhance the understanding of the practical problems inherent in the deployment and maintenance of such projects. Hence, as much as it is practical, these set of people must be involved in the planning and decision-making processes at both pre-installation and post-installation stages.

- **Clash of Interest**

Take-up of RETs has been hindered by policy makers who have stakes in the conventional methods of energy production by virtue of their investments and, as such, perceive RETs as a threat to their economic benefits. Similarly, effective diffusion of RETs has been hampered by policy makers who use political allegiance as the basis of its deployment to communities.

2.4.1 Interconnection of Barriers

Many of these barriers do not act in isolation, as their effects could be the outcome of the presence or absence of some other barriers. For example, the challenge of high cost could be as a joint effect of technical factors such as low PV sunlight-to-electricity conversion efficiency and manufacturing yield, as well as non-technical factors, such as supply and demand (Margolis and Zuboy, 2006). High cost could also make RETs to appear as financially unfriendly to end-users and this may negatively affect its acceptability, thereby leading to a low spread of its usage. Furthermore, such low spread could equally contribute to the high cost. In the same manner, absence of financial incentives could reduce RETs diffusion and acceptability among the end users, while such acceptability could also be hindered when the deployment of RETs is carried out with perceived social imbalance or political undertone. Such interconnections between barriers are depicted in Figure 2.8.

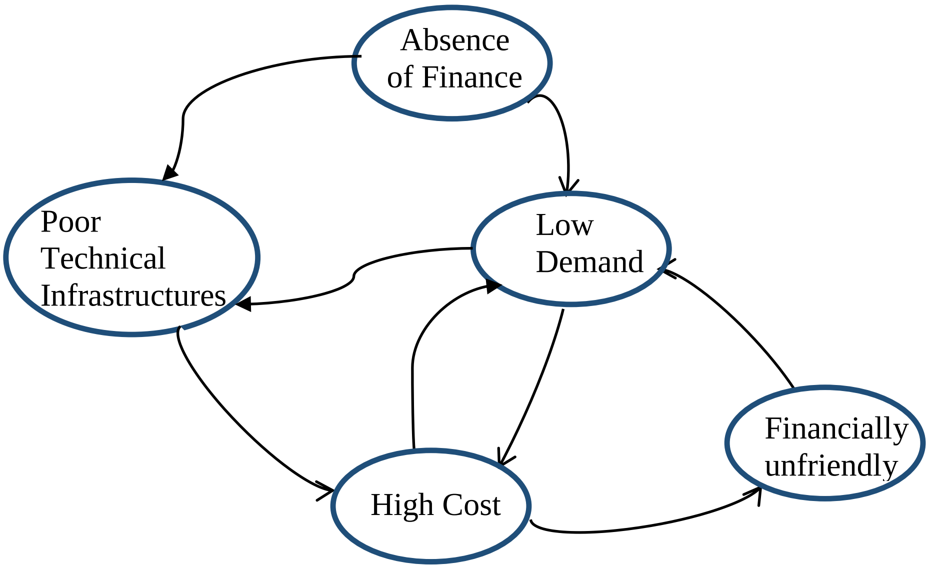

Figure 2.8**: Interconnection of Barriers**

It is worthy to note that the form of interrelation among barriers could vary in accordance to factors such as the particular RE technology being studied or the location of study since there could be peculiar issues associated with such factors. In the same vein, as one barrier is overcome, others may become apparent. Such an interrelationship between barriers as given by Müller et al. (2011) is shown in Figure 2.9.

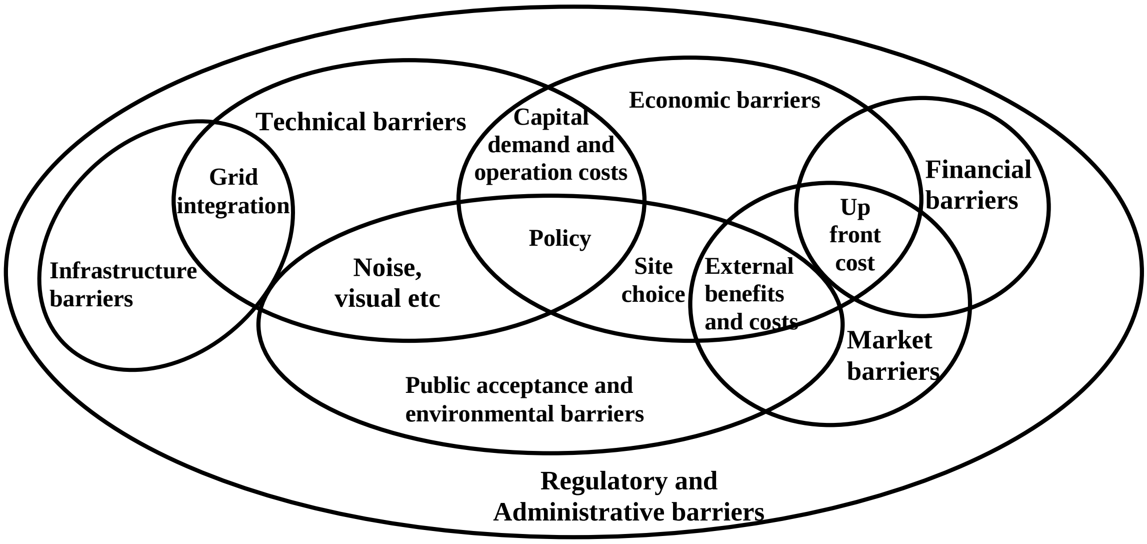

Figure 2.9: Interlinked barriers to renewable energy development

Source: Müller et al. (2011)

2.5 Assessment and Evaluation Tools

For installations in rural locations, beyond establishing if a project is viable or otherwise, strategic planning is necessary to ensure best pre and post deployment outcomes. Also as stated earlier, technology assessment is an essential factor when choosing among multiple options for supplying electricity to a location. While a number of approaches exist for such evaluation and assessment of rural installations, a few of these methods are discussed below.

2.5.1 SWOT Analysis

A traditional approach used in appraising the various design options of energy for a location is the matrix development and analysis of their features on the basis of their Strength, Weakness, Opportunities, and Threats (SWOT), thereby enabling a logical presentation of the pros and cons of each form of design options. The Strength and Opportunity features can thereby be enhanced and exploited respectively, while the weakness and threats are respectively minimized and dealt with. Although it could be used as an individual study approach, the swot analysis is more often used as a part of research strategy, and often provides a platform for further analysis based on its outcomes. The measure of robustness of analysis based on this method is often dependent on other research instruments which are used to generate the necessary data for the analysis.

A number of studies on renewable energy installations in rural locations have been carried out using this approach. Iemsomboon and Tangtham (2014) used SWOT analysis to study the state of Solar Home System (SHS) project management in remote areas of Thailand and to identify problems and obstacles associated with it. The outcome showed that low knowledge of operation and maintenance as a major challenge. Similarly, Jaber et al., (2015) used it to assess the current status of renewable energy sources and systems in Jordan to identify solar, wind and mini hydro-power schemes as the ones with are promising attributes for the country. Another conventional method used for making such decision is the cost-benefit analysis in which decision on technology to deploy among available options is based mainly on the financial implication of the project and the benefits accrued from it (Greeley 1986).

2.5.2 Life Cycle Assessment (LCA)

Yet, another popular method used in such investigation and assessment is the Life Cycle Assessment (LCA) which includes environmental dimensions with all the stages of a product's life from manufacture to end use. It is an iterative process used to analyse a product or system (Pascale et al., 2011). The LCA has been widely used analysing and comparing the environmental impacts of different energy options (Jungbluth et at., 2005; Pehnt, 2006; Frick et al., 2010). However, LCA typically only considers quantifiable environmental impacts, for instance, greenhouse gas emissions, while other criteria that may influence the acceptability of the installation are not accounted for.

Equally, studies have also been carried out based on social aspect analysis of technological assessment. Assefa and Frostell (2007) used questionnaire to evaluate social sustainability from the viewpoint of social acceptance based on three indicators: knowledge, perception, and fear to conclude that users have a low level of information and knowledge about new energy technologies while Carrera and Mack (2010) used expert judgments to rate energy technologies on a set of social indicators that were generated in a discursive process. A major shortfall of many of these studies is that the factors on which they are carried out do not encompass all the factors that may influence the successful performance of the installation, thereby giving rise to results that are skewed and, therefore, may not be generalised. It has been argued that many electrification projects in developing countries are unsuccessful due to the failure to entirely address the issues that may impact on their sustainability from the onset; rather, focus had been more on delivering the technology, and success had been measured in terms of number of installations deployed (Hulscher and Hommes, 1992; Mainali and Silveira 2015). Similarly, Rahman et al (2013) contends that many rural electrification projects have often failed due to failure to take account of issues beyond financial and technical dimensions; noting that rural electrification projects should be modelled to include socio-cultural dynamics and environmental consequences to ensure multi criteria decision support in their deployment. Along the same vein, Hirmer and Cruickshank (2014) argues that in addition to the common techno-economical factors, the assessment and measurement of the success of rural electrification projects that has been handed over to local communities should also include the value perception of end-users based on functional, social significance, epistemic, emotional, and cultural values for meaningful and holistic outcomes as shown in Figure 2.10. They contend that this assists policy makers and agencies to revealing what influences communities to ensure long life of development projects in their territory. In a recent study, Eder et al. (2015) assert that the adoption and success of renewable energy technology rural electrification is based on three critical dimensions: technical, economic, and social. They emphasised that while new RE technologies have advantages over grid system, they require viable financial systems in low-income rural markets and also the collaboration of local actors.

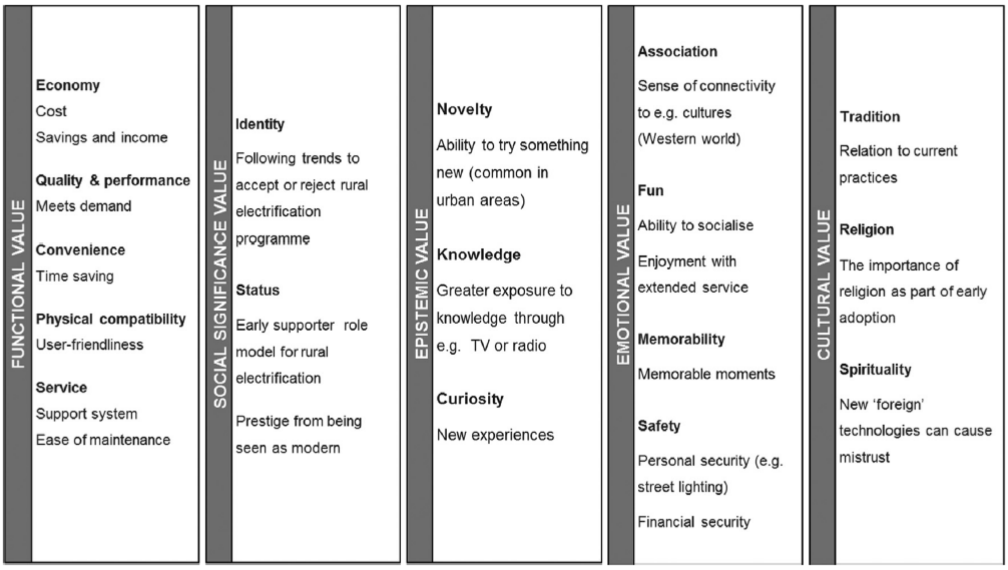

Figure 2.10: Five Pillars of user-value applicable to rural electrification.

2.5.3 Weighted Score System

In the weighted score system, weights are awarded to a set of indicators that relate to a number of aspects of rural installations such as Technical, Government regulation, Environmental and Social. In such an approach as detailed in Table 2.5, Lhendup (2008) appropriates weights to a set of 18 indicators on a performance scale ranging from 1 (Low) to 5 (High) and further gives explanation for the rationale behind the weighing criteria.

Table 2.5: Indicators and Allocated Weights

S/N	CRITERIA	WEIGHT	RANKING	
			1	5
1	**Technical Features**	**60**		
i.	Energy density of the Installation	8	Low	High
ii.	Ability to meet the unanticipated excess demand	8	Not Capable	Fully Capable
iii.	Energy payback ratio of the system	8	Low	High
iv.	Lifespan of the system	7	Short	Long
v.	Quality of supply	6	Poor	Good
vi.	Dependence on Weather and Climatic	6	Fully Dependent	Not Dependent
vii.	Incremental capacity of the system	5	Difficult	Easy
viii.	Availability of local skills and resources	5	Not Available	Available
ix.	Dependence of fossil fuels	4	Fully Dependent	Not Dependent
x.	Development of other infrastructures	3	Low	High
2	**Government Regulations**	**15**		
i.	Tax incentives	5	Not provided	Provided
ii.	Regulation on use of local resources	5	Stringent	Unregulated
iii.	Opportunity for private participation	5	Low	High
3	**Environmental and Social aspects**	**25**		
i.	Public and political acceptance	6	Not Acceptable	Acceptable
ii.	Land requirement and acquisition	6	Difficult	Easy
iii.	Risk of hazard rating	5	High	Low
iv.	Emission of Environmental pollutants	5	High	Low
v.	Interference with other utility infrastructure	3	High	Low
	Total Aggregate	**100**		

Source: Lhendup (2008)

However, while the approach could be considered simple and easy to implement, and despite the justification behind the weighing criteria, it suffers from a level of presumption since the same weight may not be allocated to the same set of indicators by another person, or the set of indicators considered may differ. This could be improved upon if the weighing criteria are developed by a group of experts constituted by relevant stakeholders.

2.5.4 Sustainability Index

A more current and well-adopted method that attempts to capture a wide range of the various dimensions and criteria is the use of sustainability index (indicators). Sustainability indexes are often used to evaluate the outcomes of a project. For example, the sustainability of an energy project will be the availability of electricity services that are reliable, available and affordable for all, on a maintainable basis (Johansson and Goldemberg, 2002). The index has recently been used to determine the preferred choice of technology to deploy to a (rural) location among a number of options (Evans et al., 2009; Rahman et al., 2013) and to evaluate and compare the status and progress of rural household energy in a number of countries (Mainali et al., 2014).

The use of sustainability criteria came into forefront after the United Nations' World Commission on Environment and Development (WCED) published the 'Brundtland Report' in 1987 in which "Sustainable Development" is regarded as the kind of development that meets the present needs without conceding the capacity of the needs of the future to be met. However, a large number of indicators along major dimensions, themes and sub-themes have since been developed. While these large numbers of indicators provide insights on sustainable development concerns, they are often difficult to realise into measurable and quantifiable entities (Kemmler and Spreng, 2007), while some are simply too general and difficult to quantify (Ugwu and Haupt, 2007). Furthermore, although several studies have been carried based on sustainability dimension e.g. Afgan et al., (2005); Brown and Sovacool, (2007); Doukas et al., (2012), there is neither in existence a single commonly accepted method for assessing and combining all of them nor a standard set of such indicators (Ilskog, 2008; Mata et al., 2011). For example, the IAEA (2005) presents a comprehensive list of thirty energy indicators for sustainable development (EISD); Ilskog (2008) utilised 39 indicators relating to technical, economic, social/ethical, environmental and institutional dimensions of sustainability (see Figure 2.11) to carry out sustainability evaluation based on information that can credibly be obtained from field studies, while the Energy Development Index (EDI) developed by the International Energy Agency (IEA) only provides an overview at a country level and leaves out the technical and environmental aspects of sustainability. In addition, while there exists a wide-ranging amount of indicators, the assessments and information on rural energy sustainability are limited (Doukas et al., 2012). However, despite the fact that the current use of indicators in the area of rural electrification is limited and it is unclear how best to collect the data for the many conflicting frameworks proposed to develop indicators, they nonetheless provide a practical method to monitor progress towards sustainable development, and enhance the presentation and understanding of outcomes (World Bank, 2004; IAEA, 2005, Reed et al., 2006). Noting that projects promoted only on the basis of information about prioritised sustainability dimensions (such as environment) may fail as a result of weaknesses in other dimensions, Ilskog (2008) stated that although her method based on the use of 39 indicators renders as a robust set of tools to be used for analysis and decision, no method may be applied to fully cover the complex reality of a project, and therefore a method may need to be complemented by specific local project indicators, as well as the application of other appropriate tools for analysis.

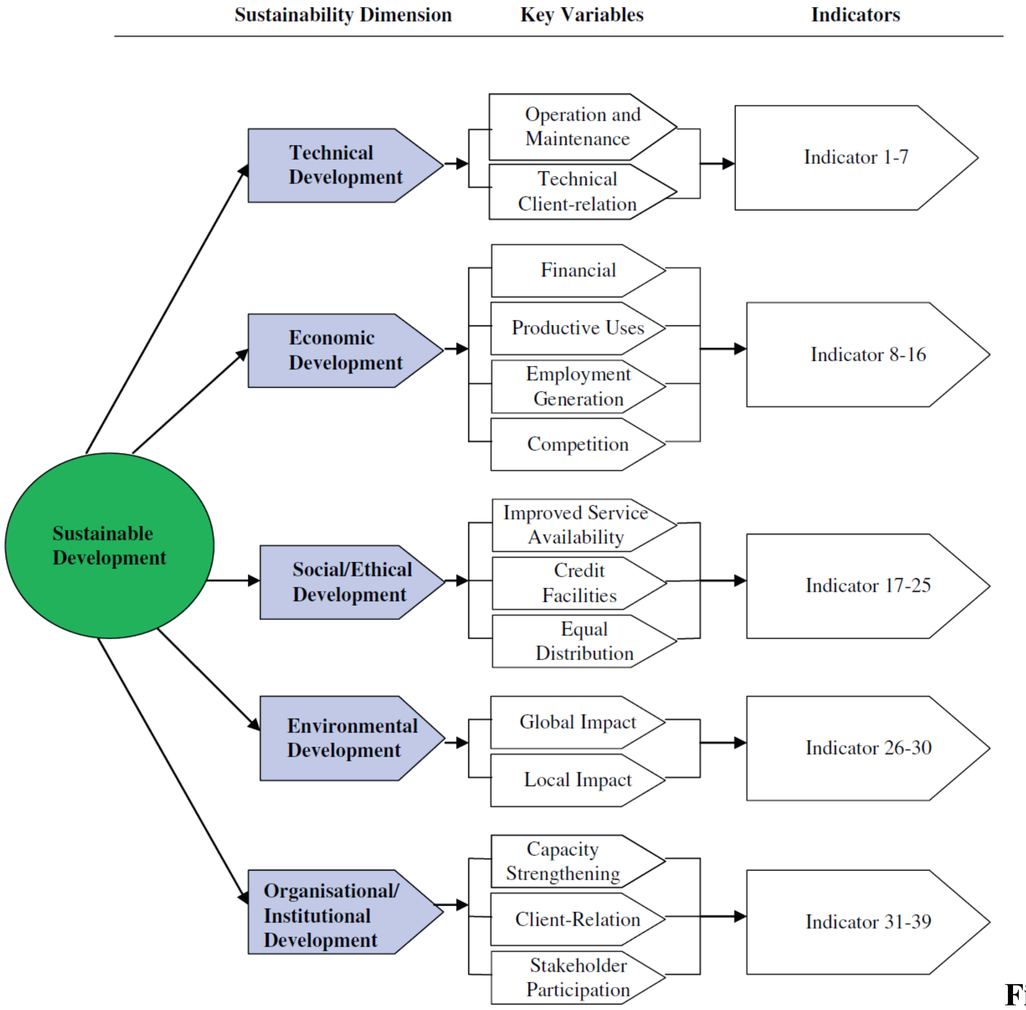

Figure 2.11: Sustainability Criteria

Source: Ilskog (2008)

With respect to off-grid electrification projects, the World Bank (2008) developed a set of constituting elements which, though may not all be present in a project, could contribute, and therefore be used to evaluate the sustainability of such projects. These are shown in Figure 2.12.

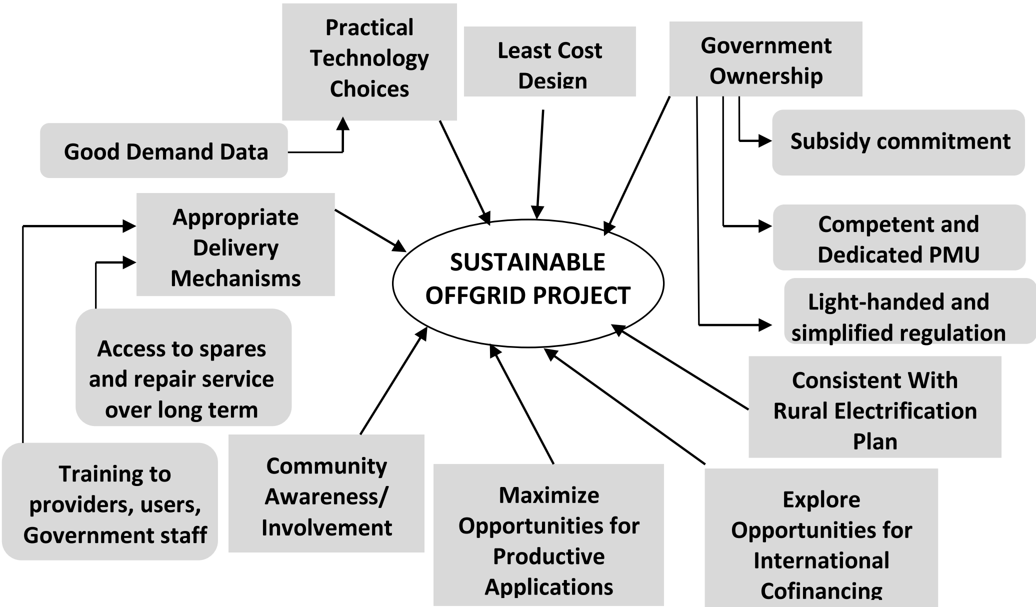

Figure 2.12: Elements of Sustainable Off-Grid Electrification Projects

Source: World Bank, 2008

It is therefore seen that number of assessment and evaluation tools are in existence for rural electrification projects. The choice of the one(s) to implement in any project may be determined by an alignment of some peculiarities between the project and the evaluation tools. In addition, two or more evaluation tools may be combined where possible tin order to obtain results that could be considered profound.

2.5.5 Framework for Assessment and Evaluation

A framework identifies the range of factors that influence a decision or process; the configuration (i.e. the combination of factors and their relative importance in a specific context) of which will help to determine the decision relating to that context. As such, with respect to the various factors that act as barriers to the effective deployment and diffusion of RETs, a RET framework outlines the configuration of a set of factors, practices and policies that could enhance the implementation and diffusion of a RE technology.

In their analysis of drivers, barriers, and strategies for implementation of renewable energy technologies in rural areas in Bangladesh, Mondal et al (2010) proposes a theoretical framework based on (1) technology and related knowledge and skills, (2) networks of actors, and (3) institutions. For successful implementation of a technology in a certain area, they opined that locally sufficient knowledge and skills must be available to implement, maintain, and if necessary, repair the technology. Furthermore, properties of the technology should include simplicity, possibility of income generation, environmental friendliness, technical feasibility, financial viability, social equity, and cultural acceptability. On the network of actors, they suggest that all relevant actors - including future owners and people who will have to implement and maintain the technology - should be involved from the beginning. Finally, the local institutional context should fit with the technology - including cultural aspects, policy programs, financial incentives, levels of education, information dissemination, and availability of material and hardware etc. While Rio and Burguillo (2009) note that environmental and energy security arguments tend to be the main drivers for renewable energy, while local economic benefits tend to get overlooked, they argued that the latter are critical for ensuring the sustainability in renewable energy in the medium to long term, hence the need for a well-designed regional framework that can reconcile policy trade-offs and identify potential complementarities among different drivers.

Whereas Burguillo (2008) argues that there is need for a well-designed regional framework that can reconcile policy trade-offs and identify potential complementarities among different drivers, Tupy (2009) emphasises that support policies should aim to reduce barriers for RETs deployment, provide a level playing field, kick-start RES industry development, build up RES market capacities, make RES cost competitive, mitigate climate change, and increase energy independency. However, rather than offering continual supervision, she further recommends a double-pronged policy approach where, through direct promotion of support programmes for RETs and indirect promotion through measures aimed at disadvantaging conventional energy, initial support is provided to RETs until a point is reached where they may compete against conventional sources independently. Such direct measures target could aim at reducing the cost of installation and enhancing the affordability of RETs ownership through the introduction of tax concessions on imported RE hardware and provision of soft loans to end users, while indirect measures could involve the inclusion of external costs such as environmental pollution in the pricing of energy from conventional sources and the reduction/removal of other prevailing benefits that have given rise to their present unrealistic low prices as earlier highlighted in this chapter. These sorts of measures could augment the competitiveness of RETs against conventional energy sources.

2.6 Examples of National Rural Electrification Programmes

As stated in section 1.1, sub-Saharan Africa and developing Asia are regarded as the epicentre of lack of access to water and electricity, especially to their respective rural populace. However, efforts and advancements have been made to reach the rural users in these two regions especially using renewable energy technologies RETs. While literatures on such rural electrification programmes in sub-Saharan are not well documented, Nepal and Bangladesh are two countries in Asia with well-documented literatures on concerted efforts to bridge the gap in the acute electricity shortage in rural communities through the diffusion and utilisation of RETs. The two countries are characterised by a large percentage of their populations residing in rural areas, with most of them lacking access to grid electricity, similar with the situation in Nigeria. The cases of these two countries and those in a few sub-Saharan African countries are discussed below to highlight lessons that may be learned from peculiar challenges encountered, and the approaches utilised in each of them to reach the rural users.

2.6.1 Rural Electrification in Nepal

In Nepal, 80% of the country’s 28.5 million people live in rural areas, with around half of these so remote that the national grid is never likely to reach them. These remote and isolated communities generally live in great poverty, and the country is considered one of the least developed in the region with about 90% of the urban population but only 34% of the rural population having access to electricity (Gautam et al., 2009; IEA, 2010). While the drive towards rural electrification in the country started over 40 years ago, the provision of electricity to remote, rural communities has been challenging due to high cost of grid extension occasioned by physical isolation, lower electricity loads, and scattered low-income consumers (Mainali and Silveira, 2011), with approximately 75% of rural communities using firewood for cooking (Lohani, 2011).

After democracy rule was restored to Nepal in 1990, various regulatory and institutional policies were formulated that created opportunities for the participation of private investors in the deployment of local energy resources to meet the energy needs of isolated and remote rural communities (Pokharel, 2003). An outcome of this is the establishment of the Alternative Energy Promotion Centre (AEPC) in 1996 to promote and provide financial and technical assistance for RETs including micro-hydro plants MHP, solar home system SHS, and improved cooking stove (ICS) (Gewali and Bhandari, 2005; ESAP, 2010).Two of such prominent policies are the Rural Energy Policy and the Subsidy Policy for Renewable Energy.

The Rural Energy Policy began in 2006 for the promotion of renewable energy in rural communities (REP, 2006). It highlights SHS as a viable alternative for rural electrification, especially where grid extension and MHP are not viable options (REP, 2006). The Subsidy Policy for Renewable (Rural) Energy (SPRE) was introduced in 2009 to improve on the existing ones and effectively promote rural electrification (AEPC, 2009). In addition to the various subsidies, the financial support includes equity and credit mechanisms. However, there still exists a huge financial gap between the cost and affordability of electrification. This has remained a crucial issue impeding a wider expansion of rural electrification in the country. The various model as being implemented in Nepal is depicted in Figure 2.13.

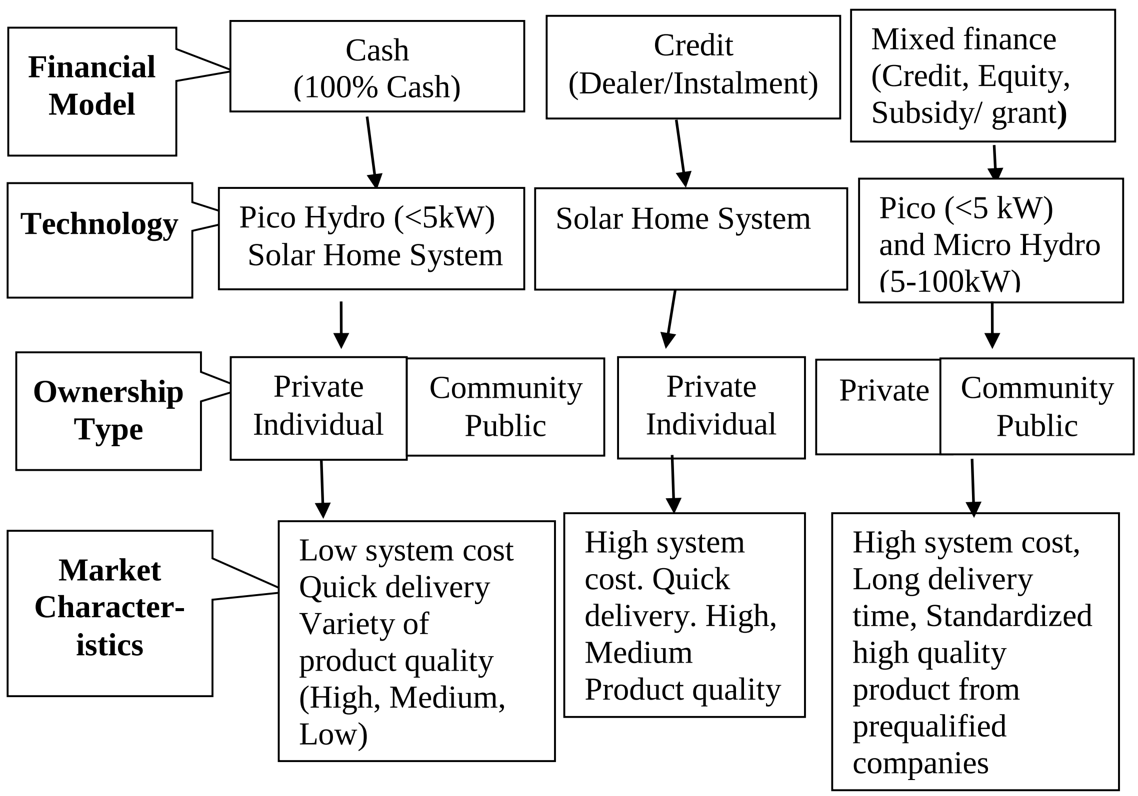

Figure 2.13: Renewable Energy Supply Models in Nepal
Source: Mainali and Silveira, (2011)

In recent years, the government commenced the implementation of decentralised RETs, especially micro-hydropower (MHP) and solar photovoltaic for geographically isolated rural settlements (Katuwal and Bohara, 2009). These approaches often offer a more realistic option for increasing the coverage of electric access in such locations as, whereas it could take up to 4 - 5 years for a major hydropower project to be completed, off-grid technologies such as wind, MHP and solar PV can be built in a few weeks; the installation of solar home systems (SHS) in households could take less than three hours, although policies and programs to promote electrification in Nepal mainly focus on access to light at household level (Zahnd and Kimber, 2009 Gurung et al., 2011).

Many of the MHP installations are privately owned by local entrepreneurs or local companies since government licences are not required by law for the ownership and operation of such installations (of ratings of up to 1000kW); thereby effectively removing the associated bureaucracies involved with their commercial operation and ownership Hence, by the end of 2010, over 2000 MHP installations with a total installed capacity of more than 15MW and covering more than three-quarters of the 75 districts in Nepal has been completed (Wegstein, 2010; ESAP, 2011).

2.6.1.1 Impediments against the integration of renewable energy technologies for rural electrification in Nepal

In spite of policy revisions and ambitious programmes by the government, and efforts put at increasing the spread of RETs in Nepal, the market development status of RETs remains low. In general, the success in their diffusion has been limited due to various factors including initial high capital cost of RET systems, inadequate credit facilities to rural dwellers, inability to obtain continuous energy supply from RETs such as solar systems, ineffective institutional base, and limited research and development in the energy sector (Shrestha, 2005). The existing subsidy policy on RETs in the country tends to favour large RET projects more than smaller projects. Hence, MHP projects, which are characterised by high initial capital outlay when compared to small hydropower projects, are still unaffordable for rural dwellers. Similarly, although the level of subsidies on solar PV technology for remote areas are still comparable higher than the subsidies for less remote areas, many of the dwellers in these remote areas are subsistence farmers with very low financial abilities and, hence, still finds the subsidised costs of the solar PV systems beyond their financial reach (Mainali and Silveira, 2011). A review of the current subsidy scheme for solar PV installations for remote areas is suggested in order to bridge the gap between the subsidised cost and economic life of the dwellers by making the solar installations more affordable to them (ibid.).

2.6.2 Rural Electrification in Bangladesh

Many authors (Nathan, 2006; Taniguchi and Kaneko, 2009; Rahman et al., 2013, etc.) have commented on the rural electrification efforts in Bangladesh as an example of where huge success has been recorded in both on-grid and off-grid rural electrification. Against the well-known relative high financial requirements necessary to take-up solar installations, the country - where more than 70% of her over 160 million people live in the rural areas – has recorded huge success of the Solar Home Systems (SHS) among a large group of low-income rural dwellers. As such, it presents a model for similar developing countries such as India, Senegal, Rwanda, and Nepal to emulate (Taniguchi and Kaneko, 2009).

Bangladesh started its Rural Electrification Program (BREP) in 1980 when only 10% of its total population and barely 2% of rural people was connected to the grid. Rural electrification has been pursued by both grid extension and standalone technology options. The standalone technologies deployed are mostly small-scale renewable energy options, such as solar home system (SHS) and biogas plants, but the former accounts for 80% of the off-grid RE option (Rahman and Paatero, 2012). Prior to the commencement of the BREP, the only organisation providing electricity for the populace was the Power Development Board, which was owned solely by the government. During this time, little emphasis was given to rural areas. However, since the commencement of the BREP, the number of rural communities with grid extension has been progressively increasing until 2006 when the number declined due to factors discussed in section 2.6.2.2. Similarly, the target set by the Infrastructure Development Company Limited (IDCOL) to install 50,000 SHS by 2008 was achieved three years earlier in 2005.

2.6.2.1 Factors contributing to the success of Rural Electrification Programme

The recorded achievements of the Bangladesh rural electrification projects have been attributed to an elaborate interplay of various factors such as the setting up of strong institutions and sound financial framework, standardized procedures and practices, community involvement, effective supervision and evaluation, and unambiguous ownership status (Rahman et al., 2013).

As shown in Figure 2.14, the setup of the BREP is based on the formation and interplay of strong institutions. Specifically, a statutory organisation known as the Rural Electrification Board (REB) was established by the government to organize and supervise rural electric cooperatives and to set maximum prices and minimum requirements for quality service delivery. Similarly, IDCOL was established by the government as an autonomous and independent body to supervise the implementation and operation of off-grid renewable energy projects that are being carried out mainly by Non-governmental organisations (NGOs) and Partner Organisations (POs).

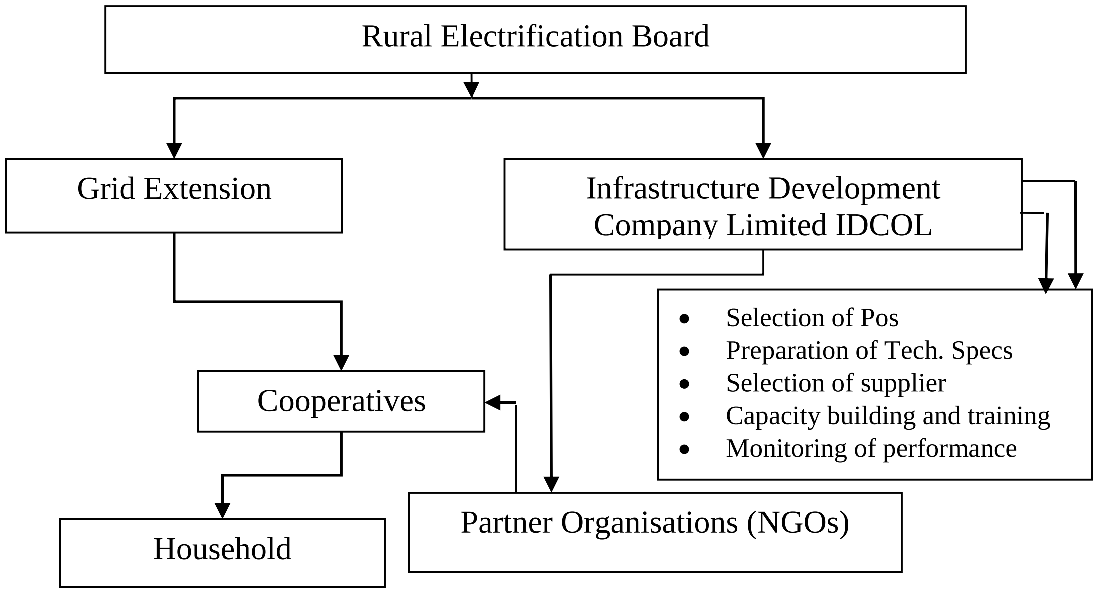

Figure 2.14: Institutional framework for grid based rural electrification program in Bangladesh

Adapted from Rahman et al. (2013b)

Although funding of IDCOL comes mostly in form of loans from international donor organisations and equity funds from the government, these are in turn given to the partner organisations as soft loans over a 10-year period. Through this financial empowerment of the partner organisations, customers are given 15% of the total cost of the installations as grant while they are required to make an initial down payment of 15% of the remaining 85% of the total cost of the system. The remaining cost, along with a 12% service charge, serves as credit facility payable as monthly instalments (Urmee et al., 2009). An outline of the financing structure is as shown in Figure 2.15.

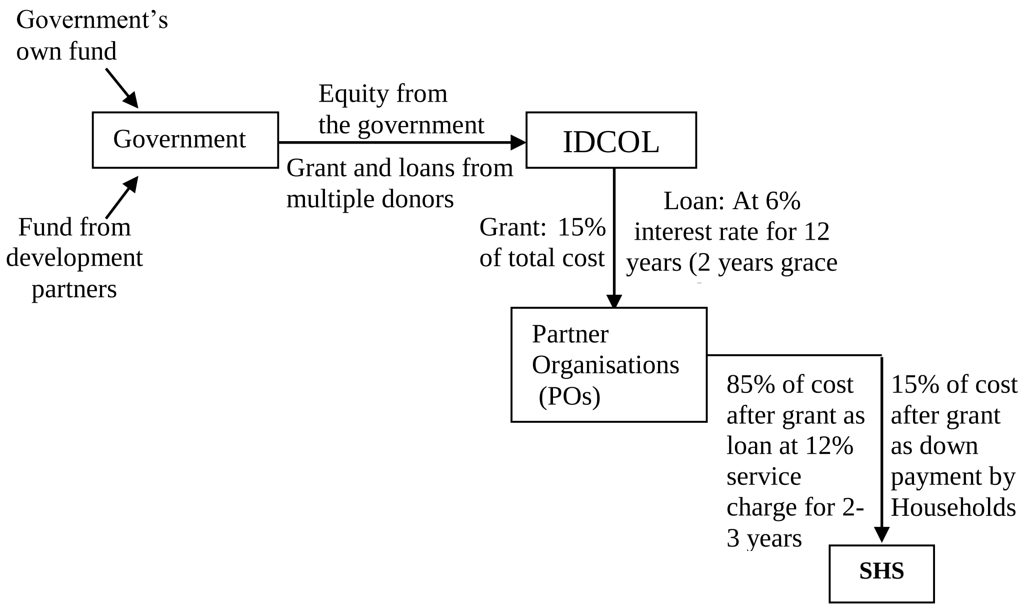

Figure 2.15: Financing structure for off-grid system in Bangladesh
Source: Rahman et al (2013b)

In addition to the above, a series of standardized procedures and practices made up of instructions on planning, administration, engineering etc., to cover all aspects of operations are developed and are strictly implemented to ensure consistency in the quality of the operations. For example, a system of centralized planning, design and construction but decentralized operations is put in place, such that, while cooperatives are enabled to make day-to-day operational decisions, their performances are centrally supervised and evaluated by the Renewable Energy Board using harmonized and objective tools (Barnes, 2007). Similarly, political influence in the selection of areas to benefit from grid extension is minimized by strictly adhering to financial viability and profitability of a project as the basis on which the choice of any location to benefit from such grid extension is made.

Other factors that contributed to success of the Bangladesh rural electrification programme include deep community involvement in which the rights of every electricity user in a community to belong to the rural cooperative are ensured by encouraging them to belong to such cooperative society; effective supervision and evaluation of installations; and unambiguous ownership status whereby IDCOL and partner organisations ensure that ownership is clearly transferred to the consumers upon installation. Such knowledge and acceptance of ownership by consumers often encourages them to take more proper care of the installations than they may be obliged to if such installations are not owned by them, and to avoid practices that could undermine the performance of the systems (Urmee et al., 2009; Asif and Barua,2011).

2.6.2.2 Factors that contributed to decline of the Rural Electrification Programme

As noted in section 2.6.2, since the commencement of the BREP, the number of rural communities with grid extension has been progressively increasing until 2006 when the number declined (Taniguchi and Kaneko, 2009). The major issues responsible for the declining performance of the programme include institutional weakness, power supply shortages, unrealistic power tariffs, and a shortage of funding (Rahman et al., 2013).

The institutional structure makes the cooperatives unable to withstand political pressure and maintain autonomy thereby making them unable to defy political influence. An effect of such political interference is the reluctance of the International Development Association (IDA), and other international donor agencies that have jointly provided over 50% of the funding for the projects, to support the programme until appropriate reforms are introduced to protect the institution from such influence (World Bank, 2010; REB, 2012). This had a negative impact on the programme. Another cause was the huge gap between supply and demand. Rural consumers experience load shedding in which, due to shortage in grid electricity, the available supply is ‘shared’ between consumers on hourly basis. Hence, most consumers do not have electricity supply for up to 18hours per day. This has dampened the passion of the rural dwellers and diminished their support and interest in the programme.

2.6.3 Key factors that influenced RET initiatives in Nepal and Bangladesh

Some key factors that influenced the success and failures of the RET initiatives in Nepal and Bangladesh are presented in Table 2.6. These bring out the fact that while some factors are common, some others are distinct to each of the country; hence, a successful system or approach in one country may not prove successful in another one. It is therefore necessary to identify prevailing challenges and align proposed approaches to align with local peculiarities in order to achieve improved performance.

Table 2.6: Key factors influencing performance of RETs in Nepal and Bangladesh

Factors	Nepal	Bangladesh
Supporting Factors	• Formulation of strong regulatory and institutional policies • Creation of opportunities for private sector participation in the deployment RETs • Provision of technical and financial support: equity and credit mechanisms.	• Strong institutional and sound financial network • Development of standardized procedures and practices in deployment of TETs • Involvement of local communities • Effective supervision and evaluation of installations • Unambiguous installation ownership structure
Inhibiting Factors	• High cost of RETs/low affordability by rural dwellers • Low development of market structure • Limited research and de4velopment	• Limited supply from installations • Unrealistic power tariffs • Shortage of funding • Negative political influence

2.6.4 Rural Electrification in Sub-Sahara Africa

In a study on electricity access in sub-Saharan Africa, Onyeji et al. (2012) found out that some factors impact differently in the region compared to other regions with comparable electricity access challenges, such as developing Asia. Hence, policies that have been successfully implemented in such regions may need to be adjusted to achieve positive impacts in the sub-Saharan African region. Specifically, results from the study indicate that while definite efforts to scale up rural electrification access in the region are not common, yet government ineffectiveness towards minimizing high levels of corruption have negatively affected the few electricity access programmes. Ironically, outcomes of the study further show that government effectiveness has a more profound effect on electricity access levels in sub Saharan African countries than other parts of Africa where such access is already high and may therefore not be affected by quality of government rule. Furthermore, the authors note that whereas electricity expansion projects usually involve large initial capital investments, many sub Saharan African countries are in dire need of large financial resources, which to a large extent, may need to be sourced from the private sector to complement domestic investments before such projects can be successfully carried out.

In Senegal, less than 25% of the rural population, which is characterized by low income and low savings, benefit from electricity service. Although, government projected rural electricity access to grow to 30% by 2015 and above 70% for 2022, the progressions achieved as at 2013 proved these figures as unrealistic (Diouf et al, 2013). The solution adopted by the government in Senegal for rural electrification is based mainly on grid expansion by the public electricity company, local micro/mini photovoltaic or diesel power plants managed by private companies. However, Diouf et al, (2013) observes that, "such solutions reach their limits when it comes to small remote villages with a low population or villages with a low density of population". He recommends individual standalone photovoltaic systems to provide people in such locations with access to electricity and cover the priority needs of lighting and mobile phones battery charge.

In Mali, only 13% of the rural population has access to electricity and more than 80 percent of the country's population use wood or charcoal for cooking and heating. The lighting and small power needs of many of these households are met through using kerosene, dry cell, and car batteries. The country's rural electrification agency, Agence Malienne pour le Developpement de l'Energie Domestique et d'Electrification Rurale (AMADER) which was created in 2003 has recorded significant achievements. Two linked key approaches employed by the agency to provide electricity for rural locations are the spontaneous "bottom-up" electrification of specific communities and planned "top-down" electrification of large geographic areas. While the bottom-up approach utilises small conventional, diesel-fuelled mini-grids with installed generation capacities mainly below 20 kilowatts to supply electricity to rural households typically from six to eight hours daily, the top-down method is based on grid extension to these places. There has been considerable success in the former approach with renewable energy technologies, particularly solar photovoltaic, successfully introduced into Mali's rural energy mix. Over a period of six years, more than 7,926 solar home systems and more than 500 institutional solar photovoltaic systems were installed countrywide. To ensure that these projects are financially sustainable, AMADER provides grants for 75 percent of the start-up capital costs (depending on the proposed connection target within the first two years, the average cost per connection, and the average tariff) to the private operators who installed and managed them. In addition, AMADER permits the operators to charge tariffs that are often higher than those charged to grid-connected customers. Furthermore, leasing arrangements are being proposed to private operators while loan guarantee programs are arranged with Malian banks and microfinance institutions to encourage them to give loans to potential operators. Through these approaches, more private operators are encouraged to participate in the deployment of RE solutions to rural locations, which would lead to an increased share of RE in Mali's energy mix.

However, the intervention by government or funding organisations can have contrasting outcomes. The cases of Zimbabwe and Kenya gives insights to this. In the early 1990s, the two countries had modest solar PV sector, however, during this time, the World Bank sponsored and embarked on a Global Environment Fund (GEF) rural solar PV program that aimed to achieve the electrification of 9000 households by the end of a 5-year period in Zimbabwe while Kenya on the other hand, was imposed with economic sanctions by the same World Bank. Hence, while all necessary mechanisms were put in motion to achieve the set out goals for Zimbabwe, the Kenya government faced a lot of financial constraints, and rural electrification was not a priority for the country (Karekezi, 2000; Duke et al., 2002). After the 5-year period in 1997, Ndlovu (1998) notes that while the Zimbabwe target had been reached and, in fact, surpassed, the majority of the installations had failed, thereby defeating the goals of the GEF and downgrading the reputation of the solar PV industry in the country. On the other hand, the Kenyan solar PV industry, which was driven by an active private sector and local entrepreneurs, grew over the same period and reached a monumental figure of 20000 installations per annum by the year 2001 (Sebitosi and Pillay, 2005).

Nonetheless, while Kenya's experience may suggest that governments need a hands-off approach to rural solar PV electrification, leaving it to the private sector, there was significant government involvement. This is because government policies and indirect participation such as price and foreign exchange control which opened markets to competition, reduction of import duties on photo-voltaic modules, and removal of value added tax (VAT) contributed to the lowering of photovoltaic system prices and enhanced both the access and spread of these systems (Hankins, 2000).

2.7 Chapter Summary

This chapter gives an overview on a wide range of issue relating to transfer, implementation and assessments of Renewable Energy Technologies RETs, especially solar PV, in rural locations. It presents the various forms of solar PV technology as commonly deployed to rural communities: local grid based solar PV ac systems are considered ideal for remote communities or group of small communities; stand alone dc systems are relatively cheaper and ideal for charging of phones, laptops etc., and for water pumping, while SHS offer lighting and limited access to electricity on individual household basis. It further appraised a number of technology transfer models and financial mechanisms as often used in rural electrification projects, and highlighted their peculiar characteristics and benefits but revealed limited availability of financial resources, challenges associated with sustainability and replicability of business models, and non-integration of rural factors as some major challenges confronting solar PV projects in many countries. Furthermore, SWOT analysis, Life Cycle Assessment LCA and sustainability indicators were highlighted as assessment and evaluation tools that have been used on rural electrification projects. While no particular approach in the assessment and evaluation of such projects may be considered as perfect, the use of sustainability indicators is regarded as a more robust approach than the former two as it enables a wider spread of indicators to be inculcated in such assessments. A number of these indicators have been developed and utilised by notable international organisations such as the IAEA, IEA and the World Bank. However, the method may need to be used in conjunction with other methods, while indicators need be aligned with existing local factors of projects being assessed to ensure viable outcomes.

The regulatory and institutional policies that contributed to the success in Nepal were highlighted. These include the creation of independent bodies that specifically provide financial and technical assistance for RETs, and the development and implementation of indigenous subsidy, equity and credit mechanisms that stimulated the participation of private investors in rural electrification projects were also discussed. Similarly, factors that limited the success of these efforts were equally highlighted to include initial high capital cost of RET systems, inadequate facilities to rural dwellers, inability to obtain continuous energy supply from solar PV systems, and limited research and development in the energy sector. It was noted that the success of the Bangladeshi case was based on the formation of strong institutional framework and financial policies, and involved the active and well-coordinated participation various stakeholders such as NGOs, community cooperative groups and rural users. The financial schemes involved the provision of grants and soft loans suitable for low earning rural dwellers while standard pre and post installation practices were provided and adhered to. In both Nepal and Bangladesh, factors such as unrealistic power tariffs and shortage of funding and political interference were noted to have contributed to the declining performance of the programmes over time. The energy situation in Senegal, Mali, Zimbabwe, and Kenya, where varied methods of electricity access including grid expansion, local micro/mini photovoltaic and mini diesel plants are being employed for electrification were also reviewed. It was found that while government-run projects performed well in Mali, the private sector drove the success in Kenya while, despite much support, international funding organisations could not achieve a sustainable success in Zimbabwe. However, government ineffectiveness towards minimizing public corruption and inadequate financial resources were revealed as common factors that have negatively affected rural electrification access programmes across sub-Saharan Africa countries. Hence, while the experiences of the success or otherwise of diverse approaches as utilised in different countries have been evaluated to understand the intricacies involved, there appears to be no perfect approach that could be employed across countries; hence country-specific models may need be developed to achieve sustainable rural electrification projects. Nonetheless, it is seen that some factors such as existence of strong institutions, and availability of subsidies and credit facilities to rural users contribute to successful programmes. Equally, factors including unrealistic power tariffs, shortage of funding, and political interference are revealed to be pitfalls to successful programmes.

CHAPTER 3 Energy and Water in Nigeria: Status and Issues

3.1 Introduction

Nigeria is located on the west coast of Africa and is the continent's most populated country, with over 140 million people in 2006 (NPC, 2006). The country, which is segmented into six geo-political zones as shown in Figure 3.1, has significant energy resources, including over 36 billion barrels of oil, making it Africa's largest oil producer and the sixth largest exporter of crude oil in the world.

Figure 3.1: Nigeria Geographical Zones

At the beginning of 2013, crude oil and gas contributed an average of about 15% to Nigeria's Gross Domestic Product GDP (NBS, 2013). However, at the present rate of extr action, it has been estimated that within the next 40 years, these massive oil and natural ga s reserves will be depleted to a point where it would not be economical to continue explor ation (ECN, 2005). Meanwhile, the country's oil production is presently hampered by the challenges of oil bunkering and disruptions to supply caused by so-called Niger delta militants who engage is pipeline sabotages.

Over the years, the energy balances of the country have inclined mainly towards the production of crude oil, natural gas and biofuels.

Table **3.1** shows the balances for 2014 (which is the latest year available) presented in thousands tonnes of oil equivalent (ktoe) on a net calorific value basis. It is seen that while crude oil, natural gas and biofuels respectively contributed 116289ktoe, 34641ktoe, and 108606ktoe of the energy production of the country, the combined contributions of geothermal, solar and heat energy have been insignificantly low and barely noticeable. It can be therefore be deduced that a departure from the prevailing trend to one that will reflect appreciable contributions of other sources of energy will require concerted efforts.

Table 3.1: Energy Balances for Nigeria for Year 2014

	Coal*	Crude Oil*	Oil Products	Natural gas	Hydro	Biofuels and waste	Electricity	Total
Production	28	116289	0	34641	460	108606	0	260024
Imports	0	0	8405	0	0	0	0	8405
Exports	0	-112926	-534	-20179	0	0	0	-133639
Internatio-nal Marine Bunkers	0	0	-371	0	0	0	0	-371
International Aviation Bunkers	0	0	-322	0	0	0	0	-322
Stock Changes	0	224	386	0	0	0	0	610
TPES***	**28**	**3587**	**7566**	**14462**	**460**	**108606**	**0**	**134708**
Transfers	0	95	-85	0	0	0	0	10
Statistical differences	0	0	1	-1032	0	0	0	-1031
Electricity Plants	0	0	0	-5382	-460	0	2614	-3228
Oil refineries	0	-3319	3315	0	0	0	0	-4
Other transforma-tion	0	0	0	0	0	-8481	0	-8481
Energy Industry own use	0	0	-302	-4224	0	0	-91	-4617
Losses	0	-353	-67	0	0	0	-421	-842
Total Final Consump-tion	**28**	**0**	**10438**	**3824**	**0**	**100124**	**2102**	**116516**

OECD/IEA (2017)

*The column of coal also includes peat and oil shale where relevant; that of crude oil includes crude oil. NGL, refinery feedstocks, additives and other hydrocarbons

**International marine and aviation bunkers are included in transport for world totals

*** Total primary energy supply (**TPES**)

The Nigeria energy sector presents a developmental paradox - a country that is well endowed in capital, natural and human resources, yet with an abysmally low record of energy provision for her teeming populace. The country is ranked 47 out of 64 countries on the 2011 IEA's Energy Development Index (EDI) - a simple composite measure of a country's progress in its transition to modern fuels and of the degree of maturity of its energy end-use. Similarly, access to safe water has been a long-standing problem in Nigeria, with coverage rates that are amongst the lowest in the world. A joint report by the World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) in 2012 indicates that over 70 million Nigerians lack access to clean, potable water. In 2000, about 4 out of every 5 of government-owned water installations in semi-urban and rural communities were regarded non-operational mainly due to broken down equipment, absence of electricity, or lack of fuel pumping (World Bank, 2000).

3.2 The Nigerian Energy and Water Sector

The energy sector in Nigeria was unattended to for many years and faced a period of underinvestment and poor planning in electricity infrastructure from 1981-99 during which period no new electricity infrastructure was built by the government, while the energy sector was consistently encumbered by major difficulties in the core areas of operation, generation, transmission, distribution and marketing (Idigbe and Onohaebi, 2009). The energy sector in Nigeria was unattended to for many years and faced a period of underinvestment and poor planning in electricity infrastructure. Between 1989 and 1999, no new electricity infrastructure was built by the government while the country's population continued to increase (Tallapragada, 2009).

The stunted growth in the country's electricity sector becomes obvious when compared with the situation in some peer countries over a 20-year period as shown in Figure 3.2. It is seen that whereas Bangladesh generating capacity was roughly 35% of Nigeria's as at 1981, its generating capacity has increased over 5-folds to nearly 200% of Nigeria's capacity in 2011 which has only witnessed a slight increase over the same period. The same appreciable increase in generating capacities is observed by other countries under comparison.

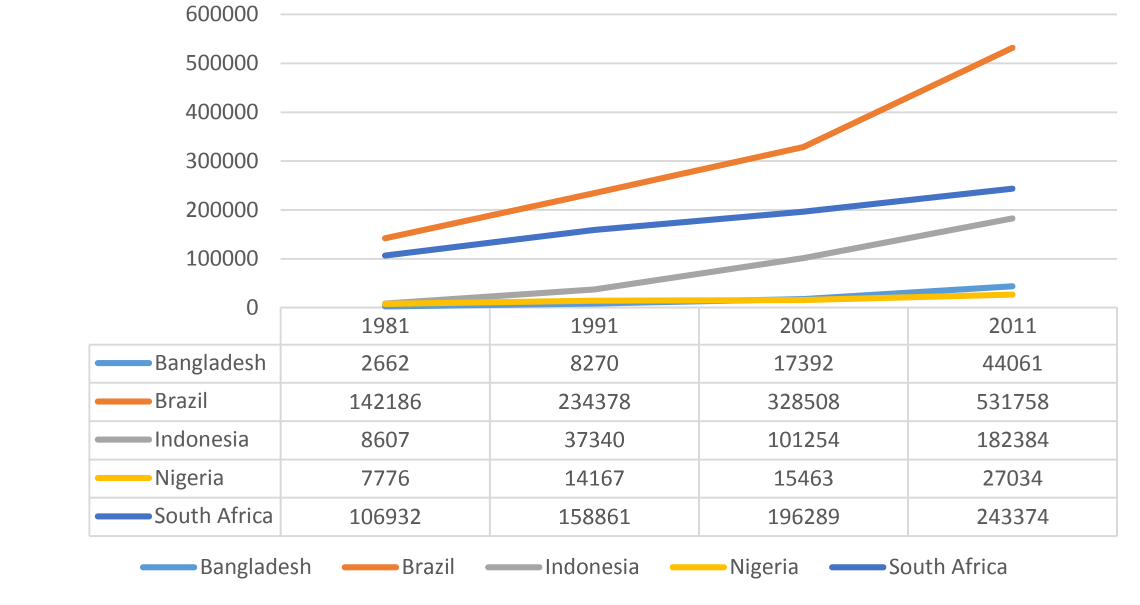

Figure 3.2: Electricity Production (GWH) in Nigeria and some peer Countries

Source: World Bank

As part of a power sector reform process to improve the energy sector, the National Electric Power Authority (NEPA) which was established in 1972 and has been the sole organisation in charge of electricity generation, transmission and distribution for the whole country, was unbundled in 2005 into eleven electricity distribution companies (DisCos), six generating companies (GenCos), and one transmission company (TCN). The Nigerian Electricity Regulatory Commission (NERC) was also created as an independent regulator for the energy sector. Furthermore, the Federal Government fully divested its interest in the 6 GenCos, sold 60% of its shares in 11 DisCos to private operators but retained ownership of the Transmission Company. One resultant effect of a steady increase in Nigeria's population without a commensurate increase in the generation capacity is a steady drop in per capita access as shown in Table 3.2.

Table 3.2: Historical Progression for Electricity Generation in Nigeria (2003 – 2009)

No.	Items	2003	2004	2005	2006	2007	2008	2009
1.	Electricity Generation (billion kWh)	22.03	23.9	24.22	23.8	23.3	21.27	20.8
2.	Energy Consumption per capita (kgoe/capita)	151.3	125.5	132.6	87.1	81.4	80.8	83.1
3	Electricity Consumption per capita (kWh/capita)	174.6	176.4	181.4	167.6	161.2	142.9	135.2

Source: Federal Ministry of Power (2014)

By its nature, the power industry is capital intensive and requires years of multi-dimensional planning and execution to deliver a long chain of projects. In most cases, governments do not find it ideal or economically rational to bear such huge funding responsibilities alone due to her responsibilities in other sectors of the economy. In the case of Nigeria, it has been estimated that to achieve a 40,000MW grid capacity by the year 2020, the country would require an investments of at least US$ 3.5 billion yearly over a 10-year period, while it could take up to six to eight years to complete a typical hydroelectric power plant (Roadmap for the Power Sector Reform, 2013). Similarly, the implementation of other RE infrastructures would also involve a large capital outlay. Hence, a viable approach to generate such funds, which are required to replace aging equipment and to build new infrastructures, is the involvement of private investors and international lending institutions. Over the past 10 years, the amount of funds released to the Federal Ministry of Power for power projects in the country has majorly been between 5 percent and 13 percent of the total (see Table 3.3).

Table 3.3: Budgetary Allocation to the Power Sector (2007-2016)

Year	Power Sector Capital Spending (₦ Billions)	Total Federal Capital Spending (₦ Billions)	Power Sector Spending as a percentage of Federal Capital Spending
2007	100.78	781.53	12.90
2008	114.38	673.16	16.99
2009	88.47	796.74	11.10
2010	189.78	1,853.91	10.24
2011	86.25	1,005.99	8.57
2012	69.2	842.93	8.21
2013	73.35	1,047.7	7.00
2014	59.1	1,100.61	5.37
2015*	5.13	265.2	2.00
2016**	433.4	1,225.0	35.38

Source: Budget Office of the Federation, Ministry of Budget and National Planning
* In 2015, the country's economy witnessed a meltdown, while a large chunk of the budget was for security purposes in a bid to tackle the menace of insurgent groups. ** As at 2016, the Ministry of Power has been merged with two other Ministries to form the Ministry of Works, Power and Housing.

It can be concluded that though appreciable amount of financial investments have gone to the power sector over the years, these have not resulted in commensurate improvement of the sector; this may have necessitated the unbundling and opening up of the sector to the private sector in 2015.

The situation with respect to access to safe water has been equally been poor. With a greater majority of the Nigerian population depends on self-efforts in meeting their daily water needs. Daily water supplies for most Nigerians come from natural sources (rivers/streams, ponds, rain and hand-dug wells) while others rely on water pumped from boreholes that are privately owned, or sponsored or developed by government (Akpabio, 2012). The unreliability or absence of grid electricity often imposes additional operational cost on such facilities. Using estimated figures by NBS (2007), Amakom (2009) notes that 72% of urban dwellers in Nigeria compared to 47% of the rural population have access to improved water sources. The breakdown down across the six geo-political regions of the country (see Figure 3.1) is as shown in Table 3.4.

Table 3.4: Regional Indicators and Access to Water and Sanitation Services

Indicators	**NE**	**NW**	**NC**	**SE**	**SW**	**SS**	**National**	**Rural**	**Urban**
Safe Water Source (%)	30.7	50.64	48.9	40.8	73.5	45.9	51.4	40.4	73.4
Safe Sanitation (%)	45.4	61.6	46.6	69.5	62.1	55.0	57.6	47.6	77.0
Incidence of diarrheal (%)	5.5	4.8	5.5	5.7	4.1	4.1	4.9	5.1	4.3
Poverty Incidence (%)	72.2	71.2	67.0	26.7	43.0	35.1	54.4	63.3	43.2

Source: Extracted from Amakom (2009)

NE - North East; NW – North West; NC – North Central; SE – South East; SW – South West; SS – South South

3.3 Energy and Water Poverty in Rural Nigeria

The prevailing energy situation in Nigeria is such that major cities and urban areas in general experience a large shortfall in the supply of electricity, with quite low electrification rates in many states across the country, especially in the North Central, North East and North West regions as shown in Figure 3.3.

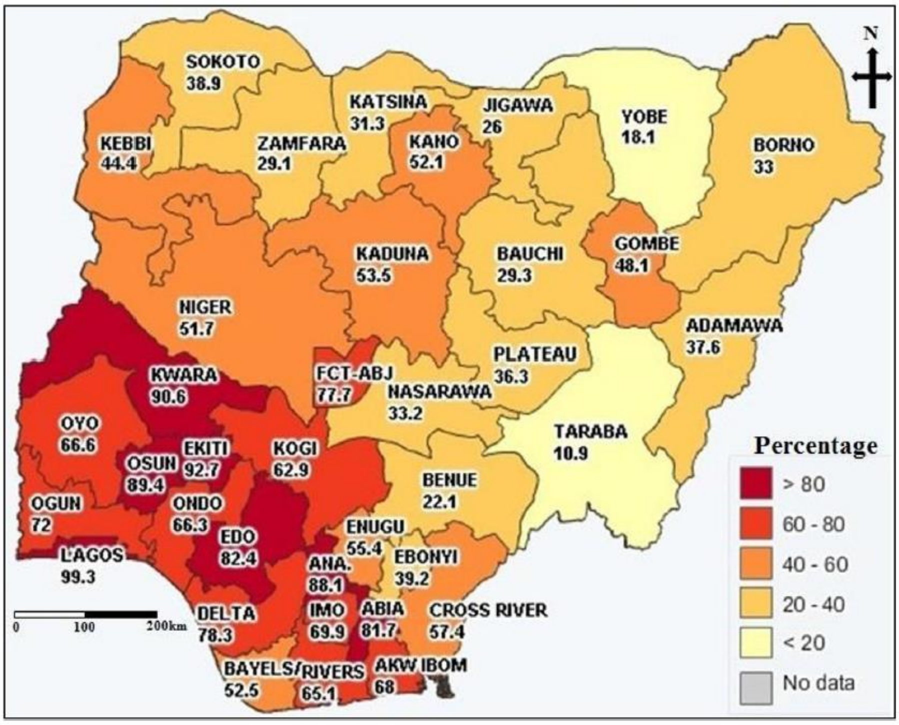

Figure 3.3: Percentage of households with electricity access in Nigeria
Source: National Population Commission

Such an acute of shortage electricity puts rural electricity needs at the lower end in the scale of preference of the supply chain, even for rural areas that can be reached through grid extension. This is much worse in many rural areas which are often difficult to access due to absence of good road networks and little access to conventional energy sources such as those from petroleum products Additionally, with the on-going reforms in the power sector such as the unbundling and subsequent privatisation of the Power Holding Corporation of Nigeria (PHCH) which is the sole government grid power utility company in the country, the business of electricity supply is being transferred to private investors. However, while the privatisation of the PHCH may be considered a good step towards the transformation of the sector, it is believed that such privatization on its own does not necessarily translate into an overall positive development of the sector (Esidene, 2008). For example, rural electrification, which does not appear profitable relative to urban electrification due to the often low population density of such places and the low economic status of most of the dwellers, may not be of priority to these investors unless there are deliberate efforts to make them to be profitable business undertakings. Therefore, there may be the need to develop indigenous schemes that could introduce some forms of impetus to either induce or make it obligatory for private energy investors to participate in the implementation of rural electrification programmes. This may be achieved through a legislative order that requires private investors taking part in the ongoing reforms in the sector to devote a percentage of their investment to rural electrification or the award of lucrative urban electrification concession to private investors may be tied to the less attractive rural electrification projects. A similar approach was adopted in South Africa where suppliers of solar home systems (SHS) to rural locations where the grid is not extended are also required to provide cooking fuel (LPG or paraffin) to the communities thereby achieving both improved lighting and improved cooking facilities which are the basic household energy needs (Balachandra, 2011; Bhattacharyya, 2012). Even against the possibility of reduced profit margins if such schemes are implemented, these would offset by the relatively highly profitable investments in urban electrification programmes. This is similar to what is being witnessed in the privatised telecommunication sector where participating companies have continued to record high earnings that surpassed their previous investment in other countries

In Nigeria, an area is classified as "Rural" if (i) it is located at a distance of more than 10 km from the boundaries of the nearest urban area or city; (ii) it has a population of less than 20,000 inhabitants or population density less than 200 per square kilometre (iii) it is located at least 20 km from the nearest existing 11 kV line (NPC; 2004). Where available, petroleum products such as kerosene and gasoline are purchased in rural areas at prices that could be more than 150% in excess of their official prices. For some time now, rural electrification has been a focus of policymakers in the country, but the sheer magnitude of the problem and the associated financial requirements may have been main factors why the problem has persisted. In a report on the Nigerian Energy Support Programme NESP, it was observed that although suppliers have provided solutions either through pilot demonstration solar solutions to provide lighting or through donor mechanism, no long-term sustainable solution has yet been implemented (GIZ, 2014), while the federal ministry of power estimates that as many as 70 million rural dwellers do not have access to reliable electricity supply (FMP, 2014). As earlier depicted in Figure 3.3, the percentage of households by electricity access on a state- by-state basis ranges from a dismal 10.9% for Taraba state to a high level of 99.3% for Lagos state. However, data from the country's National Bureau of Statistics revealed that only 6 out of the 36 states in the country have a rural electrification rate of above 10% as shown in Table 3.5.

Table 3.5: Percentage Distribution of Households with Access to Electricity by type of Electricity Supply, 2010

State	Grid (PHCH) Only*	Rural Electrification**	Private Generator	Grid/ Generator	Rural Electrification /Generator	Solar Panel
Abia	89.6	0.9	0.5	5.0	4.1	0.0
Adamawa	89.5	9.9	1.9	4.8	1.0	0.0
Akwa ibom	82.8	0.4	2.9	13.1	0.8	0.0
Anambra	81.0	1.7	1.0	15.6	0.7	0.0
Bauchi	77.5	8.0	1.4	9.4	3.6	0.0
Bayelsa	33.1	36.1	2.3	2.3	26.3	0.0
Benue	68.5	14.4	2.7	10.8	3.6	0.0
Borno	87.9	6.1	0.0	6.1	0.0	0.0
Cross river	91.7	6.2	0.5	1.6	0.0	0.0
Delta	93.6	2.7	1.5	1.5	0.8	0.0
Ebonyi	78.9	12.7	0.0	1.4	7.0	0.0
Edo	93.1	2.1	1.2	2.7	0.9	0.0
Ekiti	91.1	1.0	0.8	6.9	0.3	0.0
Enugu	75.0	16.9	1.3	5.9	0.8	0.0
Gombe	94.7	3.2	0.0	2.1	0.0	0.0
Imo	85.4	5.0	2.1	2.5	0.0	0.0
Jigawa	93.2	0.9	0.0	4.3	0.9	0.9
Kaduna	84.8	5.1	2.0	7.6	0.5	0.0
Kano	87.0	6.0	0.0	4.0	3.0	0.0
Katsina	80.4	14.7	0.0	4.3	0.0	0.6
Kebbi	86.4	1.6	3.8	7.1	1.1	0.0
Kogi	79.2	3.3	0.4	15.8	1.3	0.0
Kwara	92.8	1.8	0.3	2.4	2.7	0.0
Lagoa	67.9	1.2	1.2	25.9	3.5	0.2
Nasarawa	76.0	0.6	7.2	13.2	3.0	0.0
Niger	75.2	1.8	0.9	21.7	0.0	0.4
Ogun	94.5	0.3	0.0	5.2	0.0	0.0
Ondo	87.5	0.8	2.9	2.9	5.8	0.0
Osun	90.5	0.0	0.4	7.1	2.0	0.0
Oyo	97.7	0.9	0.5	0.9	0.0	0.0
Plateau	92.5	1.3	1.3	3.8	1.3	0.0
Rivers	66.0	26.3	6.7	1.0	0.0	0.0
Sokoto	90.4	6.6	0.6	1.8	0.6	0.0
Taraba	85.7	0.0	0.0	14.3	0.0	0.0
Yobe	77.0	6.9	1.1	11.5	3.4	0.0
Zamfara	87.0	6.9	0.0	3.8	1.5	0.8
FCT Abuja	67.4	0.9	1.9	27.6	2.2	0.0
Sector						
Urban	83.2	2.7	0.8	11.3	2.1	0.0
Rural	81.5	7.5	2.0	6.2	2.6	0.1
National	82.2	5.5	1.5	8.4	2.4	0.1

Source: GIZ (2014)

* PHCN is the Power Holding Corporation of Nigeria which is the sole government grid power utility company in the country

** Rural electrification: Electricity supply via mini-grid only, which is not connected with a distribution grid or the transmission grid.

Likewise, most rural areas depend upon boreholes or hand-dug wells for water supply wherein the former are normally reliant on generators which are expensive to maintain and operate. Failures of water supply projects within relatively short time periods are very widespread in many parts of the country. Although access to improved sources of drinking water is generally low, it is more profound in rural areas where it is estimated that more than half of the rural populace in the country lack access to improved water sources as shown in Table 3.6.

Table 3.6: Percentage Distribution of Household and Population Access to Drinking Water

	Households			Population		
Characteristics	Urban	Rural	Total	Urban	Rural	Total
Source of Drinking Water						
Improved Source	75.6	49.2	60.6	77.6	47.7	59.6
Piped into dwelling	5.5	0.7	2.8	6.1	0.8	2.9
Public Tap	9.2	4.9	6.8	9.6	4.7	6.6
Borehole	44.2	32.0	37.3	45.8	30.0	36.3
Protected well	13.0	10.1	11.4	13.1	11.0	11.8
Protected spring	0.3	0.5	0.4	0.3	0.5	0.4
Rainwater	0.9	0.7	0.8	0.8	0.5	0.6
Bottled water	2.4	0.3	1.2	1.8	0.2	0.8
Non-Improved Source	24.2	50.5	39.1	22.2	52.0	40.1
Unprotected well	3.9	23.6	15.1	4.7	26.2	17.6
Unprotected spring	1.2	4.2	2.9	1.2	4.2	3.0
Tanker Truck/drum	3.4	0.8	1.9	3.6	0.6	1.8
Surface water	12.0	1.1	5.8	8.6	0.7	3.8
Other sources	0.1	0.1	0.1	0.1	0.1	0.1
Missing	0.2	0.2	0.2	0.2	0.2	0.2
Total	100.0	100.0	100.0	100.0	100.0	100.0

Source: NPC (2014)

3.3.1 Efforts and Progress in Rural Electrification and Water Access

To arrest the poor state of the energy sector, the Nigerian government in 2001 started a series of reforms which major thrusts are the privatisation and subsequent opening up of the sector to private investors after the manner of the now vibrant telecommunication sector which was in a similar state of ineffectiveness. Such includes the adoption of the National Electric Power Policy (2001); the enactment of the Electric Power Sector Reform Act

EPSRA (2005); the establishment of the Nigeria Electricity Reform Commission, the formation of the Power Holding Corporation of Nigeria (PHCN) and its subsequent unbundling into 18 independent companies (2005 – 2007); and the full privatisation of the generation and distribution subsectors (2013). Specifically, the Rural Electrification Agency, REA was established in 2006 with core function is to promote, coordinate, and implement rural electrification projects, while a number of policies targeted at on-grid and off-grid rural electrification programmes were also initiated. According to the 2014 Draft Rural Electrification Strategy and Implementation Plan (RESIP), the overall primary objective of the Nigerian Rural Electrification Policy is to expand access to electricity as rapidly as can be afforded in a cost-effective manner that will involve full use of both grid and off-grid approaches, with subsidies being primarily focused on expanding access rather than consumption (FMP, 2014). Projects handled by the agency have been on grid extension, solar PV, mini hydro stations and installation of transformers. However, despite the restructuring of the energy sector, rural areas that are remote from the grid are not considered attractive to private investors due to logistic and economic reasons, hence, such areas may remain without grid electricity in the immediate future. The Nigerian government therefore adopted a renewable energy approach by attempting to 'take' electricity to rural and isolated areas using decentralised renewable energy systems of solar and wind (which are the two renewable resources that are technically viable in the country). To this end, the federal government formulated a principle of adopting measures congenial to local conditions, combining various sources of energy, and encouraging diversified energy usage. On a state level, the Lagos State government commissioned the Lagos State Energy Academy in October 2014 (Lagos State Electricity Board, 2014). The Academy, which is under the auspices of the Lagos State Electricity Board will be providing training in metering, solar energy, and various aspects of generation, transmission and distribution of electricity in a bid to produce the necessary qualified personnel for the sector.

However, it appears that only the high capital outlay of solar projects has made them relatively attractive to government agencies as large capital projects are preferred and little attention is given to required knowledge in terms of goals, contractors, and technical basics. Project completion or even short-term sustainability appears not to be main requirements, while at the same time, best practices are compromised (Newsome, 2012). Many solar energy based projects in the country have not performed to expectations, and cases of failed renewable energy technology systems are rife in the country (National Geographic News, 2011). Some of these are highlighted in section 3.5.

In addition, as part of efforts to achieve improved access to clean water by the populace, the country launched a National Water Supply Policy in 2000, part of which is expansion of rural water supply systems in the country and to encourage private-sector participation in the sector. Furthermore, the Federal Rural Water Supply Programme was embarked upon to address the peculiar challenges of improving access to safe drinking water to the rural and small population. Other interventions by a number of national agencies and international bodies have, at various periods contributed to improve rural water supply in rural locations. These, according to Nwankwoala (2011), include:

- UNICEF Assisted State water and sanitation projects (1981 – 2010)
- National Borehole programme (1981 – 1986)
- Japanese International Cooperation Agency's (JICA) Rural Water Supply Projects 1992 – 1994
- Petroleum Trust Fund (PTF) Rural Water Supply and Sanitation (1996 – 1999
- Improved Access to Water Supply and Sanitation Programme (2000 – 2001)
- European Union (EU) Water and Sanitation Programme 2002 – 2009

While it is not clear how well water facilities installed through these programmes continued to function after their respective international intervention has ended, such efforts by donor bodies basically serve to augment broader efforts by federal, state and local governments, and not to replace them. What is clear however is that despite these efforts, the country is still lacking behind at providing safe water for its citizenry especially those in the rural areas where the access rate has only increased to 57% in 2015 (World Bank, 2016).

3.3.2 Government Policies on Rural Electricity and Water Supply in Nigeria

The main set of players active in the rural electrification and water access efforts in the country is the 3 tiers of government (Federal, State and Local), international donor organisations and non-governmental organisations. Since the early 2000s, the federal government has developed a number of reforms to improve the energy sector in meeting the needs of the populace. The main thrusts of these include (i) the transfer of administration and financing of supply chain operations to the private sector; (ii) the setting up of an independent and efficient regulatory commission to oversee and monitor the industry; and (iii) the formulation of policies that will enhance long-term development of the energy sector by the government. It is expected that these reforms will lead to increased access to electricity services and stimulate the growth of the sector through investment and participation of private investors. A brief of some policies developed as part of these reforms are discussed below.

3.3.3 National Electric Power Policy (2001)

The National Electric Power Policy of 2001 is one of the earliest, aimed to revamp the underperforming energy sector. It emphasizes the necessity of adequate electricity supply, and targets an intensive development of both electric power and gas supply to at least 75 per cent of the country's population by 2020. It also recommends off-grid and mini-grid systems from renewable energy sources for rural areas, and aims to "to review and update electricity laws in conformity with the necessity to introduce private sector operation and competition into the sector.

3.3.4 National Energy Policy (2003)

The Nigeria's National Energy Policy (ECN, 2003) is based on energy being crucial to national development goals, and that government has a prime role in meeting the energy challenges. The policy recognizes that a substantial percentage of Nigeria's urban poor and rural populace depend on wood as fuel for cooking and other domestic uses, at an unsustainable rate. In addition, it recognises over dependence on crude oil, even though for current reserves and rates of exploitation, the expected life span of Nigerian crude oil is about twenty-five years.

It therefore plans to promote and facilitate the use of alternative energy sources to wood. In particular, the policy recognises the abundance of solar energy in the country and makes a case for its exploitation. Accordingly, it states that "the incorporation of solar energy into the nation's energy mix shall be aggressively pursued"

3.3.5 National Economic Empowerment and Development Strategy (2004)

A series of targets were proposed to be met by the power sector before 2007 under the National Economic Empowerment and Development Strategy (NEEDS). Among these are:

- Increase generation capacity from 4,200 MW to 10,000 MW from existing plants, new host generation, and reasonably priced independent power plants.
- Explore alternative energy sources, such as coal, solar power, wind power, and hydropower
- Deregulate the power sector to allow increased private sector participation.

3.3.6 Renewable Energy Master Plan (2005)

The Renewable Energy Master Plan (REMP) addresses key developmental challenges facing the energy sector through an accelerated development of the role of renewable energy. While the REMP acknowledges that crude oil and gas will continue to play a dominant role in the economic development of the country for some time, it envisages modern and more efficient conversion of solar, hydro and wind energy systems as the basis to meet the energy needs of the Nigerian populace in the long term.

In addition, it recognizes the inadequacy of the conventional centralized energy supply system to meet the electricity requirements of Nigerians for development, and considers the decentralized nature and scale of renewable energy schemes as being ideal to meet the electricity requirements of remote and under-served communities. A main aim of the REMP therefore is to put in place a comprehensive framework for developing renewable energy policies, legal instruments, technologies, manpower, infrastructure, and market towards the realization of its visions and targets.

3.3.7 Electric Power Sector Reform Act (2005)

The National Electric Power Policy (NEPP) of 2001precedes the enactment of the Electric Power Sector Reform (EPSR) Act of 2005. Most of the major provisions in the former are contained in the latter. The EPSR Act is divided into ten parts and covers areas matters such as Unbundling and Transferring of the assets and liabilities of the National Electric Power Authority, Development of competitive electricity market, Establishment of the Nigerian Electricity Regulation Commission (NERC), Tariffs, Establishment and purpose of the Rural Electrification Agency, among others. The EPSR sets out to achieve a sustainable and coordinated rural electrification strategy for Nigeria through expansion of the main grid, development of isolated and mini-grid systems, and renewable energy power generation

3.3.8 Renewable Energy Policy Guidelines (2006)

These policy guidelines specifically highlight the role and relevance of non-conventional or renewable energy as a key element in the overall strategy to rapidly expand access to electricity services in the country. The policy notes that a large percentage of rural areas will remain without electricity even with increased power generation from conventional sources and grid extensions, as these measures will not achieve rapid cost-effective electricity access in such places. Hence, the policy states that, "accelerating rural electrification coverage will require an aggressive deployment of multiple supply options and business delivery systems". The Government therefore seek to improve and meet national electricity targets through the following strategies:

- Grid-based extension for proximate areas; Independent mini-grids for remote areas with concentrated loads where grid service is not economic or will take many years to come; and
- Standalone renewable electricity systems for remote areas with scattered small loads.

The formulation of these various policies underlines governments' resolve to improve the energy sector. As noted earlier, the implementation of these policies and reforms have resulted in a number of positive developments - such as the privatisation of the previously government-owned PHCN and the construction of some new power stations. However, many of the targets set to be achieved through these polices have not been met while current realities do not project these targets as attainable. An indication of this is observed in the target of NEEDS (2004) to increase the nation's generation capacity from 4,200 MW to 10,000 MW by 2007. However, according to the Presidential Task Force on Power (PTFP) which was established in 2010 to compel the implementation of the various reforms in the Nigeria's power sector and to monitor the planning and execution of various short-term projects, the country's generating capacity stands at 6,953 MW as at the end of 2013 while it has dropped to 3400MW as at June 2014. Indeed, during the period of 2004 to June 2014, a peak generation of 4,517.6MW was achieved on December 23rd, 2012. In addition, it appears that not much has been accomplished in the aspect of aggressively deploying multiple supply options and business delivery systems to achieve accelerated rural electrification coverage.

Furthermore, the implementation of some of these policies appears to lack transparency and sincerity of purpose. Such is brought to fore in the issue of pre-paid meters which were introduced in 2006 and were being distributed to consumers preceding the privatization of the PHCN. Prior to the introduction of these meters, many electricity consumers have 'estimated electricity bills' (popularly referred to as *crazy bills* by consumers) issued to them. Estimated electricity bills are bills sent to consumers without taking the actual units of electricity consumed by them into reckoning, but is based on an estimated number of units the customers are presumed to have consumed. Oftentimes, such bills come higher than what consumers ought to have paid for the actual units of electricity consumed, hence consumers regard them as rip-offs. However, the introduction of the pre-paid meters ensures that consumers can purchase blocks of units of electricity they can afford, and enable them to regulate their electricity consumption in accordance to the number of units they procure. The resultant effect of this is a sharp drop in the amount consumers spend on electricity while at the same time the PHCN experienced a sharp drop in the revenue collected by them (Ajenikoko and Adelusi, 2015). However, after the PHCN was privatized, the allocation of the pre-meters to consumers was discontinued. Hence, consumers that were yet to obtain pre-paid meters before the take-over by the private investors remained on the estimated bill structure. Expectedly, consumers consider the stoppage of the issuance the meters as an insincere ploy to ensure they keep paying higher electricity bills than what they actually consume. Nonetheless, the NERC, which, as a regulatory body, has part of its objectives as "ensuring that customer rights are well defined and protected from abuse by operators by ensuring their right to transparent billing and adequate information" and further assures "aggressive deployment of energy meters and robust billing infrastructure", has not intervened in this scenario.

In addition, despite the implementation of some these policies, the peculiar nature of the country's energy sector may be responsible for the failure to achieve some of the desirable results. As an illustration, the unit cost of electricity in Nigeria is among the lowest in Africa (see Figure 3.4). However, while private investors in the sector demand for an 'increased realistic tariff' that could lead to improved services, consumers would rather experience improved services before such increase in tariff is implemented.

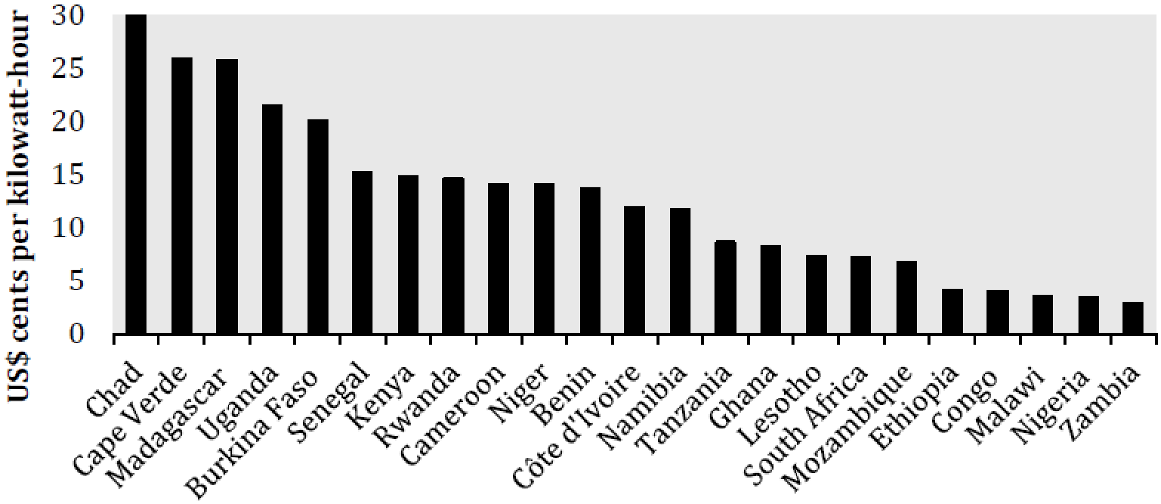

Figure 3.4: Comparison of Electricity Prices Across Selected African Countries

Source: Eberhard et al., (2009)

3.4 Organisational Arrangements for Rural Electricity and Water Supply in Nigeria

In the rural electrification sector, the most prominent federal agency is the Rural Electrification Agency (REA), while the Nigerian Electricity Regulatory Commission (NERC) and the Energy Commission of Nigeria (ECN) also play active roles. However, it appears the sector does not have a well-defined structure as some of the roles played by many of these government and non-government organisations often conflict or overlap.

3.4.1 Organisational Arrangements for Rural Electricity

In previous years, rural electrification activities centred on grid extensions projects which were handled by the Federal Ministry of Power and the Power Holding Company of Nigeria (PHCN). However, as an approach to implement a bottom-up method rather than a centrally planned rural electrification, the REA (Figure 3.5) was established in 2006 as an independent agency that is responsible for the coordination of rural electrification activities in Nigeria. The agency, which has zonal offices across the six geographical regions in the country, was created to serve three complementary functions, namely, serving to promote rural electrification generally, regulating RE projects, and implementing the RE Fund.

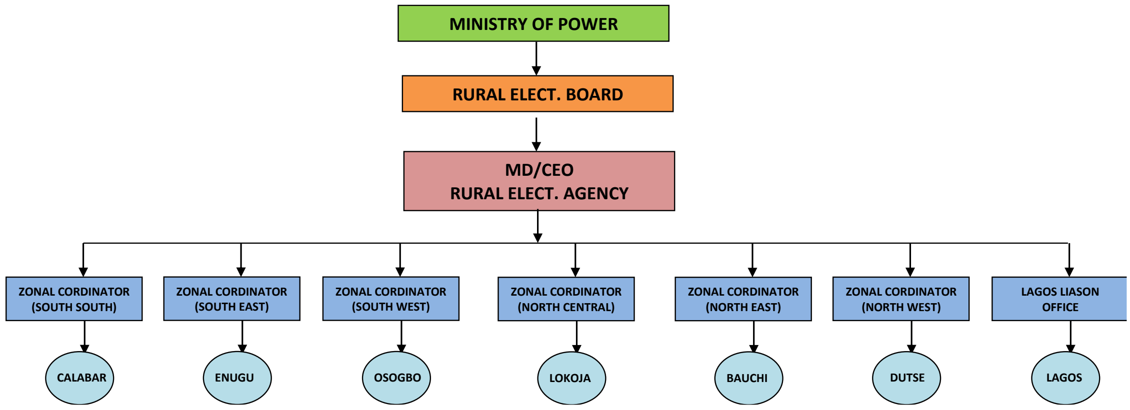

Figure 3.5: REA Organisational Structure

The REA provides overall support and coordination of rural electrification activities of various stakeholders such as public-private partnerships, private investors and community owned/operated projects. While the agency establishes the general policy direction of RE activities, the development of projects are expected to come from rural communities and the private sector.

The agency deployed 40 off-grids solar PV projects comprising 29 street light installations, 6 mini-grids installations and 5 SHS between 2006 and 2009 (Achugbu, 2012), but lists a massive 2,809 projects to have been embarked on between 2006 and 2014. However, most of the project titles do not reveal the type of technology implemented, the capacity, energy produced, or consumers supplied but these are assumed to be mainly electrification through grid extension or diesel generators, and distribution of transformers (GIZ, 2015). Despite these efforts, only 1.1% of the rural households have been connected to the national grid through them while most of the daily needs of the rural populace for heat and lighting are still met almost entirely from candles, kerosene lamps and, mostly, wood fire (Sambo, 2009; Oseni, 2012).

In addition, as part of efforts to encourage more participation in the rural energy sector, the National Electricity Regulatory Commission NERC has proposed incentives that includes simplified licensing process for RE operators in the private sector, guaranteed market for renewable energy supplies, and tariff that will allow for reasonable rate of return on investment by operators in addition to granting complete import duty waiver for parts required for power generation.

Although not explicitly defined, the organisational outlay for electrification projects in Nigeria may be depicted as developed in Figure 3.6.

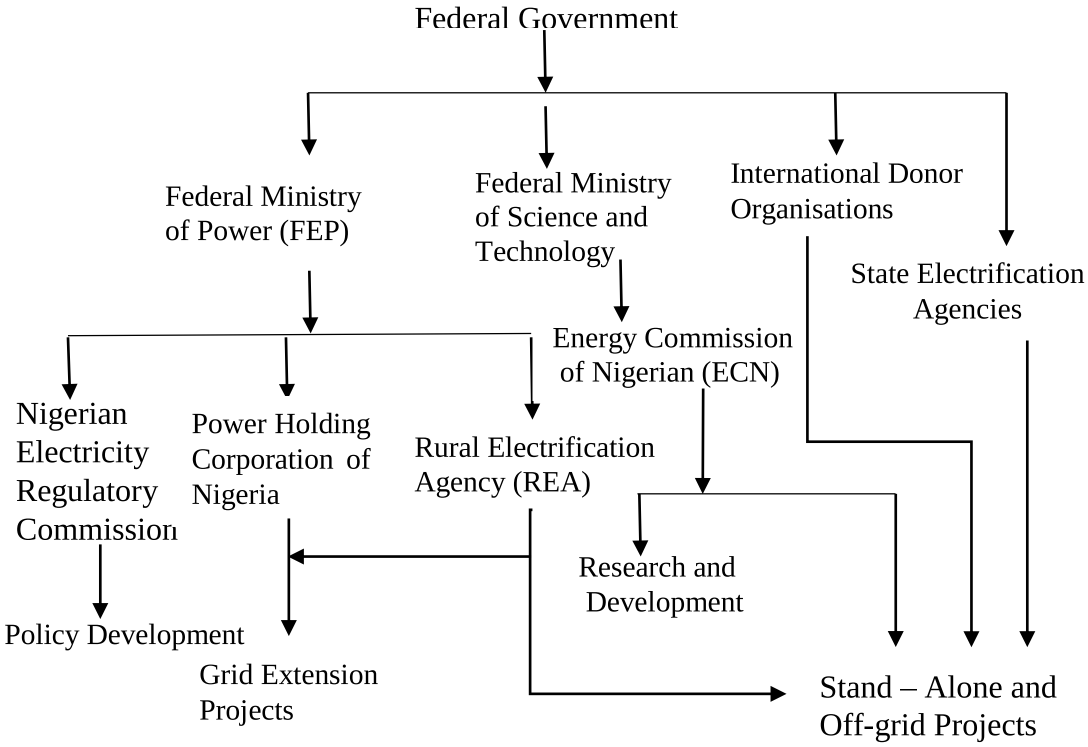

Figure 3.6: Organisational Outlay for Electrification Projects in Nigeria

3.4.1.1 Bank of Industry

The Bank of Industry Limited (BoI) is Nigeria's oldest development financing institution and has as its mandate, "to provide financial and business support services to enterprises'. Although the bank was not known as a major player in the energy sector since its mandate to transform the country's industrial sector through the provision of financial assistance for the establishment of large, medium and small projects cuts across various sectors of the economy, the organisation's recent foray into the rural energy sector of the country is gradually having noticeable impacts. The bank in collaboration with the United Nations Development Programme (UNDP) in 2015 disbursed a total of N75.8 million to two local firms GVE Projects Limited and Arnergy Solar Limited) to provide funds to implement six pilot off-grid electrification projects in six isolated rural communities in the country. The success of the projects, which are to be run on a Pay As You Go basis, and are to involve the National Agency for Science and Engineering Infrastructure (NASENI) and local meter manufacturers in the provision of accessories such as meters and batteries are to determine the direction of the bank's commitment in the subsequent years. The organisation considers the projects will complement the efforts of other organisations involved in grid electricity extension projects and would not be regarded as competitors. Additionally, the projects are considered as viable solution to rural-urban migration and poverty alleviation, especially in rural communities not covered by the national grid.

3.4.1.2 International Donor Bodies and Non-Governmental Organisations (NGOs)

While the contributions of international donor bodies and NGOs may not be well-documented, they nonetheless play a seeming 'behind the scene' role in the energy sector. The activities of international donor bodies are mainly focused on supporting policy-making, energy efficiency, provision of grants for renewable energy projects development, and provision of technical support for the reform and development of the sector. These contribute to create an enabling environment to attract more private sector participation. Some of these international agencies are the African Development Bank, the World Bank, DFID, GIZ, USAID and the EU. On the contrary, NGOs appear more directly involved in the installation of renewable energy and other developmental projects in rural locations. Many of these NGOs, especially the small localized ones, are quite experienced in handling rural affairs; a capacity they have achieved over time as they interact directly with local communities in various aspects of community development. Empowering and engaging these NGOs in developmental projects will go a long way in complementing efforts of lending institutions and international donor organisations to integrate energy services into income generating activities. Some of the NGOs active in the energy sector of the country include UNIDO, Community Research and Development Centre (CREDC), Touch of light, and the Solar Electric Light Fund (SELF)

3.4.2 Organisational Arrangements for Rural Water Supply

Similar to the electricity sector, the management of the country's water resources is shared by the three tiers of government (see Figure 3.7). At the federal level, the Federal Ministry of Water Resources (FMWR) develops policy, collects data, funds research and development, The FMWR coordinates the operation of 12 River Basin Development

Authorities (RBDAs) which operate and provide water in bulk to cities from dams and also collect hydrological data. Each of the 36 states and the federal capital in the country also has a State Water Authority (SWA) which is responsible for the operation, maintenance and quality control of water supply in urban and, in some states, rural water supply. Structurally, local water departments are supposed to exist in each of the 774 Local Government Authorities (LGAs) in the country but this is not so in reality as the majority of the LGAs do not have such department (WaterAid, 2006). Where they exist, the Local Government Water Agencies are responsible for the provision of rural water supplies

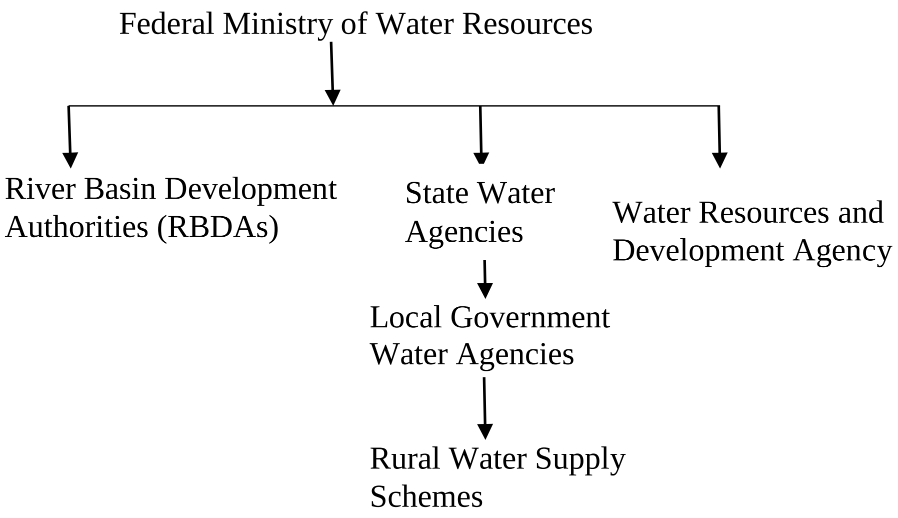

Figure 3.7: Structure of Water Resources Management

However, very limited budgets and human resources capacity for the implementation of sector activities and a lack of coordination between the three tiers of government, especially in regards to policy implementation and financial structure is a main problem confronting the sector (UNICEF and WHO, 2012). Also, the RBDAs are regarded as failed agencies which exist only to sink bore holes and execute water projects - many of which are never completed - at exorbitant costs (Akpe, 2010). For example, the Gindiri regional water treatment plant which was conceptualized in 1999 to facilitate water supply to some parts of Bauchi State was abandoned in 2005, while the Kashimbilla Dam Project in Taraba State was conceived in 1982 and expected to serve Taraba, Benue and Cross River State but has been abandoned since 2007 (Akpe, 2010). The federal government recently in 2016 vowed to treat the completion of the latter as a top priority. In addition to the three tiers of government, a number of international agencies are active in the country’s water and sanitation sector (see Table 3.7).

Table 3.7: Activities of Donor Organisations

DONOR	ACTIVITIES
DfID	Rural Water Supply and Sanitation WSS infrastructure development and local management capacity building
AfDB	Institutional capacity building in State Water Authorities National rural Water SS services planning
JICA	Rural WSS infrastructure and capacity development

Source: USAID, (2014)

A major challenge is the traditional notion that the provision of water is a government responsibility which the populace may not need to pay for (Akpor and Muchie, 2011). Hence, the costs of water infrastructure and services are often met from government allocations and aids from donor organisations rather than from tariffs and charges for its usage, while water rates, where existing, are often fixed far below the cost of service provision (Odigie and Fajemirokun, 2005).

3.5 Review of some solar PV Rural Electricity and Water Projects

There have been conscious attempts by the governments, international donor organisations and, to lesser extent NGOs to back up policy pronouncements in the renewable energy sector through a number of solar PV projects and initiatives in the bids to improve electricity access across the country. These efforts have however recorded mixed outcomes. While huge financial investments are committed to many of these projects, the high incidence of failure has been attributed to a variety of factors including poor or improper fundamental design, use of sub-standard components, adoption of poor installation procedures by inexperienced personnel, and poor maintenance culture (Sambo et al., 2014). The failed solar streetlights projects in Lagos and Abuja are notable examples, with similar experiences in several other states.

3.5.1 Lagos state solar street lighting Projects

In Lagos state, efforts by the Ministry of Rural Development (MRD) which was created in 1999 to develop the rural communities and make it attractive for rural dwellers in order to reduce rural-urban migration have not had lasting effects as many of the solar PV installations either ceased to function or performed below expectations after a few months. This is similar to the failed attempt by the state government to use solar to power streetlights in some parts of the state. Despite having committed huge amounts of financial and emotional investments to these projects, it is not uncommon to have only just 2 or 3 poles streetlights still functional on a stretch of road that could have over 30 of such streetlights poles (Nnaji et at., 2010). A number of factors including placement of solar panels at wrong angle of inclination, wrong sizing of battery bank sizing, the use of sub-standard components and unqualified personnel for the installations have been attributed to such failures. Presently, the state government has reverted to the use of large diesel-run electric generator sets to power streetlights on major roads in the state, despite the attendant noise and exhaust pollutions challenges to the environment.

3.5.2 Pilot solar PV Installations in Sokoto State

In a bid to exploit the abundant solar energy in Sokoto state, a number of solar installations were installed as pilot projects. However a government official noted that the state government was not satisfied with the outcome of the projects as many of them only functioned for a few days after their commissioning as they were either not done perfectly by the contractors or did not meet the standard required Abubakar, (2011). The failure of these solar projects prompted the state government to abandon its other solar projects - along with the accompanying federal funding - and instead endeavour to connect the state to the national grid. This has proved impractical due to the enormous capital and time required.

3.5.3 Solar PV Initiatives in Jigawa State

In Jigawa state, the state government has pursued a solar initiative over the past seven years in the bid to reach rural communities with electricity. Apart from providing SHS to individual homes, each selected community also benefits from centralised streetlights, Mosque lighting, a solar borehole, and a block of solar enterprise lock-up shops providing electricity to six small businesses which are required to pay monthly token to the government for maintenance of the infrastructure. However, the projects effectively raise a sustainability question as they are 100 per cent funded by the government. While early successes in providing solar lighting systems for households and street lightings were recorded, it was not sustainable beyond the initial funding period (Mshelia, 2011). This shows that in addition to initial monetary investments, the sustainability of such projects also depends on other post installation factors. In a similar study investigating the financial viability of off-grid electrification for a typical rural community in northern Nigeria using solar PV, Akpan and Ishak (2012), concluded that such a project will not be economically viable unless there are financial incentives such as low interest loans or financial grants, removal of barriers to private investment e.g. legal and regulatory barriers and proper risk management.

3.5.4 Solar PV Initiatives by Independent Government Agencies and Non-Governmental Organisations

In addition to efforts by individual state government in the country, a number of solar PV projects are being deployed to rural communities by independent government agencies. Prominent among them is the programme of the Bank of Industry (BoI) in partnership with the United Nations Development Programme (UNDP) in which a 24kW mini-solar electricity grid was installed in 2016 in Onono-Anam, a remote community in Anambra state, South Eastern Nigeria as part of six pilot projects planned to be implemented across six states of Kaduna, Gombe, Niger, Osun, Anambra and Delta. Earlier, two of such projects have been completed in Niger and Osun states. The project is designed to supply electricity to power 3 LED light bulbs, one electric fan, one radio/TV set and a mobile phone charging point in an average of 200 homes in each of the communities selected. The BoI gives concessionary long term loan at 7% interest over 15 years to two project developers - GVE Projects Limited and Arnergy Solar Limited. The project developer in turn implements a metering model based on a Pay-as-You-Go basis, with each household provided with a pre-paid meter. Users can in turn purchase electricity vouchers from a local vendor at affordable prices and in accordance to their financial capabilities, and load same into their pre-paid meters in order to access electricity. One of these projects is used as a study case as presented in Section 5.7. Similarly, the Federal Government and some states entered into a partnership with Schneider Electric kick-start economic and social development in rural Nigeria through the deployment of solar PV solutions to light up these places. Based on past experiences in countries such as Indonesia and Madagascar, a pilot *Villasol* project was deployed to Asore community in Ogun state by the Schneider Electric in 2011 for water pumping. Villasol projects have also been deployed in some rural communities in Nigeria including Latunde village in Oyo state and Ibong community in Akwa-Ibom state. Another one of these is used as a case study as presented in section 5.6.

A remarkable departure from failed solar projects is one handled by the Community Research and Development Centre (CREDC) – an NGO - with the support of the United Nation Development Programme (UNDP), and Energy Commission of Nigeria (ECN). This is a 4kW Solar Micro Off-Grid Facility to supply electricity to power 60 households and a 1.5hp borehole in the Roguwa community of the state. The system comprises 20 units of 200 watts solar PV panels providing (1.6kW for the community water borehole, 2.4kW for community use); and 12 units of 200AH/12V deep cycle batteries. Each household in the community is provided with two LED light points and a wall socket for low-power household devices like radio and for charging mobile phones. Furthermore, a device that limits the amount of electricity that can be consumed is installed in each household. Additionally, to boost the sustainability component of the project, the CREDC trained four members of the community who were chosen by the community as Local Energy Regulatory Committee (LERC) to manage the project on behalf of the community. The committee are to collect an agreed monthly energy payments from benefitting community members: 60 % of which is to be used for project maintenance and 40% to pay the LERC members, who work part-time.

3.5.5 Federal Government Independent and Collaborative Efforts

At the federal level, the government initiated a 'Naija Light' Solar Electrification Programme in partnership with the Indian Government, targeted at rural dwellers. It involves the distribution of various solar kits such as 50Watts and 100Watts portable solar kit equipped with a light bulb, an outlet for a fan and 10-point mobile phone charging unit; 300Mwh Solar Hair-care kits for both male and female salon owners that can power 2 lighting points, 10-point mobile charging unit and an energy efficient dipper or handheld hair dryer; and Primary Health Care Solar Kits that is equipped with a mini freezer for storage of serums and vaccines, two lighting points and a 10-point mobile phone charging unit to aid health care at rural level. However, it was not possible to assess the success of the programme as efforts made to collect data on its effectiveness have been unsuccessful. Indeed, the absence of synergy among major players such as REA, ECN, NERC, State agencies, NGOs and international donor organisation involved in energy projects, and the lack of systematic data for such projects in the country has been a major challenge.

In addition, the Nigeria government is in international collaboration with a number of foreign governments to achieve the sustainable development of various sectors of the economy. In one of such collaborative arrangements, the German government, through the German Agency for International Corporation *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) aims to improve access to sustainable energy in Nigeria by providing advice to improve relevant institutional and policy framework, and to provide supports on measures for electrification of rural and peri-urban areas through the usage of renewable energy, particularly small scale hydropower and solar plants. This has led to the building of the country's first renewable energy power plant that combines more than one technology and operates both off-grid and on-grid in 2015 by the GIZ as part of the Nigeria-Germany Energy partnership under the Nigeria Energy Support Programme (NESP). The 25kW hybrid solar PV/Wind Plant located at the National Power Training institute of Nigeria (NAPTIN) in Niger State comprises of a 10 kW solar PV field and three wind turbines of 5kW each. It serves the double purpose of supplying the energy requirements of the Institute and serving as a demonstration and training facility towards the production of well-trained and qualified technicians and engineers needed in the sector.

Many water supply initiatives deployed to rural areas have suffered the same lack of post deployment maintenance arrangement as PV projects. According to the Rural Water Supply Network (2009), an estimate of over one third of hand pumps in rural sub-Saharan Africa is non-functional. In addition, contrary to their well-touted simplicity and easy technology, hand pumps are not well suited for children who bear a fair share of the burden of collecting water. Problems of hand pumps being too stiff to operate (Musonda, 2004) and problems with leverage, improper use and vandalism (Hoko and Hertle, 2006) have been reported. Another option which is gaining interest in developing countries is the use of RE technologies, especially Solar PV, in providing safe drinking water for rural communities.

The Niger Delta Development Commission (NDDC) - a federal government agency established to develop the oil-rich Niger Delta region - installed dozens of such solar water projects costing more than $300,000 each in 2006. However, surveys undertaken suggest that the vast majority of the projects were never completed or failed shortly after installation (Newsom, 2012). Newsom further cited one such installation in which the arrays of solar panels were positioned at a wrong angle which may impede optimum functionality of the installation. In addition, such a situation could be an indication of the limited understanding possessed by contractors being used for the deployment of such projects in the country.

Some other water solar PV water installations are briefly discussed below.

3.5.6 Nasarawa state solar water projects

Another case is in Nasarawa state where over 140 solar water projects were commissioned in 2004 across various local government areas in the state. However, a review of the installations by consultants commissioned by the state government revealed that 83% of the installations had failed for various reasons such as poor technical system design and installation, inappropriate procurement of both borehole and solar array installation, little or no training given to the end users in the community and lack of maintenance (Newsom, 2012).

3.5.7 Failed solar-powered and hand-pump water Projects in Osun and Oyo States

In a report on abandoned and failed projects, Adebayo (2016) noted widespread failures among solar-powered and hand-pump water schemes in Osun State where a number of borehole water schemes had not supplied water since 2010, and have vital component parts missing. Some of these installations functioned for only a few months after they were installed. For example, a solar-powered water project installed in 2013 in Orita-Aiyetoro community which was meant to serve both the community school and the residents of the neighbourhood has already broken down. Adebayo further noted that the situation remains same with respect to the solar-powered borehole constructed by the Oyo State Government for the Elewura community in the state as the installation developed faults not long after its inauguration, hence the residents have not been able to access water from it. In the paper, a user opined that the use of manual submersible hand pump instead of solar-powered pumps would have been better as these are relatively cheaper to repair.

3.5.8 Solar Water Projects in Ondo and Lagos States

In a study carried out across four local government areas in Ondo state Nigeria on borehole sustainability, Oloruntade et al., (2014) found out that 47% solar powered/motorized were non-functioning due to broken pipes, stolen parts and damaged solar panels. However, such high failure rates were not constrained to solar-powered water installations only as the study also recorded a 57% failure rate among the 53 manual pump also evaluated. Similarly, in a study carried out in communities across two LGAs in Lagos State, Longe et al. (2009) observed that all the boreholes fitted with hand-pumps had failed while 86% of those fitted with electrical pumps had failed. In many of these cases, the causes of failure are predominantly faulty pumps and stolen parts. Likewise, a study by Yusuf et al., (2012) on the analysis of sample of 23 boreholes constructed between 2004 and 2010 in Osun and Kwara States revealed that 10 out them had become non-functional.

3.6 Chapter Summary

This chapter gives an overview of the energy and water sectors in Nigeria and reveals the low level of access prevalent in the two sectors. It further discusses the various policies that were developed and the progress that has been achieved in the energy sector. Furthermore, it was noted that recent efforts to harness solar energy in the country, especially in the aspects of solar PV installations for street lighting in urban locations and electricity provision/water pumping in rural areas had not recorded expected success as there appears to have been more failed projects than successful ones. This is in line with Newson's conclusion that the number of communities with experience of failed solar projects of one kind or another is significantly higher than the number with positive experiences where systems are still functioning properly after several years of use (Newsom, 2012). However, contrary to the situation in other developing countries like Bangladesh, Nepal and Kenya as highlighted in section 2.6, most of the solar projects in rural Nigeria are government-sponsored community projects, while individual household-owned solar home systems SHS are not widespread.

The failure and underperformance of many of these RETs installations have significantly contributed to the damaged perception of renewable energy projects both within government and among the public. Although a number of factors have been attributed to the failures, technical incompetence of the installers and absence of post installation maintenance seem to be the main causal factors. Some of these issues relating to the factors that influence the performance of solar PV projects in the country are further investigated using real case studies as presented in of this study.

It can also deduced that while the use of boreholes by governments at all levels in the country has been adopted for improved accessibility, there is no satisfactory evidence to show that adequate sustainability of the systems had been given high priority as may be necessary. Against the backdrop that initial capital costs of solar borehole systems are significantly higher than fossil fuel-based systems, and that they only become financially competitive when they remain functional over a period of years (Cloutier and Rowley, 2011), it becomes imperative that necessary post-installation mechanisms be put in place to redeem the perception and prejudices against solar installations in the country as highlighted in Section 1.3.

CHAPTER 4 Methodology

4.1 Introduction

This chapter discusses some of the research methods and techniques that could be adopted to achieve the aim of the study as stated in section 1.4, and the reasons for selecting the approach adopted. Criteria used for selecting the case studies and stakeholders are presented as well as the nature of data to be obtained from them. Furthermore, the chapter outlines the framework that will be employed for assessment and evaluation of the case study material.

4.2 Research Methodologies and Research Methods

While ‘research methodologies’ and ‘research methods’ are often used interchangeably in literatures, for this study research methodology is described as the framework that guides or relates to the entire process of research while research methods are more specific: they are considered as techniques of data collection and analysis (Creswell and Clark, 2007). The two main research approaches broadly relate to the use of quantitative and qualitative techniques. However, while one of the approaches may be appropriate for many studies, the two are often combined in a multi-method approach for others. Quantitative research mostly involves collecting data through various means and converting them into numerical form so that statistical analysis can be made, and conclusions drawn. Although there are exceptions to this, the method usually involves the testing of hypotheses, which are predetermined theories, or questions that are to be addressed, and may include predictions about possible relationships between the variables that are being investigated. This approach is related to deductive logic or “top down,” reasoning i.e. from theory (the general) to data (specific). However, this is not exclusive as some statistical techniques such as descriptive statistics, correlations, and factor analysis can be employed in qualitative studies. Quantitative methods support a more structured data collection and often allow for large amounts of data to be collected and analysed in a logical and replicable way. Hence, it is considered ideal for laboratory situations in which the environment and surrounding conditions can be closely monitored and controlled or bounded. However, the use of the method may be considered as too rigid an approach that ignores or take some aspects of social life within the “real world” for granted, and may not permit the use of alternative explanation beyond the hypothesis. The method assumes that everything in the social world can be described or measured with a numerical system (McQueen and Knussen, 2002).

Qualitative research, which includes various approaches such as "field study" (Schatzman and Strauss, 1973); "case study" (Yin, 1984); and "participant observation" (Jorgensen, 1989), is described as any research where number counting and statistical techniques are not the central issues. The data to be analysed include transcripts of interviews, notes from the researcher's observations and the systematic analysis of documents (plans, policies, minutes of meetings etc.). Coding of this data may generate a numeric representation but only after the qualitative analysis of the content has been carried out (Wright, 1995). Hence, qualitative data are considered appropriate for inquiries involving social life or phenomena to either derive theories or find out what is happening in a given situation where the researcher seeks to establish the meaning of a phenomenon from the view of participants. Therefore, qualitative data analysis tends to be inductive as the researcher identifies important categories in the data, as well as patterns and relationships through a process of discovery that may lead to theories that may be entirely new or an affirmation, extension or addition to existing ones. Qualitative research involves keen observation, systematic taking of notes, strategic questioning of respondents, and often requires a higher amount of self and time investment by the researchers than is required in a more quantitative experiment or survey. In addition, the approach affords the opportunity to examine the process of "why" and "how", not just "what". Nevertheless the approach is seen as being subjective, and but can suffer from both lack of reliability (ability to replicate) and lack of validity (ensuring that the phenomenon under investigation relates to the research question) (Bryman, 2001; Silverman, 2001). However, these issues can in part be addressed by the use of multiple approaches to collect data in a process known as triangulation. This enhances the credibility and validity of the findings beyond that of a single-approach method, and helps to mitigate some of the pitfalls usually associated with a qualitative approach using limited tools.

Of equal importance to the research methodology adopted for a study is the decision on techniques of data collection to use. Such options include the use of experiments, surveys, questionnaires, interviews, case studies, analysis of documented cases, participant and non-participant observation etc. Data collection techniques are broadly divided into three groups namely: structured, semi-structured and unstructured. The choice of technique(s) to utilize in a study is dependent on the type of data to be obtained, how it will be obtained, from where/who it will be obtained, and the method of analysis to be implemented. These techniques can be used under three broad data collections methods which are briefly explained below.

4.2.1 Structured Data Collection

The structured data collection method is considered a rather a rigid or controlled approach of data collection in which techniques used are fixed, such that they are of the same form and order. Hence, in structured interviews, multiple respondents or cases will be subjected to the same set of questions, asked exactly in the same way and in a specific and predefined order. Hence, questionnaires utilized in this method provide a relatively simple and straight forward approach for collecting large amounts of structured and easily analysable information, while a structured interview limits the responses to specifics and gives room for less elaboration. The closed question format in this method is often used in surveys to gain data representative of large populations. A major advantage of this approach is that by using a standard guide to ask questions, inconsistencies and inappropriate responses are avoided while the researcher anticipates all possible answers with pre-coded responses. In addition, the process of a structured interview can be easily replicated by other researchers in other locations. However, the method is not ideal for deeper enquiries, and its validity can be affected by misunderstanding of questions.

4.2.2 Semi Structured Data Collection

The use of semi-structured data collection method enables a mix of qualitative and quantitative information to be gathered. Semi-structured interviews are often used when a researcher needs to enquire deeply into a topic and to thoroughly understand the answers provided. The method follows a style that is somewhat conversational through a question guide which contains questions and topics that must be covered. Although the questions are standardized and the guides contain major questions that are used in the same way in every interview, the interviewer has some discretion about the order in which they are asked as well as the level of probing for information. Semi-structured interviewing is suitable when the researcher already has some grasp of what is happening within the sample in relation to the research topic. Semi-structured Interviews offer more interactive and less predetermined ways of obtaining information than surveys. They are used extensively in qualitative research for data collection and allow for greater flexibility as they afford respondents to ask questions and obtain immediate clarifications to their enquiries from the researcher. In addition, the presence of the interviewer may encourage improved participation and involvement.

4.2.3 Unstructured Data Collection

The unstructured data collection format covers a broad area of issues but follows the direction of the respondents as the interviewer does not exercise much control over the course of the discussion which can be carried out face to face, by telephone or via the internet through Skype and email. It allows respondents to tell their own stories in their own words, with prompting by the interviewer. Although this method of information gathering may lead to very rich data that can be used in qualitative analysis, it can take a long time to carry out. Hence, it may only be used when researchers can afford to spend a long period of time at the location where research is being carried out.

In addition to interviews, questionnaires and surveys mentioned above, another technique of data collection is “Observation”. Observation may be may be formal or informal. In the former, areas or situations to observe are pre-determined or pre-scheduled and the instruments of observation simply act as a guide. In the latter, areas or situation to observe are decided during the exercise, hence the researcher is said to be the instrument. In addition, the researcher may participate in the exercise (participant observation) or may take no role in the situation other than that of an observer (non-participant observation). Observation as a technique may also become appropriate when the physical state or working condition of a subject is required to be known. Although observation enables the researcher to see exactly how a situation is or how people act and interact in a given situation, such interaction may be influenced by the presence of the researcher. In addition, the type of data capturing adopted e.g. audio tape, video-tape, and field notes may also influence the situation. It is therefore important that this, in common with other techniques, is compliant with ethics standards and procedures.

4.3 Choosing the Research Methodology

In deciding on the research method to be adopted for a study, it is necessary to first analyse the nature of the research problems as the suitability of a research method is dependent on the phenomena to be explored (Morgan and Smircich, 1980). For example, Ilskog (2008) highlights the need to implement qualitative methods of research in studies with interdisciplinary themes. This is evident with rural electrification which is typically influenced by social and cultural contexts.

While the gathering of data about whether and why energy services have been abandoned, are malfunctioning, or have not been the focus of much research is important, particular attention needs to be paid to why such installations often fail (Alazraque-Cherni, 2008). As highlighted in Section 1.3, a number of studies related to renewable energy in rural areas have been carried out. However, while the approaches adopted for these studies are generally scientifically sound, they are often skewed towards the technical and environmental factors and frequently fail to study the wider influences and the stakeholders involved in the deployment and performance of such systems. Furthermore, electricity generation has often been considered the final objective rather than as an intermediate product to achieve something else, the value of which is determined by the use to which electricity can be put, and the positive impacts that result in terms of quality of life.

A significant drawback to uncovering the factors associated with the performance of solar PV installations in rural areas may have been the lack of appropriate approaches and sufficient interest in the systematic collection of relevant information from rural users and other stakeholders. Bhattacharyya (2012) argues that a number of approaches used by countries in enhancing energy access have paid little attention to whether these efforts are sustainable solutions or not. In his work, which was adapted from the robust framework developed by Ilskog (2008), he concludes that the search for sustainable country-specific solutions needed to be intensified to realise the desired objectives of sustainable energy.

Therefore, a study on the reasons for the underperformance of solar PV installations in rural locations in Nigeria requires a multi - dimensional approach that can capture the wide spectrum of possible causes. This includes interviewing different stakeholders involved in the deployment and utilisation of such installations, observing the use pattern of the installations, evaluating the physical state and performance level of the installations, etc. For this study therefore, it is necessary to implement an approach that not only 'sees' beyond the appropriateness of solar PV installations in rural locations in Nigeria as have been documented in a number of literatures (see section 1.3), but also assesses the performance and sustainability of such installations in the country. The importance of this is seen from the fact that the provision of solar PV installations to rural dwellers is not an end itself but contributes to the socio-economic development of such locations (Alazraque-Cherni, 2008).

Whereas a quantitative research approach would fall short in a study of this nature and action research - in which the researcher is engaged in the implementation process itself - is not practically viable, the adoption of a multiple methods approach was decided upon. This included case study observation, interviews, questionnaires, discussions with relevant stakeholders, and the technical evaluation of solar PV installations in rural case study communities which are considered more robust and practicable approaches that could lead to in-depth and insightful results, and are therefore adopted for this study. Furthermore, a cross-referencing of the contents of literatures and interview sessions and study cases is carried out in the study to identify key themes.

4.3.1 Case Studies

Typically, a case study is concerned with investigating single or multiple units of study, using familiar research techniques for data collection such as interviews, observations, or surveys. It enables the adoption of approaches which goes down to the level of local actors, identify detailed socioeconomic effects which may not be captured by purely numerical analysis of data, and also supports the identification of economic and social relationships which may be hidden in quantitative studies (Rio and Burguillo, 2009). Furthermore, the method is considered more appropriate where it may not be possible to obtain sufficiently large samples. By limiting the area of a study to a small number of units, the case study researcher is able to look in-depth at a topic or phenomenon of interest. More than one case is often employed to study a phenomenon or concept as this may give a more balanced overview and increases the chances of obtaining generalized results. While it may be argued that the results obtained from case studies depend on the opinions of those interviewed, the choices made by the interviewer in asking questions, and the effectiveness of data collection and interpretation to reveal the factors leading to a potential loss in scientific rigour, it is also true that new insights can be gained that are not otherwise possible from more structured approaches. Hence, Rio and Burguillo (2009) recommend that care should be taken when treating the information collected from the interviews and a mere collection of anecdotes should be avoided. In addition, it should be clear beforehand which cases are appropriate, which actors would be interviewed and what type of information would be required.

4.3.2 Identification and Selection of Sites for the study

For studies employing a case study method, it is particularly necessary to ensure that the choice of study cases give a fair representation of possible cases, and also possess features that meet the criteria for the study. For this study, the type and purpose of installation, its location, the organisation that carried out the deployment were considered in addition to the availability of relevant participants and assurance of their safety.

Furthermore, for this study, the evaluation of rural solar PV installations across the six geo-political zones of the country would be ideal. However, a number of constraints limited the sites chosen as case studies to the South West geopolitical zone which is the most stable politically and from a religious perspective and could therefore guarantee a level of safety for the researcher not assured in the other five zones. This is an important consideration since the nature of this study necessitates visiting rural locations that are often located far away from major cities and, as such, would make the study unsafe to be carried out in such places, thereby falling short of a major ethical requirement as stipulated in the De Montfort University's *Research Student Handbook*. Some of these threats include Boko Haram terrorism activities in the North West, North East, and North Central regions; incidents of kidnappings in the South South, South East, and North Central regions; and occasions of civil unrest in the North Central and South South regions (see Chidebell-Emordi, 2015). Despite these however, two rural locations in the Niger Delta areas of the South South region are used as part of the study cases when threats associated with such visits were minimal (as explained in section 5.8) in addition to five locations in the South West region.

The specific case locations for this study were selected according to the following factors:(i) they are remote communities with a low probability of having grid electricity in the near future (the exception to this is Asore Community), (ii) each case has/had solar PV installations that are/were meant to provide improved energy/water services to the communities where they are installed (iii) they present a balanced outlook for the study by including: failed and performing installations; government-deployed and privately-deployed installations; water only, electricity only and water/electricity installations that were deployed as early as 2008 and as recently as 2015. In addition, the researcher can communicate fluently in the local language of the rural dwellers in the chosen communities

(Yoruba in the South West and *Pidgin* English in the South South). This led to enhanced rapport between the researcher and the rural dwellers and therefore enabled effective interview sessions with reduced likelihood in loss in information that may be introduced by language problems or by the use of an interpreter.

These locations were identified by making formal and informal enquiries at government agencies (including the Ministry of Rural Development and the Ministry of Science and Technology) and Non-Government Organisations (NGOs) that work with rural communities. In addition, searches on the internet were made to identify the exact location of one of the study cases – Sagbokodji community- which is reputed to be the first of its kind in Lagos state. On the basis of these criteria, seven rural settlements were chosen for the study (Table 4.1). Outlines of each of them are provided in sections 5.3 to 5.9. While a casual look at Table 4.1 appears to support a causal relationship between PV water installations and failed systems, this is not actually the case as revealed in the findings of the study presented later in Chapter 5.

Table 4.1: Features of selected Study Cases

Site	Year Deployed	Approx. Population	Year of Evaluation	Type of Installation (Utilisation)	Status of the Installation
Ide I	2012 (Government)	400	2011, 2012, 2013	Water	Failed (2014)
Ide II	2009 (Government)	30	2011, 2012, 2013	Water & Electricity	Failed (2012)
Bishop Khodji	2008 (Government)	800	2012, 2013	Electricity	Failed (2009)
Asore	2011 (Private)	500	2015	Water	Failed (2012)
Onibambu/ Idi Ata	2015 (Private)	600	2015	Electricity	Functioning
Umuagwu	2013 (Private)	400	2016	Electricity	Functioning
Umuode	2015 (Private)	600	2016	Electricity	Functioning

In addition to the identification and selection of sites as case studies, it is necessary to determine the stakeholders that will be interacted with in the study, and the type of information to be sought from them. Since the study covers both pre and post deployment periods of the installations, it is necessary to include stakeholders that are active during both of these periods. These include officials of government agencies, contractors and officials of private energy provider organisations that are involved in the deployment and, sometimes, maintenance of these installations. The information sought from these participants included the procedures involved in the deployment of the installations, the nature of agreements with contractors and the challenges encountered during deployment and maintenance. Also, the end users (the rural dwellers in this study) would be invited to share their experiences in the usage of the installations and how they have influenced their daily lives, the challenges (if any) encountered by the use of the installations and their suggestions about improving the services rendered by them.

4.3.3 Obtaining Approval for study

After identifying the locations for the study, it is important to make initial visits to ascertain the existence and condition of the installations, the possibility of conducting the study in the communities and the ease of access. These could provide a means for the researcher to avail himself of the culture or practices of the communities and prepare accordingly, and to notify and obtain permission from the local government or local authority (where necessary) of the intent to carry out the study. In the case of Ide I and Ide II, notification for the study was made to the local government office under which jurisdiction the communities belong. A formal letter of "Notification of Field Study and Data Collection" was sent to the Local Government Authority highlighting the aim and objectives of the study and guaranteeing that the study was devoid of tribal, religious, or political agendas (see Appendix 1). At the local government office under which Sagbokoji Village falls, a formal notification for the study was deemed not necessary by the council officials, and a verbal approval to carry out the study was given. In the case of Asore, Onibambu, Umuagwu and Umuode communities, approval was obtained at community level through their respective village head or representatives. In addition, prior to the assessment and interviews sessions, a courtesy visit was made to the head of the community or any other persons known to have authority or influence in the community; these were both to explain the purpose of the study and to gain their support (and, tacitly, possible positive influence on the community members). This is against the backdrop that despite having notified and obtained approval from the local government council, the local people may be less inclined to participate in the study if it does not have the support of the village heads (as encountered in Ide I and Sagbokoji communities).

4.3.4 Data collection.

Contrary to what pertains in developed countries, the availability and authenticity of data from rural communities poses particular challenges to researchers in most developing countries (Pachauri and Cherp, 2011; Zhang et al., 2009). This could include transportation difficulties in accessing such communities, low literacy level of the rural dwellers that may limit technical discussion and the possibility of written responses, or deeply entrenched cultural values that may hinder research (Pierce and Scherra, 2004). For example, based on social or religious factors, some communities may not grant access for a male researcher to converse with married women in the communities, while some may expect even strangers to greet them in a culturally accepted way before interacting with them. Hence, in addition to an understanding of these cultural factors, a level of perseverance was needed by the researcher to be granted some interview sessions.

Since a main objective of the study is a post-deployment evaluation and assessment of rural solar PV installations, the primary data collection method employed for this study was through semi-structured interviews and non-participant observations that were aimed to obtain a combination of detailed verbal descriptions about the issues, attitudes, settings, and experiences in the use of the installations, to constrictions or challenges faced in accessing their outputs, responsiveness of maintenance officials, etc. In particular, the interviews and observations were aimed at evaluating the technical-related attributes of the installations and the financial/economical sustainability of the services provided by them in each of the study locations; their social/ethical and environment effects; and the influence of existing institutions and government policies on their deployment and performance in accordance to the sustainability dimensions which are considered fundamental to their sustainability (see section 4.3.6 and Table 4.4).

Rural dwellers were interviewed in the seven communities individually, and in groups (in which questions were used to stimulate discussion). The use of a semi-structured, open-ended and inductive style of questioning enabled different dimensions of the issue to be explored in-depth and allowed further probing questions to initial responses in which the respondents were not restrained to choose from a set of answers. However, question guides (see Appendix 2) were employed to introduce more structure to the interview process while maintaining a relatively high degree of flexibility. In addition, to enhance better understanding of the questions by the respondents, and to further boost the credibility and validity of the exercise, the questions were translated and administered in the native languages of the rural dwellers: Yoruba language in five communities, and Pidgin English in two communities.

As introduced above, other stakeholders included officials of government agencies, contractors, and installers. Hence, the collection of data included uneducated rural dwellers that converse only in their native languages to government officials who are often reluctant to provide fundamental information under the guise of officialdom, and contractors who often found it inconvenient to grant chats /interviews. For example, the researcher was only granted an interview with officials of the Ministry of Rural Development after his third visit to the Ministry, while after many futile attempts to have a face-to-face discussion with a senior official of the private energy provider Organisation that deployed one of the installations, a phone interview was eventually granted (see section 5.1.4). As in the villages, perseverance was needed by the researcher to obtain information from some officials and professionals. An outline of the dates of the visits to the seven rural communities used for the study are given in Table 4.2.

Table 4.2: Dates of visits to study locations

Site	Location	Dates of Visit/Interview
1	Ide I	September 2011; November 2011; November 2012; August 2013; June 2016
2	Ide II	November 2011; February 2012; August 2013; June 2016
3	Sagbokodji	July 2013; February 2014
4	Asore	March 2016; June 2016
5	Onibambu	March 2016; July 2016
6	Umuagwu	June 2016
7	Umuode	June 2016

Furthermore, the questions asked varied with the respondents. In this regard, while government officials were asked questions like “explain the processes involved in the award and deployment of the RE installations; ‘how do your agency ensure that bias is not introduced in choosing the community to deploy an installation”, contractors were queried on the procedures they underwent leading to the award of the project, the nature of the contractual agreement and the challenges encountered in executing the projects, whereas the emphasis of questions posed to end users relate to issues on the demand side of the installation such as the impact of the installations on the community, the mechanism put in place to ensure proper performance and maintenance, and their evaluation of the adequacy of the installation. The main areas of questions which were inquired of each group of stakeholders are provided in Table 4.3, while a more detailed set of question guides used for the interview sessions are given in Appendix 2. These areas of questions evolved from the knowledge gained and trend observed in the review of literature (CHAPTER 2) and the assessment of the status of energy and water in Nigeria (CHAPTER 3). All participants in the interview sessions were informed about the purpose of the study, how the information obtained will be used, what is required of them, and that their participation is voluntary.

Table 4.3: Areas of Questions to stakeholders

Stakeholders Group	Areas of Questions
Officials of Government Agencies	• Reasons for the deployment of the installation • Process of choosing or deciding communities to have installation deployed • Nature of contracts and process of award • Lessons learned from both successful and failed installations
Contractors/ Energy providers	▪ Experience in deployment of solar PV Installations ▪ Process of obtaining contracts and the contractual terms ▪ Business Model implemented for the deployment ▪ Opinions on how sustainability of installations can be improved.
Consumers (Rural Dwellers)	▪ Degree of satisfaction with performance of installation ▪ Social Impact of the installation on the community ▪ Affordability of the tariff (if any) ▪ Types of training (if any) provided for community members and post-installation maintenance arrangements available

In addition to interviewing the stakeholders, data relating to the physical state and performance of the installations were obtained through observation and physical evaluation of the installation in each of the study locations, while their influence on the rural users were collected through non-participant observation. This involved spending between 3 to 10 hours in a study location on each visit and taking notes or pictures of what is seen, such as how the installation may have influenced social activities and interactions among the users, and of the physical state of the installation. These are noted and recorded within the confines of ethical considerations as explained in section 4.5.

The details of the interview sessions and observations are presented in CHAPTER 5

4.3.5 Recording of Data

The responses during the interview sessions with stakeholders were recorded as hand written notes since they (the respondents) were not receptive to having their responses on tape. While this mode of data capture was not the ideal, it was utilized because the researcher would rather have the full cooperation of the respondents under a condition that offers them the free will to give unrestrained personal interpretations. Furthermore, in addition to interacting with the rural dwellers and recording their responses at each of the study locations, it was necessary to physically observe and appraise the condition of the installations and their effects on the daily activities of the rural dwellers. This was done through non-participant observations that were recorded both as notes and as pictures within the confines of ethical considerations (see section 4.5). After the collection and recording of these data, they were prepared for analysis and incorporated into the framework for assessment and evaluation.

4.3.6 Development of Framework for Assessment and Evaluation

A framework can be regarded as an overview or outline of a generic set of factors that can be considered in a specific context or location. The framework itself can then be modified on the basis of the knowledge gained from these individual, ‘unique’ cases. As such, a framework to support the evaluation of solar PV installations in isolated rural communities outlines the configuration of a set of factors, practices and policies that could enhance the implementation and diffusion of the installations in such technology. In this study, the generic framework is to be developed from the literature and will be modified by findings from the case studies. The benefits of such a framework is that it is not case specific but provides the key attributes for evaluation and could then be modified and implemented in different circumstances or in the same location over time. Hence, while such a generic framework may contain a range of factors in which some may be more or less relevant or important in a specific setting, they can be used to evolve indigenous frameworks that can reflect country-specific practices and institutions. Therefore, the framework developed here is to an extent specific to Nigeria and is based on indicators that can be credibly identified and evaluated on a local project level.

As discussed in section 2.5, there are a number of assessment and evaluation tools that could be used to appraise the performance and sustainability of rural PV installations. Among such approaches is the use of 39 indicators by Ilskog (2008) based on information that can be obtained from field studies relating to the technical, economic, social/ethical, environmental and institutional dimensions of sustainability. In addition, the set of indicators evaluated may exclude some relevant aspects as seen in Lhendup (2008) where 18 indicators cutting across Technical Features, Government Regulations, and Environmental and Social dimensions were evaluated but Economic indicators were not captured. For this study, Technical, Economical/Financial, Environmental Impact, Social-Ethical Development, and Institutional Development and Government Policies sustainability dimensions are considered as the five core dimensions that can capture all relevant aspects. The justification of these choices and their respective descriptions are given in the subsequent sections.

4.3.6.1 Justification of core sustainability indicators

In the review of the literature (Chap 2) and appraisal of the status and issues relating to energy and water in Nigeria (Chap 3), a number of barriers and factors that could influence the sustainable deployment and performance of solar PV installations were encountered. In particular, section 2.4 highlights Awareness and Information, Financial and Economic, Technical, Market, Institutional and Regulatory, Behavioural, Insufficient Capabilities, Lack of understanding of local Needs, Business and Institutional Limitations, as well as Political and Economic constraints as some of these factors. These were broadly categorised as Economic and Financial, Institutional, Technical, and Social, Cultural and Behavioural in Table 2.4. In section 2.5, different criteria and sustainability indicators as encountered in renewable energy projects and a number of assessment and evaluation tools that can be used in their analysis were discussed. Similarly, in the review of some solar PV rural electricity and water projects in Nigeria (section 3.5), technical, financial, legal and government regulations are broad factors that were seen to have influenced the performance and sustainability of these projects while specific factors included bad technical system design and installation, inappropriate procurement of installation component parts, and lack of maintenance and little or no training given to users.

It is therefore necessary to integrate sustainability indicators from the recommendation of key literatures as highlighted in sections 2.4 and 2.5, align them with the ones identified in section 3.5, and also to develop the assessment and evaluation tool to implement for this study. As a first step towards such an integration, it is essential to identify and separate the set of indicators that are applicable (and measurable) to this study from the ones that are not applicable. This is done for three key literatures Lhendup (2008), Ilskog (2008) and set of sustainability elements by World Bank, (2008) below.

Lhendup (2008)
Indicators/Criteria

Technical Features

Energy density of the Installation (N/A)

Ability to meet the unanticipated excess demand (✓)

Energy payback ratio of the system (N/A)

Lifespan of the system (✓)

Quality of supply (✓)

Dependence on Weather and Climatic (N/A)

Incremental capacity of the system (✓)

Availability of local skills and resource (✓)

Dependence of fossil fuels (N/A)

Development of other infrastructures (✓)

Government Regulations

Tax incentives (✓)

Regulation on use of local resources (✓)

Opportunity for private participation (✓)

Environmental and Social aspects

Public and political acceptance (✓)

Land requirement and acquisition (✓)

Risk of hazard rating (N/A)

Emission of Environmental pollutants (N/A)

Interference with other utility infrastructure (✓)

Ilskog (2008)
Indicators/Criteria

Technical Development

Efficiency (✓)

Conformance with national standards (N/A)

Technical losses (N/A)

Compatibility with future grid service (X)

Availability of support infrastructure (✓)

Daily operation services (✓)

Availability of services (✓)

Economic

Profitability (✓)

Costs for operation and maintenance (✓)

Costs for capital and installation (N/A)

Share of profit set aside for re-investment in electricity service business (✓)

Share of electricity consumed by businesses (✓)

Share of electrified households using electricity for income-generating activities (✓)

Business development (✓)

Social/ Ethical Development

Number of electricity service organisations in the area (N/A)

Share of health centres and schools with electricity (✓)

Number of street lights in the area (N/A)

Share of public places and specialised businesses where TV/ telecommunication/internet is provided (N/A)

Micro-credit possibilities available for electricity services connection (✓)

Share of population with primary school education (N/A)

Share of population with access to electricity (✓)

Distribution of electricity client households in income groups (N/A)
Subsidies offered for electricity services (✓)

Share of economically active children (N/A)

Environmental Impact

Share of renewable energy in production (N/A)

Emissions of carbon dioxide from production (N/A)

Share of electrified households where electricity has replaced other energy sources for lighting (✓)

Share of electrified households where electricity has replaced other energy sources for cooking of main meals (N/A)
Any serious local environment impact identified (N/A)

Organisational/ Institution Development
Share of staff and management with appropriate education (✓)

Degree of local ownership (✓)

Number of shareholders (N/A)

Share of women in staff and management (N/A)

Staff turnover in organisations (N/A)

Number of years in business (N/A)

Share of non-technical losses/Default rate (N/A)

Level of satisfaction with energy services (✓)

Auditing of financial reports on yearly basis (N/A)

World Bank (2008)
Sustainability Elements

Practical Technology Choices (✓)

Least Cost Design (✓)

Government Ownership (✓)

Subsidy Commitment (✓)

Competent and dedicated post maintenance unit (✓)

Light-handed and simplified regulation (✓)

Consistent with rural electrification plan (✓)

Explore opportunities for international co-financing (✓)

Maximise Opportunities for productive applications (✓)

Community Awareness/involvement(✓)

Training to providers, users, government staff (✓)

Access to spares and repair service over long term (✓)

Appropriate delivery mechanism (✓)

Good demand data (✓)

Legends

✓	-	Measurable and applicable to study cases
N/A	-	Not Applicable to study cases

In selecting the indicators that are applicable to this study and are therefore to be used for evaluation and assessment of study cases, it is observed that Lhendup (2008) used Technical Features, Government Regulations, and Environmental and Social Indicators as core indicators, Ilskog (2008) utilised technical, economic, social/ethical, environmental and institutional as sustainability dimensions while the indicators in World Bank (2008) were not categorised under core sustainability dimensions. Hence, for the sake of uniformity and consistency, and to avoid a process that could bring up instances of repetition of indicators, it is considered appropriate to categorise the indicators to be used for further assessment and evaluation under five core sustainability dimensions of Technical, Economical/Financial, Environmental Impact, Social-Ethical Development, and Institutional Development and Government Policies. These core sustainability dimensions capture all relevant indicators in the three literatures, those encountered in section 2.4, and also align with indicators revealed in the review of some rural solar PV projects in the country in section 3.5. In this regard for example, indicators which appear under 'Technical' in Table 2.4, 'Technical Features' (Lhendup, 2008), and 'Technical Development' (Ilskog, 2008) are all categorised as under 'Technical' sustainability dimension while those under 'Market Failure/imperfection', 'Market Distortions', 'Economic and Financial' (Table 2.4) and 'Economic' (Ilskog, 2008) are categorised under 'Economical/Financial' sustainability dimensions since market indicators can be regarded to be largely influenced by Economic and Financial considerations. The outcome of such integration of relevant indicators under broad 5 sustainability dimensions is the development of 38 indicators to be used for assessment and evaluation in this study as shown in Table 4.4. Indicators which appear across each of Lhendup (2008), Ilskog (2008), World Bank (2008) and Table 2.4 are recorded as single entries on the table.

A brief explanation of the 38 indicators categorised under the 5 sustainability dimensions considered relevant to this study is presented in the next section.

4.3.6.2 Description of Core Sustainability Dimensions of Indicators

As stated above, 38 indicators are selected for this study. These comprise of 10 technical, 10 economical/financial, 3 environmental, 8 Social-Ethical, and 7 institutional development and government regulation indicators. A brief description of each of them is given below.

Technical Sustainability Dimension: The technical sustainability dimension of indicators relates to those indicators which determine the inherent operation and performance of the installation with respect to the constituent parts, its design, availability of maintenance structure and trained personnel, and other technical-related indicators. These are regarded as important because they combine to go a long way in determining the sustainability of installations. A case of such technical impact was highlighted in section 3.5.5 where the wrong positioning of solar panels (i.e. bad design) was noted to impede the performance of an installation. The same applies to the use of sub-standard component parts. Hence the *efficiency* indicator is meant to present a measure of the performance of the installation. While efficiency is ideally presented quantitatively, this is not be possible in the study as the researcher does not have the resources or access to obtain some necessary quantitative values. Hence for this and many other indicators, the degree of incidence or activeness will be obtained from the testaments and evidences of users, outcomes of interview sessions with energy providers, contractors and government officials, and the observations made by the researcher during interactions with users and physical evaluation of installations at study cases locations with respect of each indicator. As explained in more details in the next section (see Table 4.5), such level of incidence or activeness are simply categorised as Low (Poor), Medium (Average) or High (Good). On *availability of support infrastructures*, the human and material resources available for continual functioning of an installation are assessed. However, for installations that have already broken down, the availability of support infrastructures will be evaluated against the time an installation was functional. This is against the backdrop that such support infrastructures that may have been previously available may no more exist after an installation become non-functional. This would have necessitated '0' score for such an installation and as such, may not reveal the degree the indicator may have contributed to the sustenance or otherwise of an installations. *Daily operation services* is an assessment of the relevance of the daily operational measures that are designed and integrated into the running of the installation to ensure optimal performance while *availability of services* presents how obtainable are such services. Also, while *incremental capacity of the system* presents the level of degree an installation can accommodate further increase in users without negatively affecting its performance, *lifespan of the system* is a measure of the years an installation remained functional before breakdown compared to the expected lifetime of such installation. Hence, this indicator will not be applicable to the four functioning installations of the study cases as highlighted in Table 4.1. *Quality of supply* gives an indication of the quality of services provided by an installation and *availability of local skills* indicates the degree of existence and availability of locals that can provide basic maintenance services for the installation. The impact of an installation on other infrastructures is presented under *development of other infrastructures* while *practical technology choices* indicates how practicable and realistic the implementation of solar PV technology is at each of the study locations.

Economical/Financial Sustainability Dimension: Economic and Financial indicators are regarded as fundamental because they often determine how receptive the users consider the services provided by the installations in financial terms. They also signify the level of financial incentives available for both installers and users, how easy it is for these to be accessed, etc. The indicator *profitability* gives a measure of how cost-effective and financially-rewarding an installation is. This will be obtained from energy providers that deploy such on commercial basis and becomes non-applicable to installations deployed on non-commercial basis e.g. an installation donated by an individual or deployed to a community by government as a social responsibility. *Low costs for operation and maintenance* takes cognisance of the financial implication of constantly keeping the installation in a good working state. The *share of profit set aside for re-investment* will also be applicable to the installations considered under *profitability* and will be obtained from the energy providers. *Share of electricity/water consumed by businesses (income-generating activities)* will reflect the number of business outfits that make use of services (water or electricity, or both) provided by an installation as observed during the visits to each location of study, while how such services has contributed to the growth of such business ventures will be indicated under *business development.* A reflection of how well efforts have been made to positively exploit the availability of services provided by installations will be given under *maximise opportunities for productive applications,* while an indication of the cost appropriateness of the implementation of the solar PV installations at each of the study locations will be given under *least cost design*. The existence and accessibility of m*icro-credit financial arrangements to consumers* will be assessed as a measure of micro-credit financial incentives available to consumers, while an indication of if/how well opportunities for international co-financing options are exploited will be presented under *explore opportunities for international co-financing*. Finally under economic/financial indicators, *proper pricing and affordability of tariff* will be assessed through interactions with energy providers and users to know if the tariff implemented is minimally sufficient for profit-taking on the part of the energy providers, and also how affordable it is to the consumers.

Environmental Impact Sustainability Dimension: Environmental-related issues are of global concern in many national and international discussions and their non-inclusion in decision criteria have often been seen to contribute to the failure rural installations (see section 2.1). The essence of this core dimension in this study is to evaluate the direct and indirect environmental effects of solar PV installations in rural communities and how these affect their sustainability. In essence, the indicator *land requirement and acquisition* will assess the land size required for an installation in relation to available land size of the community and the impact of the installation on the landscape/scenery. In what way and to what degree the environmental impact of an installation has affected the performance of other existing infrastructures will be assessed under *non-Interference with other utility infrastructures*. An appraisal of the extent to which the installation has led to the use of more environmental-friendly sources at household levels will be carried out under *households where electricity/borehole water has replaced other sources*.

Social-Ethical Development Sustainability Dimension: Indicators under this dimension cover the influence of installations on the social and ethical development of the users. These set of indicators are often considered central among reasons for deployment of solar PV installations to rural communities and they are majorly assessed through the observations made by the researcher during the visits to the study locations and information obtained through interactions with the users. Essentially, it is necessary to evaluate how receptive the installations are among the public and the political class/ government under *public and political acceptance.* A measure of the number of health centres and schools which an installation is serving will be indicated under *share of health centres and schools benefitting from installation* while a similar measure will be given under *share of population with access to water/electricity.* It is also necessary to establish if the existence of an installation conflicts with the culture or run contrary to the beliefs of the users, and if impartiality exists in the deployment of an installation to a community - how it has improved or strained the relationships among neighbouring communities. These two issues will be addressed under *non-cultural conflict* and *social equity in the deployment of RETs* indicators respectively. The level of satisfaction observed and attested to by the users on the services of the installations will be given under *level of satisfaction with services,* while the level of knowledge on the capacities and limits of solar PV technology will be presented under *awareness of users on potentials and limitations of the technology.* Lastly, it will be evaluated if all relevant stakeholders were involved in both the determination and deployment of an installation to a community. This will be provided under *active participation of all stakeholders in the choice/ deployment of installation*.

Institutional Development and Government Regulation Sustainability Dimensions: Indicators under these dimensions are used to gauge the sustainability of installations against existing institutions and government policies. This is against the backdrop that such institutions and policies may determine the format to adopt for the deployment of the institution, the players that are active in the sector, the market structure etc., which may all influence the performance and economic feasibilities of such installations. In this regard, how the prevailing price of grid electricity renders solar PV technology attractive or otherwise is considered under *competitiveness of current energy market prices* while the existence of government policies that could lessen trade obstacles on PV solar technologies is considered under *availability of policies to reduce trade barriers.* The extent of activeness of foreign investors in the solar PV market is presented under *degree of foreign investments in solar PV market.* Likewise, a measure of the opportunity accorded private investors to participate in the sector is presented under *opportunity for private participation,* while the indicator *legal/regulatory frameworks to enhance the use of solar PV systems* will indicate the level existence and implementation of such frameworks that could boost the uptake of solar PV systems by the populace. The level of *availability of standard and codes and certification* will be evaluated against their existence while the *degree of regulation on use of local resources* will also be determined. The indices of the Institutional Development and Government Regulation indicators will be obtained from the documented evidences as encountered under status and issues of energy and water in Nigeria (see CHAPTER 3), evidences encountered during visits to locations of study and interactions with government official and private energy providers.

A list of the 38 indicators and the interpretation of the range of scores awarded them is provided in Table 4.4.

Table 4.4: Sustainability Dimensions and Indicators for Assessment and Evaluation

Indicators	**Interpretation of range of scores**	
Technical (10)	Poor	Good
Efficiency/Performance	High level of breakdown with poor electrical output	Low occurrence of breakdown and good electrical output
Availability of support infrastructures	Insignificant existence of technical and human support and services	High existence of technical and human support and services
Daily operation services	Insignificant daily operational measures	Significant daily operational measures

Availability of services	Low level of existence of operational services	High level of existence of operational services
Incremental capacity of the system	The installation cannot accommodate additional users	The installation can accommodate additional users
Lifespan of the system	Lifespan of 3 years and below	Lifespan of 7 years and above
Quality of supply	Poor quality of supply characterised by faults or breakdown	Good quality of supply void of faults or breakdown
Availability of local Skills	No local resident to provide basic maintenance services	Local residents available to provide basic maintenance services
Development of other infrastructures	Negligible contribution of the installation to the development of other infrastructures	Significant contribution of the installation to the development of other infrastructures
Practical technology choices.	Solar PV technology is impractical at the study location.	Solar technology is regarded suitable at a study location
Economic/Financial (10)		
Profitability	The installation is not profitable financially	The installation is financially profitable
Low costs for operation and maintenance	Low financial requirements for the running and operation	Significant financial requirements for the running and operation
Share of profit set aside for re-investment	Insignificant portion of the profit set aside for re-investment	Significant portion of the profit set aside for re-investment
Share of electricity/water consumed by businesses	Small magnitude of electricity/water consumed by businesses	Moderate share of electricity/water consumed by businesses
Business development	No or slight increase in businesses plainly attributed to availability of electricity	High increase in businesses plainly attributed to availability of electricity
Maximise Opportunities for productive applications	Low utilisation of electricity for other fruitful activities	High utilisation of electricity for other fruitful activities.
Least Cost Design	The cost of the solar PV installation is considered expensive	The cost of the solar PV installation is considered economical
Micro-credit financial incentives available to consumers	Non-existence or ineffective credit initiatives	Suitable and effective credit mechanism available
Explore opportunities for international co-financing	Low or insignificant level of international financial	Significant level of international financial support
Proper pricing and affordability of tariff	Low profit to energy producers; unaffordable by consumers	Highly profitable to energy producers, and highly unaffordable by consumers
Environmental Impact (3)		
Land requirement and acquisition	Difficult-to-obtain large size of land requirements	Easily obtainable small size of land requirements
Non-Interference with other utility infrastructures	Disturbs or negatively affects other infrastructures	Does not impact negatively on other existing infrastructures
Households where electricity/borehole water has replaced other sources	Small number of household where such replacement has taken place	Large number of household where such replacement has taken place
Social-Ethical Development (8)		
Public and political acceptance	No enthusiasm to replicate installation by government; low passion shown by users	High number of replication of installation; high level of passion manifested by users

Share of health centres and schools benefitting from installation	No health centre or school benefitting from installation	Health centres or schools benefitting from installation
Share of population with access to water/electricity	Insignificant number of population with access to water/electricity	Majority of population have access to water/electricity
Non-cultural conflict	The installation does not run against the culture/belief of the users in any known way	The installation runs contrary to the culture/belief of the users in some ways
Social equity in the deployment of RETs	High level of bias manifested in the deployment of an installation to a community	Absence of impartiality in the deployment of an installation to a community
Level of satisfaction with services	High level of disappointment and frustration shown by users	High level of satisfaction and pleasure shown by users
Awareness of users on potentials and limitations of the Technology	Absence or low level of knowledge of potentials and limitation by users	Substantial level of knowledge of potentials and limitation by users
Active participation of all stakeholders in the choice/ deployment of Installation	Many stakeholders did not participate in the choice/ deployment of Installation	Majority of stakeholders participated in the choice/ deployment of Installation
Institutional Development and Government Regulations (7)		
Competitiveness of current energy market prices	Cost of electricity from installation is remarkably higher than that from grid	Cost of electricity from installation is noticeably lower to that from grid electricity.
Availability of Policies to reduce Trade Barriers	No or insignificant number of policies on trade barrier reductions	Existence of a good number of policies on trade investment reductions
Degree of foreign investments in solar PV market	None or small number of foreign investors	Significant number of foreign investors
Opportunity for private participation	Absence of prospects of private investors' participation	Existence of prospects of private investors' participation
Legal/regulatory frameworks to enhance the use of solar PV systems	Non-existence or ineffective legal and /regulatory frameworks to improve solar PV systems uptake	Existence of a number of effective legal and /regulatory frameworks to improve solar PV systems uptake
Availability of standard and codes and certification	Standard and codes and certification not available or ineffective	Existence and implementation of standard and codes and certification
Regulation on use of local resources	No regulation on use of local resources	Existing regulation on use of local resources

4.3.7 Data Presentation and Analysis

To enhance analysis of data collected in the study, scores are allocated to the 38 indicators according to the degree of their incidence or presence in each of the study cases. This is similar to the approach adopted by Ilskog and Kjellström (2008) in which scores are awarded in accordance to the level reached by each study case in comparison with the other cases included in the study. However, unlike in Ilskog and Kjellström, the aim of this study goes beyond ranking of the study cases among themselves in order of their performances, but seeks to reveal underlying reasons for their (under)performances. Therefore, scores are allocated mainly on the basis of existence or absence of an indicator in each study case without necessarily ranking them relative to the degree of their presence in each of the other study cases. Furthermore, to make the allocation of scores more pragmatic and less subjective, a 4-level scoring system to categorise the existence or degree of incidence of an indicator is employed as “Low” (Poor), ‘Medium” (Average) and “High” (Good) which are respectively allotted numerical scores of “1”, “2” and “3”, while “0” is allotted when an indicator is absent whereas it is relevant/necessary for it to be present. As shown in Table 4.5, a score of ‘1’ is allocated to an indicator which is present or exists at a degree that is considered minimum. Similarly, a score of ‘2’ is awarded when the occurrence or existence level of an indicator is adjudged to be average – in-between minimum and maximum possible levels, while ‘3’ is awarded to an indicator which degree of existence is considered to be above average. The interpretation of scores as presented in Table 4.5 can be considered generic as the terms ‘minimum’, ‘average’, and ‘maximum’ may assume different meanings under each of the indicators based on the indexes a specific indicator expresses in a study case. For example, while the indicator “availability of support infrastructures” accesses the nature, type and effectiveness of both human and technical support services available against a benchmark that is considered essential for it in each of the study cases, the nature and type of such support services may not be same across all study cases. Similarly, the indicator “Business development” evaluates the number of businesses that has developed by virtue of the existence of the solar PV installation in each community. In this wise, while the development of one business enterprise due may be regarded as “High” in a very small community, this same number may be regarded as “Low” in a relatively larger community where more opportunities for such business development exists. This is contrary to the approach adopted by in Ilskog and Kjellström (2008) where scores range of 1 to 7 are allotted to each of the seven cases being analysed. Such allocation of scores, which is more of ranking and awarding positions to each study case, could be highly subjective and become cumbersome if a larger number of study cases are being considered. It is also noted that some of the indicators as listed in Table 4.4 - especially those under ‘Institutional Development/ Government Policies - may be considered as general indicators which impact equally across all study cases. Therefore, while their level of impact may be assessed, they may need not be allocated scores on case study-by-case study basis, but are discussed generally.

The cumulative scores and average scores obtained by each study cases under each of the five sustainability dimensions are obtained and explained in section 5.10, while further analysis and integration of the outcomes are integrated into the findings of the study in CHAPTER 6 .

Table 4.5: Interpretation of Scores

Level of Incidence	Numerical	Interpretation of Scores
Absent	Not Applicable (N/A)	N/A is awarded against an indicator that does not occur because it is not related or relevant in the context of the study.
	0	A score of ‘0’ is awarded against an indicator that does not occur or does not exist despite the possibility or necessity of such existence in the context of the study.
Low/Poor	1	The score is awarded to an indicator which is present or exists at a degree that is considered minimum.
Medium/Average	2	An average occurrence of an indicator is awarded a score of ‘2’. Such score will be given for an indicator which is adjudged to exist at an average level average.
High/Good	3	A high score of ‘3’ is awarded to an indicator whose degree of existence is considered to be above average level.

To further give credence to the outcomes of this study, additional analysis of data collected from the interviews and discussions held with the various stakeholders, and from the non-participant observation and evaluation of the RETs in the locations of study are carried out along with those from documented data as earlier reviewed. This is done by cross-referencing between data and evolving themes in the study cases in order to identify and correlate key themes that could contribute to the framework development. Specifically, the data were analysed to reveal the various process, factors and actors involved before, during and after the deployment of RET Installations to rural locations and how they may have contributed to the (under)performance of the installations in these places. While indicators that reflect some of these factors are already captured in Table 4.4, this approach may be regarded as using a checklist of requirements that are fundamental to the effective deployment and performance of installations and is therefore used to further evaluate and assess the study cases on a current theme basis. This is done in section 6.2.

4.4 Stages of the Methodology

The methodology adopted for this study involved various stages as shown in Figure 4.1.

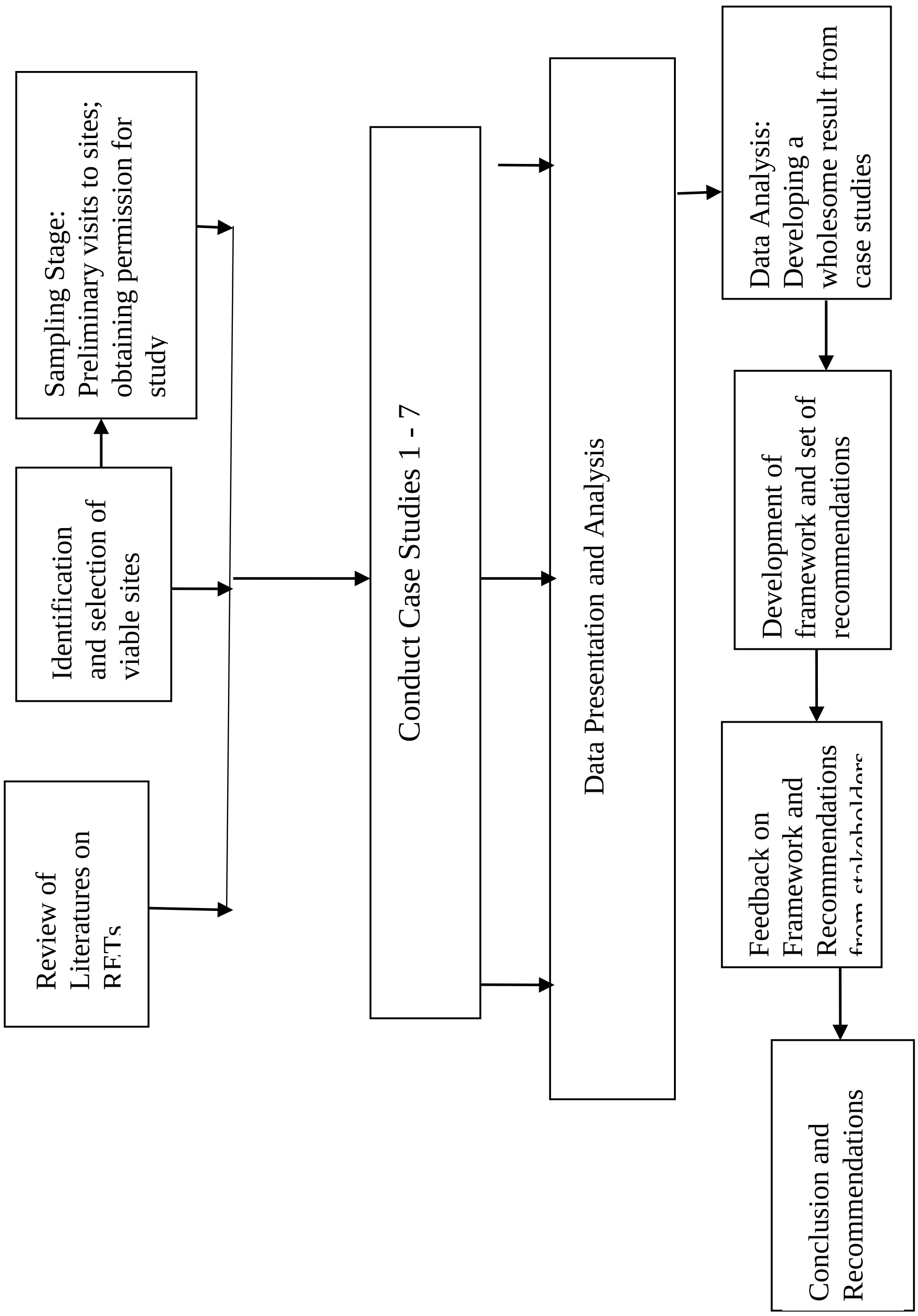

Figure 4.1: Outline of Stages of the Study

4.5 Ethical Considerations

In accordance with De Montfort University's policy on Research Ethics as contained in the 2013/2014 *Research Student Handbook* of the University, appropriate approval was sought and obtained from local authorities before the setting out to visit the locations to conduct the research (see Appendix 1). The interview participants were informed about the purpose of the study, how the information obtained will be used, what is required of them as participants, that their participation is voluntary and that they are not obliged to answer any questions they do not want to. In addition, while they were assured of the confidentiality of their identity, they were made to know that they could withdraw from the interview at any time.

The researcher treated the participants with respect and established a cordial but professional liaison with them, and showed appropriate care for their welfare. In one instance, on the behalf of one of the communities used for the study, the researcher made an official complaint about the non-functional condition of the installation in the community to the Ministry of Rural Affairs. This contributed to the respondents not having a 'hit and run' disposition towards the researcher. Greed (1990) explains this as a situation whereby the researcher is felt to have used the participants simply as a means to achieve his own end. Finally, the researcher ensured that he responded to all relevant inquiries and clarifications from the participants. Through these, their understanding of the functioning of the installation was enhanced while some of the unrealistic expectations and incorrect notions they had about the installation were addressed. This was especially the case during the interactions with the rural dwellers.

4.6 Chapter Summary

This chapter highlights the process of choosing the research methodology adopted for this study and underscores the necessity to align the methodology with the nature of the research. It therefore gives justification for choosing a Case Study approach for the study among a number of options, and highlights the process of identification and selection of locations to be used for the study. It further gives credence to the method of data collection, data presentation, and choice of assessment and evaluation method to be implemented in the study. In addition, the chapter considers how the framework will be developed from integrating the findings from the study cases. Finally, the chapter gives insights on the measures taken to ensure that the study is carried out within the ambit of ethical considerations as stipulated by De Montfort University.

CHAPTER 5 Results from Interviews and Case Studies

This chapter presents the results of interviews with stakeholders, and from case studies in seven isolated communities. The purpose of the interview sessions and case studies is to gain insights and obtain primary data with respect to deployment, diffusion and utilisation of RE installations. These are intended to inform the development of an improved framework for effective deployment, diffusion and utilisation of RE installations in the country.

5.1 Interview Sessions with Stakeholders

Interviews were held with a number of actors/stakeholders in the solar PV sector including government officials in the Ministry of Rural Development who are involved in the planning and award of renewable energy technology (RET) contracts, the Contractors and independent energy providers who carried out the installations of the solar PV systems, officials of a support-providing company, and the end users (rural dwellers) whom the installations are meant to benefit.

5.1.1 Interview Sessions with officials of Ministry of Rural Development

Two sessions of interviews were held with officials of the Ministry of Rural Development (MRD). This is the government agency responsible for the deployment and maintenance of RETs in rural locations. The first session was a brief informal discussion with two senior officials who are also engineers in the agency. However, due to constraints of time, another interview session was arranged. This lasted two hours and was a more formal meeting with the two engineers and two other technicians who are all involved in the deployment and installation of RE systems to rural locations in the state. The purpose of the interview sessions was to establish the procedural stages and factors involved in the deployment and maintenance of RETs to rural areas, the financial schemes available, the experiences of the personnel that have been involved in the installations, and to obtain any other relevant information as may come up during the course of the interview. A large part of the responses were given collectively by the two engineers since, as senior officials, they are more involved in both the technical and administrative running of the ministry. The interview process was recorded on paper because, as stated in section 4.3.5, the respondents were not receptive to audio recording of their responses. Some of the broad areas covered during the interview sessions are discussed below.

5.1.1.1 Deployment of RETs to Communities

During the interview sessions, the engineers explained that the MRD carries out periodical enlightenment of rural dwellers on the benefits of clean water, electricity and improved hygiene. Posters illustrating such benefits are also placed in community buildings such as the community health centres to keep such awareness alive in the mind-set of the dwellers. In addition, they stated that the Ministry also assesses the needs of settlements and the RE intervention that could be provided for them to improve their standard of living. Such assessments, they explained, are undertaken across all the local governments in the state to ensure an unbiased spread. Meanwhile, the MRD encourages rural communities in the same vicinity to constitute Community Development Associations (CDAs) which serve as their representative bodies in matters between them and the MRD such as making a request for a RET installations. A typical CDA is constituted of representatives of each of the communities overseen by it and is expected to make a payment of Five Thousand Naira (approximately £20) every year to the MRD. Towards this, CDAs are expected to raise such funds from their constituting communities.

A major issue that confronts the Ministry is the selection of the communities to have RET actually installed. This is because, at any point in time, there are usually a number of communities reckoned to be in need, and regarded eligible for such installations. However, according to one official, "the MRD lacks the financial capacity and workforce to achieve a 100% spread of RET installations to every rural community where such needs have been established at any given time". The officials explained that this is because "the MRD operates under an annual financial budgetary allocation which is determined by the government, and is normally inadequate to achieve such a purpose. In addition, they stated that the workforce required to meet the demands of the number of locations requiring RE installations far outweighs the capacity of the limited workforce of the Ministry.

On being asked about the decision process and course of actions involved in the deployment of RE installation to a community, the officials explained that apart from assessments carried out by the Ministry, the following are the means through which the MRD receives requests for a RET installation.

- **Notification of Request for RE Installation**

i. Requests made by communities through the Community Development Association (CDA).

ii. Philanthropy: A citizen donates the installation of a RET system to a community of his/her choice by providing the finance required. However, the technical and social viability of such installations in the community is firstly verified by the Ministry.

iii. Government Intervention: This may be the outcome of a visit of a senior government official such as the Governor of the state during a courtesy call, political campaign, outbreak of disease such as cholera etc. Upon being probed by the interviewer, the respondents conceded that deployment of RETs to communities could also be made to particular communities based on the political alignment of such communities. However, in order to avoid making such biased deployments obvious, and cause resentments among communities, they are mostly made under the guise of "Government Intervention". A typical case of such an installation allegedly deployed on the basis of the political alignment of a community is the solar PV installation at Ide II settlement; this is discussed in Section 5.4.

However, the officials emphasised that irrespective of the means through which a request for RET installation is received, further assessments of the communities are carried out to determine their suitability for the installation and availability of necessary infrastructures.

- **Assessment of Communities**

The respondents explained that the requests received through any of the means stated in previous section are further subjected to additional assessments by the MRD for evaluation and validation purposes as stated below.

i. To validate claims made by the community to support their request for RE installation, and other information as may be stated in the request letter. Claims based on population and geographical size, and current sources of energy/water as may be contained in the request letter are verified by MRD officials who are sent to the location.

ii. To determine the type of intervention that should be provided for the community. This is usually the provision of off-grid electricity or water systems access (or both) using solar PV systems.

iii. To determine the appropriate size (rating) of installation for the requirements of the community.

iv. To ensure that the community can provide or possess the necessary infrastructures as may be required for the installation. A major issue in this respect is the provision of an appropriately-sized parcel of land as may be needed for the installation in the event their request is granted. In view of the fact that land ownership is an important and, sometimes, sensitive issue in rural communities, such a parcel should neither belong to any family/clan nor should it be under any form of litigation or dispute. Where the land belongs to a family, they must be willing to give up such ownership. In addition, the piece of land should be appropriately located e.g., central within the community.

v. To ensure that the weather conditions of the location are ideal for the proposed installation. The officials explained that MRD mainly deploys solar energy-based electricity/water systems to isolated low-density rural locations as such installations could readily be employed to meet the low capacity water and energy requirements of such settlements. They added that over time, solar radiation readings have been taken for granted since the country is located in the tropics, hence, making solar installations generally appropriate.

- **Determination of type of RET Installation to be deployed**

Two types of systems are normally available; the micro-water scheme which is deployed to communities with populations above 5000, and the Solar Power Modified Type 'A' which is used for settlements with a population of less than 5,000. The officials explained that micro Water Schemes are deployed to major settlements and use grid electricity (where available) or diesel generators to pump water from bore-holes to large overhead tanks which supply the residents of such settlements. However, most isolated rural settlements do not have access to grid electricity, and are typically characterised by a small population and relatively low energy and water requirements, hence they are often deployed with the Modified Type 'A' installations. These are solar-powered water systems, thereby negating the necessity of fossil fuels and the related challenges that may be encountered in obtaining fuel in such isolated locations.

If the necessary conditions and infrastructures required for the deployment are in place, the process of awarding the contracts for the installation is initiated. The decision process, as explained by the officials, is depicted in **Figure** 5.1.

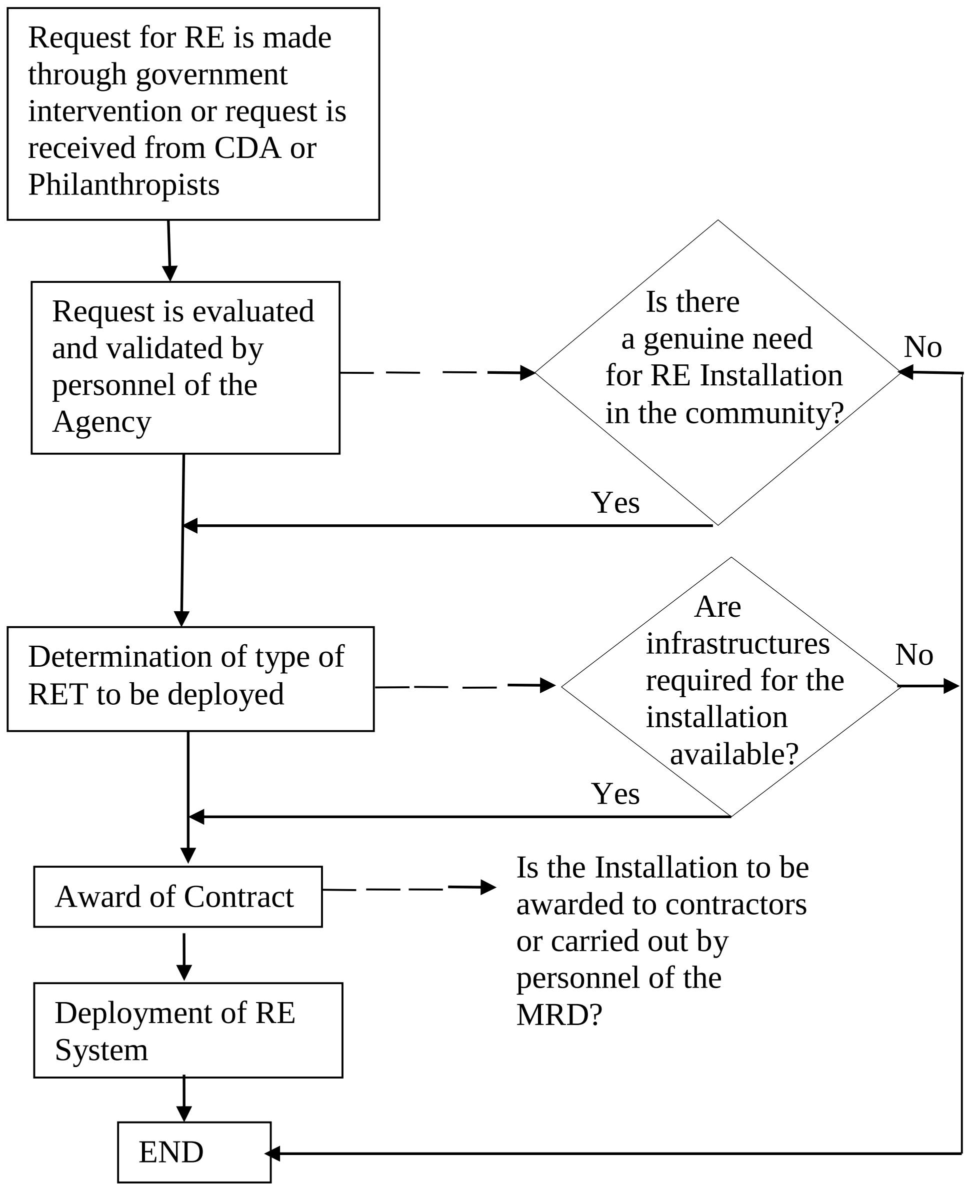

Figure 5.1: Decision diagram for RET deployment

5.1.1.2 Award of Contract

After the criteria for the deployment of RE installation have been met and the type of RET to be deployed determined, the officials explained that the MRD prepares a Bill of Quantities based on the required design and specifications of the installation. However, the actual award of contract is subject to availability of funds for the installation since the MRD, like other government agencies, have fixed budget allocation for capital expenditures in any fiscal year. The deployment of the system is either awarded to qualified competent contractors or carried out through Direct Labour by the staff of the Ministry. The respondents explained that in the earlier years of the MRD, most of the deployment of the installations were awarded to competent contractors. Under this arrangement, contractors that have been pre-qualified based on technical competences (type and scope of previous experience and expertise in providing related services) and staff strength are requested to submit bids for deployment of installations based on the specifications developed by the MRD. The contractor with the lowest financial bid is thereafter awarded the contract while staff of the MRD supervised the installation to ensure compliance to specifications and standards as indicated on the design. The officials further explained that this arrangement of awarding the installation to contractors was mostly adopted when the MRD had not developed the technical competences of its staff in the deployment of such installations.

However, over the years, the MRD has involved its personnel in various training and development programmes that were designed to endow them with the skills and expertise to effectively deploy the RET installations directly by themselves rather than awarding them to contractors. This, the officials explained, has further enhanced capacity building of the personnel of the MRD (as most of them are now able to install RET), and has also led to reduced cost of installation due to reduction or absence of profit and tax margins that would have been included by contractors. This is because the MRD is not a profit-oriented government organisation and, therefore, benefits from waived or reduced taxes. In this study, the RE installation in Ide was carried out in 2012 by the personnel of the MRD (see Figure 5.7), while the one in Ide II was awarded and carried out in 2009 by a contractor (see Figure 5.12).

5.1.1.3 Post Installation Procedures

On being asked about the processes involved after the completion of the installation, the officials explained that the MRD carries out the following:

a. Transfer of Ownership

Upon the completion of an installation, its ownership is handed over to the host community. This transfer of ownership is normally done publicly, usually during the commissioning of the installation and is backed with an official document which is handed over to the community head or the CDA (if such is in place). They further stated that the essence of this practise is to imbibe a sense of ownership on the community so as to provoke good operation and maintenance culture in them. However, realities on the ground often contradict this assertion as encountered in one of the study cases (Ide community) where the community dwellers retained the notion that the ownership of the installation in their community remained with the government even after such installation was being used by them. This and other related issues are discussed in more detail in sections 5.3 and 6.1.

b. Basic Operation and Maintenance of Installation

The officials revealed that after installation of the RE system in a community, the installers (i.e. personnel of the MRD or the contractor) trains some community members on basic operations of the installation. This would include how to carry out minor maintenance operations e.g., repair of broken taps. The targets for such training are men from the community they are considered more predisposed to handle such technical repairs as may be required. In addition, the communities are encouraged to constitute 'Water Committees' among their members. Such a committee is expected to coordinate the proper running of the installed system e.g. weekly/monthly contributions of small amounts of money that could be used for immediate repairs when such needs arise. The committees are also expected to liaise with the Community Development Association which, as highlighted in section 5.1.1.1, are made up of members of communities in the vicinity, and which, in turn, will contact the MRD in cases of major breakdown that are beyond the capability of those that have been trained locally.

However, as reported in section 5.2, findings from the case studies revealed that water committees do not exist in any of the two locations handled by the MRD that formed part of this study while lack of effective post installation maintenance remained a pressing issue. In addition, claims by the MRD officials that members of the host community are trained to carry out basic maintenance on the installation were refuted at Ide I and Sagbokoji settlements where the dwellers maintained that no member of the communities underwent such training with the installers and as such, none of them could carry out any repair on the installation (see sections 5.3.1 and 5.5.2). However, at Ide II, a member of the community was said to be able to carry out basic repairs on the installation although it could not be established if he was trained for this purpose by the installers. Nevertheless, a member of the community felt that the "endless fiddling" of this person on the installation contributed to its eventual breakdown. This is presented more fully in section 5.4.2.

c. Provision of Security

The MRD officials mentioned that the Ministry ensures that the installations are either fenced or barb-wired on completion to discourage unauthorised access which could compromise the operation. Such security measures are considered necessary because there have been previous complaints to the MRD where unauthorised persons have been alleged to have tampered with such installations thereby negatively affecting the performance (a case of this is encountered in Sagbokodji in section 5.5). To further ensure that members of the community do not have cause to loiter around the installations under the guise of accessing water from it, water taps are, in most cases, installed away from the systems. Furthermore, host communities are encouraged to provide additional security as may be considered necessary to ensure that the operation of the installations are not compromised by unauthorised persons. As highlighted in section 5.5.2, the provision of such local security arrangement by the community is only one of a number of interconnected factors that could enhance the overall performance of such installation.

Thus, according to the MRD officials, the basic stages involved in the deployment of a RET installation to a community by the Ministry can be summarised as follows.

- Request for installation is received by the Ministry of Rural Development (MRD) or a case of need is established by the MRD e.g. as an outcome of sensitization visits or outbreak of disease.

- A feasibility / viability study is carried out in the community
- Decision on type/size of system to be installed is taken
- Provision of a suitable piece of land by the benefiting community at no cost
- Contract is awarded to competent contractor OR carried out through direct labour by the MRD
- Installation of the RET system
- Training of some community members on basic maintenance procedures
- Formation of Water Committee by the host Community
- Transfer of ownership to the community
- Provision of Security by the host community

5.1.2 Discussion with Officers of the Lagos State Electricity Board (LSEB)

The Lagos State Electricity Board (LSEB) was established in 1980. It is the implementing agency under the Lagos State Ministry of Energy and Mineral Resources (MEMR) responsible for Energy Development, Independent Power Projects, and Public Lighting for Lagos State. Hence, solar street lighting implementations fall under the purview of the Board. One interview session was held with two officers (an energy engineer and another senior official) of the agency. While this study focuses more on rural areas, it was thought necessary to find out the reasons behind the failed attempt by the state government to use solar to power streetlights in some parts of the state. As highlighted in section 3.3.1, this failure necessitated the state government to resort to the present method of using large diesel-run electric generators to power streetlights on major roads in the state despite the noise and exhaust pollutions associated with the method. The interview with the officers of the LSEB was undertaken with a view to establish if there is a correlation between the inhibiting factors in the deployment and performance of RE installations to urban and rural locations in the state, and to find out if there are practices being applied by the LESB that can introduced into the MRD deployment process towards achieving improved performance of systems in rural communities.

The officers were asked whether they were “aware of the many failed streetlight projects in the state?” To this, they answered in the affirmative but added that, “the LSEB is taking appropriate steps to correct the damaged reputation caused by the underperformances and subsequent failures of many streetlights projects in the state". When asked the reasons for the underperformance of the installations, the officers suggested the failures were due to a myriad of factors including a dearth of qualified contractors, poor design, lack of standardization and inadequate maintenance. They explained "the LSEB recently developed a set of criteria and standards for solar installations and this contains the specifications of all the accessories for the installation as well as standard practices to be adhered to by both contractors and end users". They further stated that prospective contractors for solar projects in the State are expected to meet stringent pre-qualification criteria set out by the board. In addition, the officers explained that although the LSEB has been in existence for some time, it was not until recently that the state government put the Board in charge of Solar PV streetlights in the state; the initial failed ones having been handled by the Ministry of Science and Technology.

When asked for the rationale behind the present approach of the state government of using diesel generators to power streetlights in major highways in the state, the officers conceded that the government resorted to this course of action because of the earlier failed attempts to use solar PV to power the streetlights. This option, they stated, "has a higher long term cost implication than using solar". In addition, they stated, "we believe this option will be dropped by the state government as soon as the LSEB could further prove the reliability of using solar energy to power the streetlight". Towards achieving this, they explained that the LSEB has presently embarked on a pilot scheme to prove the feasibility, reliability and other inherent advantages of solar streetlight technology by using the new criteria and standards to install the technology on a major street in Lagos Island, noting that the LSEB believes that through a robust design and careful supervision, solar streetlights can play a pivotal role in improving the street lighting issue in the state. In carrying out the pilot programme, 30 contractors were shortlisted to 3 by independent reviewers engaged by the LSEB who systematically assessed each company's technical capabilities using a distinct matrix of definitive criteria to primarily assess the robustness of each technical design, sustainability of the system, maintenance and after-sales service. Though presently on-going, the project involves a performance and cost analysis comparison of the solar streetlights with the conventional street lights being presently powered by diesel generators. The project, they said, is expected to highlight the capabilities, effectiveness, and efficiency of solar streetlights technology over the diesel generator approach. It is hoped that highlighting such improved performance and cost indices of the solar streetlight would help to revive the government's diminished confidence in its use and lead to its being re-adopted as a credible way of improving the streetlight issue in the state.

A deduction from the discussion with the LSEB officials is that some factors relating to the performance of solar PV installations are independent of the location where the installations are being deployed, hence measures taken to mitigate such factors in the urban areas may be introduced into the rural areas' deployment process. Conversely, some factors could come up as location-dependent as seen in the case of benefiting rural communities being encouraged to provide additional local security measures for RE installations as highlighted by the MRD officials in section 5.1.1.3, which is often not an issue of concern in urban areas. These and other related factors are further explored in the case studies in section 5.2 and consequently incorporated into the framework for effective deployment of RE installations to local communities as presented in Figure 6.4.

5.1.3 Discussion with Contractors

In a discussion held with one of the contractors that deployed the RET installation at one of the rural study locations (Ide II), it was confirmed that the contract for the installation was awarded by the Ministry of Science and Technology (MST) through a process of competitive bidding. This was in 2006 but the award of the contract took place in 2008. The contractor stated that the deployed system was meant to serve the community by providing power to the streetlights, the water pumping system, and the village hall. He further affirmed that the MST did not enter into any contractual arrangement with his company relating to installation maintenance. However, when asked if he was aware that problems started only a few months after installation, he claimed that "when information about the incessant breakdown of the installed system got to our knowledge, the independent investigation we carried out revealed that some of the residents 'tapped' electricity from the streetlights to their homes, thereby overloading the system". Some members of the community also insinuated that cases of sabotage by residents from neighbouring settlements contributed to the recurring faults. The contractor further explained that unofficial reports he obtained from a technician with the Ministry of

Science and Technology (MST) corroborated his findings as the technician stated that investigations carried out by the MST revealed that some villagers illegally ‘tapped’ electricity from the installation into their homes from wires running by their buildings. He further stated that wires were found cut indiscriminately at various parts of the settlement. When asked for the reasons why the villager may have embarked on such illegal acts, the contractor explained that it was more of a case of disobedience rather than ignorance since the villagers were informed by the deploying ministry that the installation is meant to supply the designated places in their community, and not their individual homes.

However, when the village head was presented with these claims during the case study visit to the settlement as detailed in section 5.5.2, he did not refute them but maintained the claims remained unsubstantiated. He also reiterated that cases of sabotage by unknown persons contributed to the final breakdown of the installation. These issues are further highlighted in the case studies section and discussed more in-depth in CHAPTER 6

5.1.4 Discussion with Energy Providers

Interview sessions were held with officers of two independent companies ‘Arnergy Solar Limited’ and ‘GVE Projects Limited’ that installed the PV installation in three of the study cases. While the former installed the system in Onibambu community (see 5.7), the latter installed the ones at Umuagwu and Umuode communities as presented in sections 5.8 and 5.9 respectively. After many failed attempts to arrange a face-to-face interview, it was mutually resorted to have the interview session involving Arnergy Solar Limited as a phone interview.

i. Discussion with Arnergy Solar Limited

A phone interview was arranged with a co-founder of Arnergy Solar Limited in April 2016. During the interview, the officer explained that the installations being deployed by the company in conjunction with the Bank of Industries (BoI) are pilot projects and their success or otherwise may determine future support from the Bank. When asked how the communities Onibambu/Idi-Ata were chosen for the installation, since a number of other communities must have met the selection criteria, he explained that BoI normally requests them to submit the names of three communities which meet their selection criteria. The

BoI makes a further appraisal and takes the final decision on the community to have the installation. He stated that apart from being typical isolated communities, such communities must also possess signs of commercial viabilities in which case small commercial ventures must be able to thrive, while the dwellers must indicate a willingness to pay for electricity. He further stated that in the case of the proposal submitted by his company, the BoI recommended Onibambu and Idi-Ata communities, which are two isolated rural communities that are about 1km apart, and could therefore be supplied by a single solar PV installation. Additionally, Onibambu community had small commercial shops that could grow their businesses on the availability of electricity, while the residents of the two communities expressed willingness to pay their bills when electricity is provided for them. On typical pre-installation land related issues faced in rural locations, the energy provider explained that though the installation is situated in a border land that is approximately halfway between the two communities, it is actually owned by Onibambu community. He further stated that the land was purchased from the community at reduced price and the processes of the transaction were appropriately documented.

Additionally, he stated that although the installation is rated 37.8kW, the assessed load demand of all lighting and household equipment including refrigerators in the two communities is slightly over 20kW. Hence lately, small-scale businesses such as welders, are in the process of being connected to the supply. While the interviewee was unwilling to reveal the specific tariff being implemented, he noted that the cost of the installation will be covered by the tariff plan over a 15-year period. He further stated that when they eventually get connected, business enterprises will be charged a slightly higher rate than residential homes

On post-installation issues, the officer explained that the company has put in place a three-tier post-installation arrangement to provide repair and maintenance services for the installation and the consumers. The 1st tier is provided by the three-man energy committee headed by a young man who is also in charge of the day-to day operations of the installation, and also acts as the contact between the locals and the personnel of the energy providing company. The 2nd tier is provided through an arrangement with technical personnel who reside in nearby towns and could, therefore, get to site within a day of a fault occurring. The 3rd is provided by the personnel of the company head office in Lagos state in conjunction with their technical partners. He said mobilisation in the case of any serious fault could take place as soon as the day following the occurrence of the fault. While the officer stated that they have not had any case of sabotage, they had recorded a major fault in which a faulty inverter had to be eventually replaced by their technical partner.

ii. Discussion with GVE Projects Limited

The discussion with the Chief Executive officer of another Energy Providing Company GVE Project Mr Ifeanyi Orejaka was held in two parts. The first part was held in May 2016 in Accra, Ghana and the second part in Port Harcourt, Nigeria in June 2016. During the interviews, the respondent stated that his company has deployed a number of solar PV installations from grants obtained from both international and local donor organisations. Specifically, he mentioned the Institute of Electrical and Electronics Engineers (IEEE), Smart Village, and Bank of Industry as funders. He further stated that their business plan/contractual agreement involves a three-layer arrangement for maintenance and repairs in which trained local hands provide a 1st layer for minor faults; the company's engineers provide a 2nd layer for more complex issues which the locally trained hands could not handle while, by virtue of after-sales Warranty/Contractual Agreement with renowned companies such as Schneider Electric (Nigeria) from which major equipment such as inverters are sourced, a 3rd layer maintenance platform for faults beyond the capacity of the company's engineers are handled by such companies. This, he said, has proved effective in resolving faults whenever they arise. The outlay of the business structure of the company for the deployment of a typical PV solar installation to a rural community is shown in Figure 5.2.

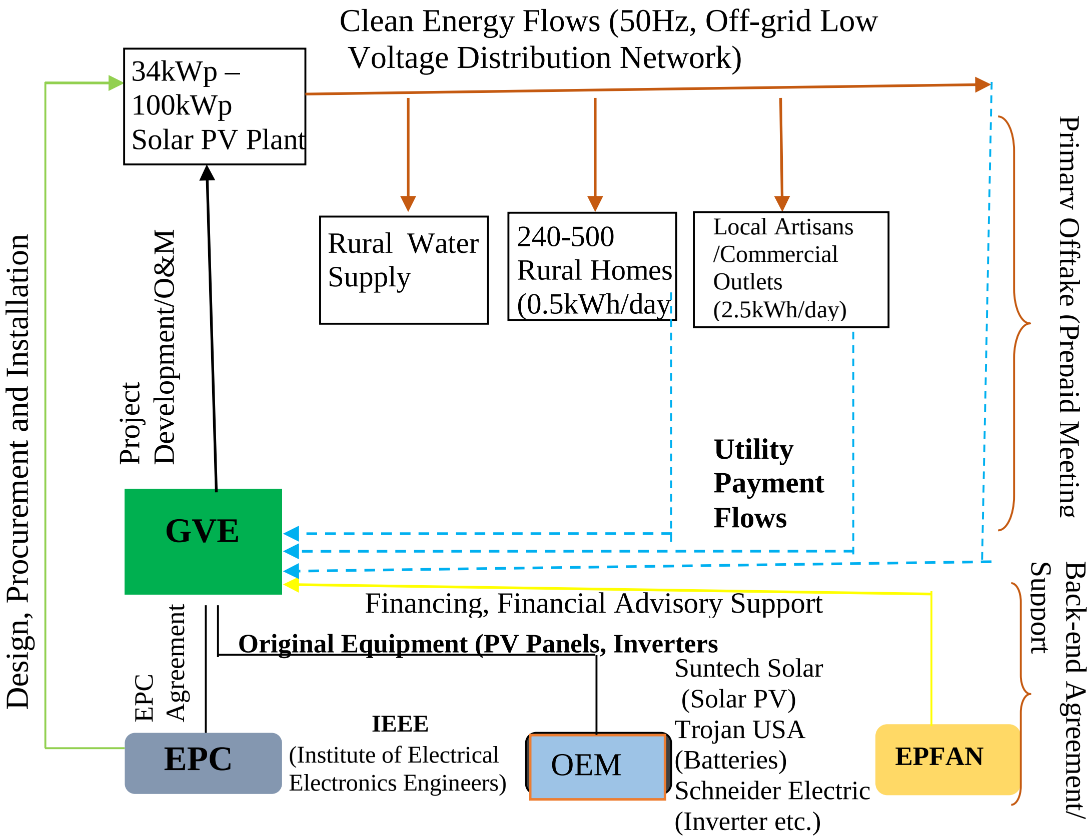

Figure 5.2: Business Structure of GVE Projects Limited

On issues relating to the vandalism of installations, he stated that his company has not experienced such occurrence in any of their installation sites but clarified that the manner of land acquisition and creation of pre-installation rapport with the community could discourage the likelihood of occurrence of such acts. In addition, he stated that although the communities are encouraged to provide local security to discourage such actions, the company takes out comprehensive insurance policies on their installations which, though add to costs, limit their risks. Furthermore while electricity provision to each household is billed, streetlights are installed and powered freely by the company as a form of Corporate Social Responsibility (CSR) to the communities.

On major challenges faces by contractors and entrepreneurs in the RE sector, the Chief Executive stated that a main factor is for the role of Government to be limited to providing an enabling business environment and not necessarily getting directly involved in the provision of energy services to the people. He specifically noted that while government presently provides an import duty waiver (in which tax and duty concessions is granted) on solar panels only, such waiver needs be extended to other solar PV installation components like the Inverter, charge controller and batteries as this could further contribute to the reduction in the installation cost of solar PV systems.

5.1.5 Interview with Technical Partners to Energy Providers

An additional interview session was held with a Business Development Executive of Schneider Nigeria Ltd in March 2016 during which it was stated that Schneider has established tested experience globally and has deployed over 5GW solar installations around the world. He noted that a major shortcoming of the solar PV market in the country is the use of sub-standard equipment, saying Schneider invests much on research and development to ensure that their products can stand the test of time.

In the same vein, he attributed the failings of batteries as one of the major reasons why many solar installations, especially solar street lights, do not last beyond a few weeks of installation. He noted that installing batteries on top of poles at temperatures that are mostly above 30’C has the tendency to damage such batteries. He added that Schneider has developed a miniature battery arrangement that that can withstand temperatures of 40^{o}C and last for upwards 10 years upwards when used on solar-powered streetlight. In addition, the executive noted that whereas conventional solar street lights may be targets of acts of vandalism since the solar Panel or battery can be used for other purposes, Schneider has developed and deployed a design where the solar panel, battery, control circuit comes as a single enclosed module which, apart from being more compact, could not be put to other uses.

To substantiate his notion that the use of sub-standards components is a major cause of failure, the official recounted a solar PV project handled by Schneider, and which was to be deployed using their products. However, due to the intense pressure being mounted on them to meet the project deadline coupled to an unanticipated delay in the arrival of their products which were being shipped from outside the country, locally sourced component parts were used for the installation. Nevertheless, barely 3 months after the installation was commissioned, it malfunctioned due to failure of the components. These eventually had to be replaced with Schneider’s high performing products (which had arrived by then) and resulted to an improved performance of the installation. In addition, the officer further noted that although it may appear that Schneider products are relatively expensive compared to other brands, their superior performances have gradually led to their being used in a number of solar installations across the country.

He also explained that a solution normally adopted by his organisation is to train partner companies who ‘buy’ the rights of the projects from them upon being deployed. Such partner companies are thereafter responsible for the maintenance of the project, and also put in place subsidised tariff structure for the dwellers. Finally, he noted that during deployment to rural communities, local members are normally trained for the purpose of carrying out basic maintenance procedures but a persistent challenge encountered is that of the trained members later on migrating to urban locations without training anyone in their stead.

5.1.6 Discussion on Interviews with Stakeholders

The discussions with various stakeholders as presented above bring out a number issues. It highlights the decision process implemented by the MRD in deploying RE installations to rural communities as well as other pre and post deployment procedures. It was however learnt that these are not rigidly adhered to. In addition, suggestions on the common causes for the underperformances and failures of RE installations were provided to include poor design, lack of standardization and inadequate maintenance and unlawful practices by local users. In addition, it was noted that government agencies hardly include post-installation maintenance arrangements in contractors’ contractual agreement. Private energy producers provided insights on existing tripartite collaborations between them, government agencies and international donor organisations in the deployment of solar PV installations on commercial business models. They further suggested that rather than getting directly involved in the provision of energy services to the people, the role of government should be limited to providing an enabling business environment and provision of import duty waiver on solar panels and other accessories.

5.2 Study Cases

As mentioned in sections 4.3.2 and Table 4.1, seven rural settlements: Ide I, Ide II, Sagbokoji, Asore, Onibambu, Umuagwu and Umuode villages are used as study locations in this research work. The locations, with the exception of Asore community, are typical remotely-located rural communities characterised by difficult topography, low population density, absence of industrial loads, and with low probability of grid extension in the immediate future. The locations also present a mix of failed, partly successful and successful cases of solar PV installations that ensures a balanced study of solar PV installations in Nigeria.

An initial visit was made to access and assess each location and to notify the local council of the intent to carry out the study. In the case of Ide I and Ide II, notification for the study was made to the local government office under which jurisdiction the communities belong. This was by means of a formal letter of "Notification of Field Study and Data Collection" to the Local Government Authority highlighting the aim and objectives of the study, and assuring that the purpose of the study is devoid of tribal, religious, or political undertones (see Appendix). However, at the local government office under which Sagbokoji Village falls, a formal notification for the study was deemed not necessary by the council officials, and a verbal approval to carry out the study was given. Thereafter, for the purpose of evaluation, assessment, and interviews, the various locations were visited between once and four times over a period of five years (2011 - 2016) as indicated on Table 4.1, with a visit to each of the locations lasting between 3 to 10 hours. Two of the case villages Umuagwu and Umuode villages are located in the often turbulent Niger delta region of the country and would, ordinarily, not have been included as part of the study for safety reasons. However, the visits were facilitated by an officer of the Energy Company that installed the solar PV installations in the two villages and had good relations with the villagers. This further enhanced the participation of the people of the communities.

The details of the visits to each of the study cases are presented in the following sections.

5.3 Ide I Village

Ide I (also referred to as Ide Nla) village is the major village in congregation with a group of smaller villages located by the Lagos lagoon in Ibeju-Lekki Local Government of Lagos State. The Lagos lagoon is a body of water that flows through the heart of Lagos metropolis and into the Atlantic Ocean. The settlement is accessed by using a paddled canoe to cross the lagoon from a jetty located in another settlement called Sherawon. While Sherawon and other settlements around it are supplied with grid electricity, all the villages located *after* crossing the lagoon have no such access. The probable reason for this is the high cost to transfer power across the lagoon to the low-income earners in the sparsely populated settlements on the other side of the lagoon.

The settlement has one Health Post and one Elementary School (Figure 5.3) which serve the adjoining villages as well.

Figure 5.3: The Health Post and Elementary School at Ide I Village

At the early part of this study, there was no RE installation in this location; the health post has a government-provided borehole which utilises a gasoline-powered generator for pumping while the Elementary school also has a similar installation.

However, during the course of this research study, the state government, through one of her agencies - the Ministry of Rural Development - installed a solar-powered water system (Figure 5.4) for the community in May, 2012.

Figure 5.4: Community Solar Water Installation at Ide I Village

Prior to this installation, a community well has been the main source of (unhygienic) water for the dwellers. Water is abstracted from this hand-dug well by the 'bucket & rope' method where a rope is tied to the handle of the bucket which is let down into the well to collect water before being pulled out. During the visit, it was observed that the collection of water from the well, which requires a level of physical strength to raise the bucket of water out of it, was being mainly carried out by women and children. This may be rooted in deep-seated beliefs that are prevalent in many rural locations of developing countries, where the female gender carries out most of the daily chores such as water and wood collection, and are not encouraged to participate in many educational, socio-cultural, and income-generating activities (see Maldonado and Gonzalez-Vega, 2008 and Baguma et al., 2013). In addition, the well does not have a cover slab to prevent ingress of contaminants. However, members of the community occasionally have opportunities to obtain water from a borehole in the Elementary school which, like the one at the Health Centre, runs on a gasoline generator. Such opportunities arise when the school management gets monetary allocation from the government for the purchase of fuel to be used to pump water from the borehole.

Hence, whereas two separate water borehole systems exist in the community; one each at the Health Centre and the Elementary school, the two boreholes only provided water for the community infrequently due to the persistent challenge of not being able obtain gasoline to run the generator for their operations. In addition, although the two boreholes are within the community, they are installed primarily to meet the respective water needs of the health centre and the community school, and are, therefore, not under the exclusive control of the community. Thus, the purpose of the solar-powered water system installation in the community is to alleviate the prevailing challenges being experienced by the residents in accessing clean water by providing a water system that belongs to them, and one that does not require gasoline for its operation unlike the two existing ones. The recent installation is designed to pump water to two overhead tanks that feed the community through five water tap outlets that are located at strategic points in the village.

During the course of this study, five visits were made to this location between 2011 and 2016; the reports of which are given below.

5.3.1 1st Visit

The first visit was made to the location to appraise the settlement and obtain appropriate permission from the local authority. As stated in section 5.2, at the onset of the visits, audience was sought with the village head to explain the purpose of the exercise and to seek his cooperation. However, when informed that the community head was not available, the community elementary school was approached and the purpose of the study was explained to the head teacher and some members of the teaching staff. The head teacher thereafter delegated a member of the teaching staff along with two members of the community who are non-teaching staff of the elementary school to accompany the interviewer to the village, to introduce him to the villagers, and to request their participation in the assessment and interview sessions. This measure ensured active participation of the dwellers in the interview sessions during the subsequent visits made to the community.

5.3.2 2nd Visit

The second visits (November 2011) was made *before* the solar- powered water system was installed in the community by MRD. During this visit, which lasted over 5 hours, the researcher observed the activities of the dwellers with respect to how they access and use water and electricity, and engaged some of them in informal chats and discussions. During this visit, the general response among the villagers to the enquiry ‘What do you consider as your greatest need in the village?” or “What is the foremost provision the community desires from the government?" was "water", "clean water". After water, the respondents regarded the provision of electricity as the next most important need. This, they explained, is because they consider water and electricity as basic necessities which could improve the standard of lives in the community. They also pointed to the fact that "even a smaller village next to ours has a government-provided water system". This was in reference to Ide II village which already had an existing government solar water system installed 2 years earlier.

At the community Health Centre, a female member of the community who acts as a medical assistant attended to the inquiries of the researcher. Responding to an inquiry on how the Health Centre is being supplied with energy, she explained that there is a 6.5kVA gasoline-powered generator that pumps water from the bore-hole and provides electricity for the health post during the working hours. "However", she added,

> *"getting the gasoline required to power the generator has always been a problem most of the times due to failure of the local government authority to provide the money required for the procurement of gasoline".*

Even when such allocations are available, the process of obtaining fuel is usually daunting as the nearest fuel station is located in a major town at the other side of the lagoon. Hence, obtaining fuel requires crossing the lagoon. She further explained that whenever the generator breaks down, repairs usually take a long time as there is no technician that can handle such repairs in the village. She added,

> *"Sometimes when we succeed in getting a technician from town, obtaining the funds from the health agency to carry out such repairs takes time"*.

On being probed about why the patients could not make the money required for the fuelling and maintenance of the generator available, she explained that the patients often lack the financial ability to sustain such an undertaking.

The villagers explained that although a few of them have small gasoline-run electricity generators which on few occasions are used to supply electricity to individual household at night, most of them depend on glass-covered kerosene lanterns for lighting purposes while, they carry out their cooking activities using fire wood. However, when moving round the village in the process of conducting the interviews, it was observed that a generator was running in one of the buildings in the daytime. Closer observations and further enquiries from residents revealed that the owner of the generator runs a semi-commercial venture where residents pay a token to charge their phones whenever he puts on his generator during the daytime, which he does for a few hours about twice a week.

On the issue of water supply, it was observed that women were the ones mostly engaged in collecting water from the village well, while a number of them did their laundry by the lagoon banks at the outskirt of the settlement. When a woman was asked why many of them do their laundry by the lagoon banks rather than in the village using water drawn from the well, she explained, "having our laundries done by the lagoon banks is less energy-demanding than having to first collect water from the village well for the purpose". She further explained that they have access to unlimited volume of water by the lagoon relative to when their laundry is done within the village. "Hence", she finally stated, "while most of us collect water from the village well for cooking purposes, we prefer to come down to the lagoon banks to do our laundries"

At the elementary school in the community, similar challenges to the health centre were highlighted with respect to the non-availability of funds to purchase gasoline for the borehole system. One of the teachers explained that

> *"whenever there is allocation for gasoline from the funds released to us by the government, we pump water for the children, and the community members also come around to fetch water. However, most of the time, the taps are dry"* (Figure 5.5).

The teacher suggested that they do not have the funds to purchase the fuel to pump water from the borehole, thereby leading to 'dry' water taps.

Figure 5.5: Dry Taps at the Elementary School

Taking over from the teacher, the head teacher stated,

> *"… however, the greatest need of the school at the moment is the refurbishment of the dilapidated buildings, especially the staff buildings"* (Figure 5.6). He explained that *"the school authority has made several efforts over the past two years to get the government agency in charge to carry out necessary repairs on the buildings, but response from them has been slow in coming"*.

Figure 5.6 : Dilapidated Staff Office Buildings

5.3.3 3rd Visit

The third visit to the community was made in November 2012, some six months *after* the installation of the solar-powered system (Figure 5.7) in the community by the village by the Ministry of Rural Development (MRD) as stated in section 5.4.1. During this visit, the residents explained that the installation was carried out directly by the MRD. They further stated that, apart for providing a suitable piece of land for the solar PV system, the community also provided the labour during the installation. In responding to enquiries on how the installation has affected them, the villagers were unanimous in acknowledging that the installation has affected them positively. “It’s a life changer!” one of them exclaimed excitedly, while they all chorused, “we now get clean water from the taps!”

Figure 5.7: Installation at Ide I

However, a major complaint of many of the respondents was the inability to get water from the taps at ‘all times’. They explained that whenever they attempt to obtain water in the late evening/early morning, “we find that the taps are not running”. However, on being asked if they were not aware that solar water systems may not provide water for them continuously throughout the day due to the intermittency of solar radiation, they conceded that upon the completion of the installation, the installers intimated as much.

However, upon getting to the location of the installation, a noticeable feature was a large pool of water formed around it. After taking a closer look, it was observed that the water was leaking from the surface pump of the installation (Figure 5.8). When inquired from two of the villagers who reside nearby, they explained that the installation started having problems barely 3 months after it was installed. On what caused the problems, they replied that none of them is aware of the cause of the fault as “we simply got to the installation one afternoon and found that water was leaking from it". A respondent added that "the leakage did not appear a serious problem initially. However, a pool of water recently got formed around the installation, as the fault has not been attended to".

Figure 5.8: Leaking Surface Pump at Ide I Village

Upon enquiring why the community has not fixed the problem, some respondents stated that no one in the community is equipped with the ability/knowledge to carry out repairs on the installation, and that nobody was trained by the installers for such purpose. To this, some of them added, "We were instructed by the installers not to go near the installation". When asked about the steps that have been taken by the community to have the fault repaired, they replied that they had a contact in the Ministry of Rural Development (the installers) who they contacted by phone about the situation, but while they were assured that a technician will be sent down to carry out the repair 'very soon' there was no assurance of the exact day. "Meanwhile", they added, "we were further admonished by the person not to go near the installation out of concern or worry we may have due to the leaking pump" A final enquiry made during this visit was on the issue of security, in which a male member of the community was asked about the local security arrangements put in place by the community to ensure that the installation is not tampered with by unknown or unqualified persons at any time. To this, he responded that the barb-wire fencing serves as the only form of protection for the installation, explaining further that cases of theft, vandalism and related acts of sabotages are uncommon in the neighbourhood.

5.3.4 4th Visit

The 4th visit to the community was made about 9 months after the preceding one and was primarily meant to appraise the condition of the installation since the last visit. Therefore, the first point of call was the location of installation where it was found out that the water leakage fault had been rectified, and that the installation was functioning properly. Upon making enquiries on how the fault was rectified, one of the residents stated that “when the person (technician) sent by the installers (i.e. MRD) initially came around, he appraised the fault and explained to them that he did not have the right tools with him to rectify the fault and will, therefore, have to come back another time”. It was learnt that it took the technician over 1 week before he came to rectify the fault eventually. Overall, it took over 4 weeks between the time the case of the leaking surface pump was reported to the installers and when it was repaired.

While moving around the community, the opinions of many of the residents were sought on the benefits and ownership of the installation. Many of them acknowledged that the installation had remained functional over time and that the community had benefitted from it by having access clean water. They however complained however that ‘many’ of the water outlets around the village are blocked. Upon investigation by the researcher, it was found out that three of the five taps located at various points in the community were blocked (although the probable cause of the blockage could not be established), hence the dwellers could only access water through the two functional taps. Some respondents were of the view that the large distance between the installation and the taps may have caused the blockage and, therefore, suggested that the challenge of blocked water taps could be overcome if the taps were located closer to the solar water installation. This, they reasoned, will reduce the distance between the installation and the tap outlets and the likelihood of the taps being blocked. When it was brought to their notice that this would mean they will have to move down to the installation (which is located at one end of the village) for them to get water, the respondents regarded this as a small inconvenience if it can improve their access to clean water. When questioned about the ownership of the installation, many of the respondents answered that, although it is located within their community, its ownership remained with the government and not with the community. They asserted that the ownership of the installation was never transferred to the community.

Lastly, a stop at the elementary school during this visit revealed that extensive and partial refurbishments had recently been carried out on the classroom block and the staff building respectively, as shown in Figure 5.9. In addition, although the refurbishment were carried out in 2013, they were labelled ‘2011 project’ – an indication that they were carried out from the budgetary allocations of the year 2011.

Figure 5.9: Refurbished Classroom block and the staff building

5.3.5 Follow-up Visit (2016)

A follow-up visit was made to this community on 30th June 2016 during which, rather surprisingly, the solar water installation in the community was found to have stopped functioning and the site of the installation was looking neglected and abandoned, with weeds gradually taking over. Appearing rather dejected over the situation, members of the community interviewed explained that the installation ‘stopped working’ over two years ago. They recounted the failed efforts that have been made in trying to get government officials to have the installation repaired. One of such respondents explained that the community has called them on phone several times but they neither showed up to appraise the fault nor to repair it. When asked how they presently access water for drinking, they explained that they have been left with no choice but to resort to the village well for drinking and cooking water. While the exact nature of the fault could not be established, none of the components of the installation appeared missing. However, the fact that the installation has remained in an unused state for some time was obvious from its forlorn appearance.

5.3.6 Case Discussions

The various visits made to this community bring out a number of issues and situations. From the 1st and 2nd visits, water and energy poverty were evident as is the case in many rural locations in sub-Sahara Africa in general (see CHAPTER 2 . The visits further revealed village wells and streams and lagoon banks as common unhygienic sources of water in the absence of improved sources and also highlight some prevailing challenges in the effective operation and maintenance of water and energy installations in such locations. These include obtaining funds for fuel, and, oftentimes, getting fuel when funds are available. Related to these are challenges faced in getting qualified personnel for repairs for generators. These problems could be avoided by the installation of systems that would be relatively less dependent (or independent) on fossil fuel, and which would also require less maintenance/repairs. As highlighted in section 2.2, solar installations are characterised by these features. In addition, interactions with the staff members of the community school suggested that government does not always provide the necessary funds to support the effective operation and performance of installed water systems in the community, thereby limiting the positive impacts such installations could have on the people. Also, the statement of the head teacher that *the school authority has made several efforts over the past two years to get the government agency in charge to carry out necessary repairs on the buildings, but response from them has been slow in coming,* is an indication that the absence of fast and effective response and service delivery by the government is not peculiar to water installations only. Finally, the fact that the villagers pay small amounts of money to have their phones charged may be regarded as an indication that they may not mind paying to have improved water and energy sources.

The information gathered from the 3rd visit revealed that the community contributed to the installation of the solar water systems by providing a suitable piece of land for its installation in addition to providing the labour that was used to carry out the installation works. The former agrees with the pre-installation assessment requirement that must be available before such systems are installed as stated by the MRD officials in section

5.1.1.1. In addition, it was found that although the impact of the installation on the residents of the community has been positive as it actually meets some of the water requirements of the people, not being able to get water from the taps at 'all times' could be as result of partial understanding of the limitations and working mechanism of the installation which occasioned their desire to have access to water from the installation at all times. A means of achieving this may be to appropriately increase the capacity/rating of the installation, but as highlighted in 5.1.1.1, this may not conform to the prescribed standards of the supervising agency, which in this case is the Ministry of Rural Affairs. In addition, the visit also revealed that the installation developed a water leakage fault barely 3 months after it was installed. However, while this appeared a relatively simple fault, no member of the community could (attempt to) rectify it, since the residents claimed that none of them was trained by the installers for that purpose. This is seen to contradict the assertion of the MRD officials as stated in section 5.1.1.3 to the effect that some community members are normally trained on basic operation and maintenance after the completion of such installation. Finally, with regard to the provision of local security for the installation, it was observed that although such an arrangement was not in place in the community, there was no incident of alleged or recorded case of sabotage on the installation.

"Excessive bureaucratic procedures" was mentioned as one of the institutional deficiencies to RE development in section 2.4, these could also be related to the award of contracts and release of funds for non-RE projects as seen in the case of the classroom and staff buildings which were found to have been recently refurbished in 2013 on a 2011 budgetary allocation. This tends to give credence to the claims made by the contractor in 5.1.3 that the 2-year difference between the time the contract was awarded and executed was due to a delay in the release of funds for the installation. From this visit to the community it was also found that the fault-reporting arrangement put in place by the installers, in this case, the MRD, requires the residents of the community to communicate with the MRD about any fault, thereafter, a technician is sent by the MRD to appraise and rectify the fault. Considering that the community is an isolated one and that the MRD is located in the state capital, it could take days for such a technician to get to the location, and additional days to have the fault repaired if the technician is ill-equipped for the job on the first visit as encountered in this study. Hence, a more effective approach that could achieve a faster solution to fault appraisal and subsequent rectification may need to be devised by the MRD; this is considered further in CHAPTER 6 . In addition, it is seen that such delayed response to notification of fault in isolated communities may not be limited to RE installation as highlighted by the late response to the requests to have the community school buildings refurbished. Finally, contrary to the explanation made by MRD officials in section 5.1.1.3 that the transfer of ownership to the benefitting communities is normally done publicly, the residents suggest that the ownership of the installation remains with the government. This is an indication that the MRD either did not carry out such transfer, or it was not done publicly to the knowledge of the residents. It was however noted that there was no report of any form of cultural conflict or intolerance created by the deployment of the installation to the community.

The follow-up visit made in 2016 revealed that a lack of continuous and robust maintenance arrangements underpinned the on-going failure of the installation to function. While the exact nature of the fault could not be established, the fact that solar PV installations are characterised by low maintenance requirements, and also that none of the components of the installation was missing could suggests that the fault may not be a major one. A further analysis of the information gathered in this study case using indicators scores under the five broad sustainability dimensions of section 4.3.6 is given in section 5.10.

5.4 Ide II Settlement

5.4.1 Background

Ide II (Figure 5.10), as the name implies, is located near the main settlement, Ide I. The community, which could be referred to as a hamlet, comprises of about five families and has a population of less than thirty. However, the community possesses some basic infrastructures that are not available in the bigger Ide I community.

Figure 5.10: Ide II Settlement

While Ide II has neither an elementary school nor a Health Centre/dispensary, it has a government-deployed solar installation system consisting of a miniature solar street light arrangement and a solar bore-hole and hot water system as shown in Figure 5.11. Three visits were made to this location and due to the small size of the community and number of the residents, each of the visits lasted between one and three hours.

Figure 5.11: Solar borehole system at Ide II Settlement

5.4.2 1st Visit

During the first visit to this community in November 2011, discussions were held with residents and access was granted to assess the RET installation in the settlement. In the course of the assessment carried out by the researcher, it was noted that the installation was implemented by a contractor on behalf of the RMD in year 2009 (Figure 5.12). This is in contrast to the installation at the previous settlement, Ide I, which was both supervised and implemented directly by the RMD as stated in section 5.4.1. In addition, this appears to give credence to the claims of the MRD officials in section 5.1.1.2 that, while the earlier installed RE systems were awarded to contractors, the latter ones were through direct labour by the MRD personnel.

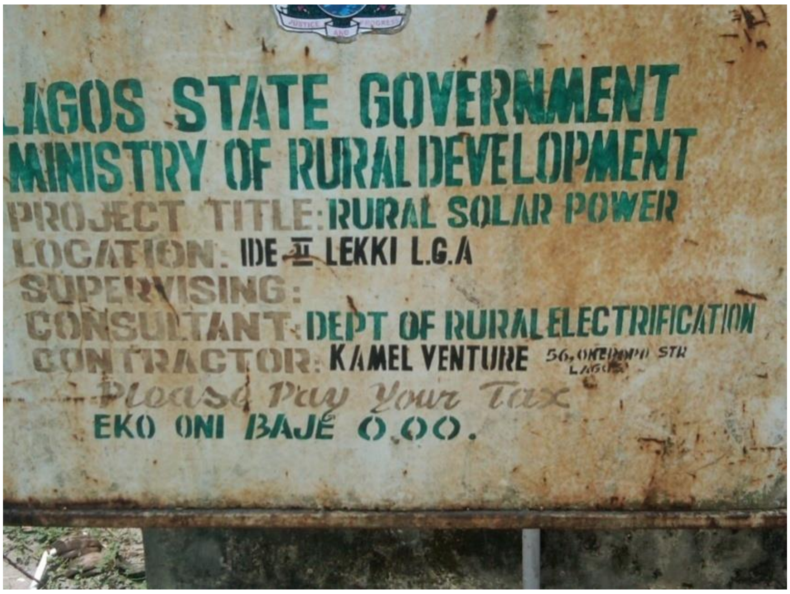

Figure 5.12: Sign Post of the Solar Installation at Ide II

A question that came to mind during the assessment of the installation is, ‘why should a village (Ide II) with less than 30 inhabitants possess a relatively bigger government-assisted electricity/water installation while another village, (Ide I), which is barely 10 minutes’ walk away and with over 450 inhabitants, does not have any form of such installation?’ When this question was posed to the residents of the settlement, they explained that the installation was deployed to their community on instructions from the ‘seat of government’. By this, they meant that government agency in charge of such installations deployed the installation to their community on the directives of the state government. However, the residents could not explain why the community was considered to be more eligible than other communities in the neighbourhood. However, relating to this issue, the residents of Ide I community had earlier explained that the dwellers of Ide II settlement are actually a breakaway group from their community who, unlike them, aligned with the political party that eventually won the state government elections. The installation, they alluded, is the ‘reward’ for their support. This was not well received by the residents of Ide I and led to a degree of bitterness; a situation that remained until a RET system that could be considered less elaborate (as highlighted in section 6.3.2.1) was installed at Ide I about 3 years after the one at Ide II.

In response to an enquiry about the performance of the installation, the residents of the community complained that although the installed system is meant for both water and lighting, they have only been using it for water pumping as previous attempts to use the installation for lighting purposes have resulted in the damaging of their lighting fittings. According to them, “the installation appears ‘too powerful’ for our lighting systems”. This is presumed by the researcher to be due to the output voltage of the installation being higher than the expected value of 220V, as it was observed that the bulbs used by the residents are the 220V compact fluorescent bulbs CFLs that are commonly available in the country.

5.4.3 2nd Visit

A 2nd visit was made in August 2013 during which the residents explained that the installation had ceased to function about eleven months earlier. Furthermore, they stated that on several occasions, they had notified the government agency that oversees the installation to have it checked/repaired but they had not received any positive response from them. A resident however suggested that the “endless fiddling” of a member of the community on the installation, under the guise of carrying out maintenance on it, may have contributed to its breakdown. The person, who could not be reached during the visits, claimed to have some knowledge of the installation although he was neither trained by the installer nor by the government agency. Due to the failure, the researcher was unable to measure the output voltage of the system in order to verify the earlier presumption that the output voltage of the installation was too high.

5.4.4 3rd Visit

On 30th June 2016, a follow-up visit was made to the community in order to find out if any action has taken place with respect to non-functional installation. However, it was observed that the installation has further degenerated and no attempt has been made to repair it since the visit made in 2013. In addition, on close observation, it was noted that some parts of the solar panels had become loose and fallen out from the array while the batteries appeared unserviceable (see Figure 5.13). It was also found that the construction of an entirely new water borehole powered by a 5 kVA generator was almost complete (Figure 5.14). This, the residents stated, was being handled by the Local Government since the solar PV installation deployed by the state government had been non-functional for over two years. It was also found out that while the gasoline generator was supplied as part of the installation, the purchase of the fuel is to be borne by the residents. On the issue of financial burden this will put on them, the residents stated that they will put in place a system of periodical contribution that would be used to purchase fuel.

Figure 5.13: Dilapidated Solar panels and Bank of Batteries

Figure 5.14: Gasoline generator powered water borehole under construction

5.4.5 Case Discussion

The situation at Ide II, in which a larger installation is allocated to a community of relatively smaller size and with a smalle r population, demonstrates a lack of equity in the deployment of RE installations to rural communities. One result of this has been the creation of bitterness and animosity between the villages. This could lead to the sabotage of the installation such as alleged in the case of the installation at Sagbokoji village (reported in section 5.5.2). An absence of any form of post-installation maintenance arrangement is also obvious, and this could have contributed to the eventual breakdown of the installation. From the follow-up visit made in 2016, a lack of synergy between the state and local governments becomes manifest. Whereas the developmental efforts of the two tiers of government should be complementary, they appear disjointed in this case. Hence, while the state government deployed a solar PV system to the community, the local government deployed a borehole system powered by a gasoline generator to the same community after the solar system failed. However, as stated in earlier, gasoline generator powered boreholes are also characterised by peculiar operating and maintenance challenges in isolated rural communities - in this instance, the availability and cost of fuel. Additional analysis of these data using indicators scores under Technical Development, Economic/Marketing, Social/Ethical Development, Environmental Impact, and Institutional Development/Government Policies are provided in section 5.10.

5.5 Sagbokoji Village (S3)

5.5.1 Background

Sagbokoji Village (Figure 5.15) is a settlement of over 800 people, and is located on an island in the Lagos lagoon surrounded by smaller neighbouring villages. The predominant occupations of the residents are fishing and traditional boat making. Over the years, small gasoline generators have been employed by the villages to provide electricity on household level while water is accessed from the village wells. These generators, as noted in CHAPTER 2 are characterised by high levels of air and noise pollution, in addition to being expensive to maintain.

Figure 5.15: Views of Bishop Sagbokoji Settlement

However, as part of the drive to improve the living standards of the residents of some rural areas in the state, the state government, through the Ministry of Science and Technology installed two 300-watt photovoltaic (PV) systems with battery storage in this settlement. The installation, which is the first of its kind in the state (Omisore, 2011), was deployed in 2008 under the auspices of the Lagos State Ministry of Science and Technology (MST).It was meant to power the community building, the primary school, a church, a mosque, sixteen streetlight units, and a water pump that was installed at the village well to push water into an overhead tank. Although the Ministry of Rural Development (MRD) did not deploy the project, it is an example of an installation deployed through 'government intervention' as explained by the officials of the MRD in section 5.1.1.1.

5.5.2 Report on Visits

Upon getting to the village, the first visit was to the residence of the village head, who, upon being told the purpose of the visit, showed great interest and regarded the visit as an opportunity to reveal the circumstances that led to the prevailing condition of the installation in the community. For this reason, he volunteered to personally accompany the interviewers through the village to the location of the broken down RET installation in the settlement. He also willingly provided relevant information with respect to the purpose of the study and encouraged other residents to answer questions posed to them, and to contribute their opinions freely. Apart from the location of the broken down RET installation in the community, the community school and health centre were also visited.

The installation was found to be in a dilapidated and non-functional state. It was also observed that the many component parts of the installation such as the batteries, charge controller, switches, and other related accessories were missing; the only hardware remaining were the PV panels that are now being used to dry clothes. In addition, the surroundings of the installation appear unkept and show signs of abandonment (see Figure 5.16).

Figure 5.16: The dilapidated and non-functional Solar-Powered System at Sagbokoji Settlement

When asked about how and when the installation got to be in such a dilapidated state, some of the residents explained that “the installation functioned for barely 3 months after it was installed before it developed problems and ceased to function”. This development, they claimed, abruptly ended the euphoria experienced by the residents and plunged them back to the same situation they were prior to its installation. On being asked of the steps taken after the installation ceased to function, the village head explained that at the onset of faults, messages were sent to the government agency (the Ministry of Science and Technology) that installed the system, but not long after repairs were carried out, the installations developed further problems. He stated that “after the first time, the installation developed faults on three other occasions and on each occasion, the installers were called to fix the fault which they did. However, after the last fault, the installers came around like the previous times but could not repair the fault. Since then, they did not show up again”. When presented with claims made by the contractor (see 5.1.3) that the cause of the recurring breakdown was due to unauthorised connections made by some members of the community to their homes, the village head conceded that although such allegations and suspicions were rife, and may have been true, he was of the opinion that the claims could not be substantiated. He added that “since the government agency failed to repair the fault, we have become helpless as no member of the community was trained to carryout basic repairs on the installation”.

A number of residents were also asked of what could have led to the breakdown of the installation, but many of them claimed ignorance of the reasons for the breakdown but simply stated that, “suddenly, the installation ceased to function”. However, a few others opined that the installation must have developed problems due to wrong design/installation procedures since it only functioned for a few months before the bouts of recurring faults started.

Based on the bare state of the installation, and against the backdrop that benefitting rural communities are normally encouraged to provide additional security arrangements for the installations (see section 5.1.1.3), the village head was asked on the circumstances that led to the installation to be in the present state. To this, he explained that the community initially provided appropriate security for the installation right from the time it was installed and during the period it was functional. He explained that the security arrangement was in form of a number of vigilante groups constituted by member s of the community, which took turns in watching over the installation overnight in order to protect against unauthorised access to the installation. He further stated that this arrangement was however discontinued after the installation broke down and was not repaired for a number of months, noting that "it became illogical to continue providing security for a non-functional installation". According to him, "when, after a long period of time, the technicians no longer showed up to effect repairs on the recurring faults of the installation, the security provided for it could not be sustained; the withdrawal of which led to the installation being vandalised and the battery banks and other accessories carted away by unknown persons". He further alluded that these unknown persons were from neighbouring communities that do not have such an installation and, probably, vandalised the installation out of envy and bitterness. However, some of the residents contended that the act was carried out by people from outside the area. When asked why they held this opinion, they explained that the component parts of the installation must have been carried away by these unknown people due to their economic worth, noting that "these are not components that could be secretly installed in any community within the vicinity"

At this point, the village head was asked on what he considered could have been done to prevent the vandalising of the installation even when it was not functional. He opined that such acts of sabotage might be curtailed if the location of the installation is well thought-out at inception such that a separate security arrangement may not be necessary for it. Along this line of reasoning, he said, "locating the installation within the compound of the village head (for example) could achieve that purpose".

On present actions being taken to restore the installation to a functional state, one respondent despaired that after 3 years of non-functionality, it appears all hope is lost, as most of the residents have come to accept the notion that the system may not become functional again. Another respondent added "it is for this reason some of the dwellers now use the solar panels as planes to spread - out laundries for drying while others simply dump rubbishes there". Another respondent added "we now use generators for our electricity while we collect water from the village well". On the part of the village head, while he maintained that technical factors were probably responsible for the initial malfunctioning of the units, he was more worried by the present dilapidated state of the installation due to occasions of sabotage on it. According to him, “the present state of the installation may discourage any further attempt by the government agency to restore the installation to a functional condition due to the anticipated high cost to have it repaired”.

When the community school and health centre were visited, a gasoline generator water borehole system was seen at each of the locations. The village head explained that the borehole at the community school has not been used for some time due to non-availability of fuel as there was no fund to purchase it; the fund were to be released by the local government agency that facilitated its construction. However, on getting to the health centre which is situated just beside the community school, it was found that installation works were still in progress on the gasoline borehole system at the location. Upon enquiring, a female nurse at the health centre confirmed that the local government is handling the installation at the centre while a different agency handled the installation at the community school, though she could not give the name of the agency.

5.5.3 Case Discussion

From the visits to this community, a number of issues are evident. It is seen that actions and decision taken by stakeholders may be both dependent and interconnected, and may combine to the breakdown of installations. This is seen in the series of actions and decisions that purportedly led to the breakdown and subsequent damage of the installation in the community. As highlighted in section 5.5.2, the provision of local security arrangement by the community is just one of a number of interconnected factors that could enhance the overall performance of such installation by discouraging unauthorised access and sabotage of the installation.

The two other borehole projects located in the community school and health centre respectively, and handled by different agencies, demonstrate lack of coordination between the agencies. These issues are further analysed in section in 5.10 under Technical Development, Economic/Marketing, Social/Ethical Development, Environmental Impact, and Institutional Development/Government Policies, and the outcomes are integrated into the development of the framework presented in Figure 6.4.

5.6 Asore Village

The visit to Asore community was made in March 2016. The community is located barely 2km off the Lagos - Idiroko Expressway that links Nigeria to a neighbouring country, the Republic of Benin, through Ogun state, and has a solar-powered installation deployed in 2011 as part of a pilot programme jointly executed by the state government and Schneider Electric (Nigeria) in a bid to provide rural communities in the state with access to renewable energies using the latter's Villasol power project model. This is a solar PV installation (with batteries) capable of producing up to 4kW of power to provide domestic and commercial energy services that could be used to support community services such as streetlights, water supply, and lightings to schools and health centres.

A notable feature on arriving at the community however is that although it has been presented by the state government as one of the villages where solar energy have been exploited in the effort to bring development to rural communities, it does not have the outlook of a typical rural community as encountered in other communities used as study cases in this study. Apart from its proximity to the main road, a notable difference is the existence of grid electricity supply which the residents stated was extended to the community 2 years after the solar water system was installed. It therefore contradicts a main characteristic of rural areas as stated in section 3.3.

The site of the solar water installation wore a forlorn look; an indication that it has not been in use for some time. The installation, which is located opposite the residence of the village head, comprises of two water tanks raised on a scaffolding, 12 panels (the ratings of which could not be ascertained) and a small building housing the batteries and the control equipment, while the distribution network consists of a simple underground wiring system

When the village head was interviewed, he confirmed that the installation has not functioned for over three years. According to him, the installation was commissioned by the state governor in 2011 but functioned barely for a year before it broke down. He added that repeated attempts to get government officials to have the installation repaired were not successful; they had visited to assess the fault but they never came back to repair it. A number of villagers interviewed confirmed that although they accessed water from the solar borehole installation during the time it was functional, it has ceased to function some time ago and they have come to regard it as unserviceable. They further stated that while the extension of grid electricity brought great relief to the community in terms of electricity services, they still access water from wells in the community (for free), and also purchase water from a grid/gasoline-powered borehole which is privately-owned by a member of the community.

The researcher decided to find out from the local government why there have not been any attempt to repair the installation. At the Ado-Ota Local government secretariat, two officials interviewed at the Works and Services department stated that the installation is not under the custody of the local government. They added that the department was not involved in the deployment of the installation, saying that it was strictly a state government project. When it was put to them that such a project in a rural community should ordinarily be under the local government, they agreed that this should normally be the case, but is not the practice in all cases.

5.6.1 Case Discussion

Asore community underlines the fact that while some rural communities may eventually get connected to grid electricity, this is likely to take place earlier in communities that are close to major towns or roads since the financial implication for grid extension to such communities are considerably less than for those in isolated locations. In addition, it is seen that while the extension of grid electricity may lead to improved energy access, it may not necessarily eliminate all prevailing challenges as manifested by the lack of a grid electricity-powered borehole system. In this regard, it shows that grid electricity may not readily supplant all services provided by solar PV systems but could operate *pari passu* with them as would be the case if the solar PV water system is repaired to continue serving as a community water source or the system is adapted to run on grid electricity.

The case study also demonstrates the failure of different tiers of government, in this case, the state and the local governments, to work together for a common goal but rather independently. This is made evident in this case of a rural project not being under the jurisdiction of the local government but under the state government as claimed by the local government officials.

Another take-away from the community is the tendency of (rural) citizens to excessively depend on government to provide amenities which they could probably provide themselves as manifested by the existence of a privately-owned grid/gasoline-powered borehole system in the community. These issues are discussed more in section 5.10.

5.7 Onibambu

Onibambu/Idi-aba are two neighbouring rural communities located about 20km from the highway linking the cities of Ibadan in Oyo State to Ile-Ife in Osun State. Staff of the Ife North Local Government advised that the route is characterised by quite difficult and undulating terrains, so the journey is better made with a 4-wheel drive vehicle. Hence, the drive to the communities from the highway took 56 minutes due to the nature of the road. About half way, some 11kV electricity poles and transmission lines were observed to have been erected in an apparent earlier-failed attempt to extend grid electricity to the communities. Collapsed poles and transmission lines were strewn on the road at various points. As most often the case with government projects as highlighted in section 3.3.1, this failed attempt must have involved a substantial amount of financial investments.

The solar mini-grid system in the community was installed by an energy provider Arnergy Solar Ltd., and funded via a 44 Million Naira loan granted the energy provider by the Bank of Industry (BoI) in a typical "Financial Institution and Energy Company Partnership" as highlighted in section 2.3.3.2. The installation (Figure 5.17) is a mini grid system providing electricity to the two communities, and is strategically located between the borders of the two communities. The low-voltage transmission lines runs through the length and breadth of the two communities as shown in Figure 5.18.

Figure 5.17: The Solar Array

The solar array comprises 126 solar panels of 300W rating each. The Balance of System equipment comprising of 24 units of heavy-duty 6V batteries, four units of Inverter of ratings 8.5kW each and related accessories are housed in the control room. In addition, each household in the community is installed with a pre-paid meter which enables users to buy electricity and load such into their metring systems. The installation was commissioned 6 months earlier in October 2015 and its positive effects on the daily activities of the residents of the community were profusely attested to by every member of the community interviewed during the study.

Figure 5.18: Low Voltage lines at Onibambu Village

A member of the community called Bisi was recruited by the installers to monitor the installation and acts as the contact person between them and the community. He explained that he monitors the installation and relays its performance, faults or any other incident by phone to the installers who are located in Lagos. He also acts as the local vendor from whom residents purchase electricity vouchers which they use to load electricity to their meter. The energy provider sends the pin codes of vouchers to him through phone short message service (sms) whenever he makes financial payment to their bank account.

In the control room (Figure 5.19) of the building housing the equipment, it was observed that it is not well ventilated as it has only one door and one window while no air-conditioning system is installed, making the air inside to be rather hot. This was corroborated by Bisi who stated that the room normally becomes unbearably hot in the afternoons but that the company is in the process of installing an air-cooling system in the building.

Figure 5.19: The Control Room and Balance of System Equipment

When asked if there has been any major fault occurrence, he confirmed that there has been such an occurrence when the circuit breaker in the control room tripped and efforts to put it back on were not successful as the tripping was persistent. During this time, he stated that there was no electricity supply to the villages for one-and-half days until the technicians from the energy provider finally remedied the situation. Asked how much electricity each household purchases on the average every month, Bisi, explained that it varies between households to household, and depends on equipment being used. He said that a 10-unit (i.e. 10kWh) electricity voucher which is purchased for 1000 naira could be used for upwards 5 weeks. This 100 naira/kWh costs nearly five times the 21.30 naira/kWh cost of grid electricity in the country.

Asked about the affordability of the tariff, a member of the community who is a farmer, said he considers the tariff quite fair and affordable. He further stated “the community members are aware that urban dwellers pay far more for electricity services which are usually not constantly available like our own”. Similarly, a middle-aged woman who runs a provision and drinks shop in front of her house also testified to the impact of the installation. She stated that she has been recording increased sales in her business since the availability of electricity has enabled her to run her businesses till late in the night unlike before when she normally closes in the evening. In addition, she said she has now purchased a refrigerator that has added value to her shop and helped to improve her sales as she now sells cold drinks to her customers. In the same vein, many other members of the community testified that the since the commissioning of the installation, they have been enjoying uninterrupted supply of electricity every day.

However, a noticeable feature is the absence of improved water source as the villagers obtain water from wells and streams. This was rather unexpected as the solar power system could be used to power a borehole installation, had such been in existence.

5.7.1 Case Discussion

The installation in the community is a departure from the previous study cases in terms of its size, elaborateness and good performance. A prominent feature is the post installation maintenance arrangement put in place by the energy provider company as seen in the remarkable responsiveness to cases of fault which required technicians to come to the site from Lagos which is about 5 hours' drive away. This is a notable difference from similar projects deployed by government agencies as earlier discussed which are typified by slow or complete absence of post installation maintenance arrangements. However, such fast responsiveness to fault situations might be connected to the fact that unlike government deployed installations, the installation in this community is a revenue-earning platform for the energy providers, from which they cannot earn any income during the period when it is not working. In addition, having constant electricity in an isolated rural community is quite a commendable feature since such uninterrupted supply of electricity is quite uncommon even in major cities in the country like Lagos.

Another lesson learned from the visit to these communities is on the earlier bold but obviously failed and expensive attempt at grid extension to these locations. As is most often the case with government projects, this failed attempt must have involved a substantial amount of financial investments. This underscores the notion that grid extension is often impractical and uneconomical in such locations. In addition, the absence of a borehole system that could serve as a source of improved water access even when there is availability of electricity that could power it tends to give credence to the statement by a personnel of another energy provider that most international donor organisations hold the belief that basic lighting and energy to power low power home appliances such as radios and cell phones are the most prevailing energy needs of rural dwellers and therefore adapts their grants for such purposes (see section 5.8). Additional analysis of information from this study case is carried out under the five sustainability dimensions of Technical, Economic/Marketing, Social/Ethical Development, Environmental Impact, and Institutional Development/Government Policies in section 5.10.

5.8 Umuagwu Village

Umuagwu Village (Figure 5.20) in Egbeke Etche Local Government Area of Rivers state is a settlement of about 60 households. A visit was made in June 2016 in conjunction with the chief executive officer of the installing company. The solar system (see Figure 5.21) in the community was installed in 2013 by an energy provider company, GVE Projects Limited through an 80% grant received from an international donor organisation with major interest in measuring the development impact of such initiatives in rural communities, and 20% grant from a local organisation respectively. The 6.8kW solar PV installation comprises of 24 units of 285W solar panels while the storage system comprises of twelve 200AH batteries which are housed in the control room shown in Figure 5.22 .

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Figure 5.20: Low Voltage Lines supplying Community Homes at Umuagwu Community

Figure 5.21: The Solar Array at Umuagwu Community

Figure 5.22: The Control House and Balance of System Equipment in the Control Room

However, as pointed out by the officer of the installing company during the visit, although about 6.0kW of energy is distributed, the present demand considerably exceeds this figure. Hence, the installation is normally switched on in the afternoon and used until it is exhausted late into the night. The officer further stated that when newly installed, the installation initially sustained the community for between 18-20 hours per day, but this has reduced to an average of 10 hours daily due to the joint effect of increased demand and the probable reduction in the performance of the storage elements due to degradation. On the issue of metering, the officer explained that due to lack of meters, one meter may serve 2 or 3 households where the households jointly contribute to purchase units of electricity whenever necessary. Meanwhile, there are plans by the energy provider to upgrade both the storage facilities by increasing the number of batteries and the metering systems to smart meters that will be pole-mounted while only the user unit will be in the homes. The upgrade is to be financed independently by the energy provider partly from bills paid by the users, and is being implemented to tackle the prevailing rising incidents of meter by-pass and illegal connections by some consumers in the community. To further curb such activities, a 3-man monitoring committee was recently set up by the community to apprehend anyone that engages in such illegal activity and to disconnect such households. The offence is further punishable by levy of 1 goat, 1 jar of local drink, 10 tubers of yam, 8 kolanuts; *or* a payment of a fine of 15,000 Naira (an amount that could purchase electricity for an average household for 5 months). Meanwhile, a case of one household which was involved in such illegal connection and had hitherto been disconnected was settled and re-connected back during the visit. The re-connection was carried out by two technicians who are trained members of the community (Figure 5.23).

Figure 5.23: Local Technicians carrying out reconnection and repairs on the system

In terms of tariff, the chief executive officer stated that the villagers purchase electricity at rate of ₦127/kWh which is nearly six times the ₦21.30/kWh tariff the country's public electricity utility company PHCN supplies grid electricity to residential homes. When enquired on why there is such a wide disparity between the two tariffs, he further explained that the tariff being charged the rural dwellers is the realistic amount that could sustain such a commercial deployment of the installation. He further noted that the grid electricity tariff of the public utility company is unrealistic and is comparably low because of the immense government funding and subsidies which the public utility company enjoys and which are either only partly extended or not extended to the renewable energy sector. Asked how the consumers pay for units of electricity, the officer explained that company adopts a pre-paid metering revenue collection system where consumers purchase scratch cards from a local agent. The cards contain numeric codes that will be entered into the user unit for the number of units of kW/h purchased. However, when the cost of production of the scratch cards was becoming burdensome, the company resorted to sending the numeric codes to the agent through phone Short Message Service (sms) which is now entered into the user unit on a keypad (see Figure 5.24), similar to the method adopted in Onibambu Community.

Figure 5.24: Pre-paid Meter Unit at a Consumer's Premises

In addition, interviews were conducted with 19 households, and questions asked on the effect, challenges, experiences and expectations with respect to availability of electricity in the community. While many of the respondents stated that having electricity in their homes have made life more enjoyable for them, they also wished that the tariff could be reduced to make it more affordable. One respondent further explained that each household spends an average of ₦3,000 per month on electricity which they only use to power their lighting fittings and household electronic gadgets such as radio and television sets, and charging of phones. He further stated that not every household can conveniently afford the cost of electricity, and there has been occasions when some household resorted to the use of kerosene lamps for about one or two weeks pending when they could afford to purchase enough units of electricity. This was however found to be ironic as findings from the local fuel seller at the village (Figure 5.25) revealed that kerosene and petrol are being sold at exorbitant prices of N200/bottle and N180/litre respectively; an increase of about 25% above the official prices. A member of one household however conceded that while they could easily afford to purchase kerosene in small quantities for their lamps, the lamps have limited use as they cannot be used to charge their phones! He further added that access to electricity through the solar installation in the community has improved their standard of living and have enabled greater awareness to on-going issues in the country.

Figure 5.25: Local Fuel Seller at Umuagwu Community

Moving round different households in the community also revealed that lighting fittings in all the households are mainly the energy-saving compact fluorescent lamp with ratings of 30W and below. On enquiries, the villager explained that the Energy Provider officials enlightened them against the use of energy-consuming incandescent lamps that, they were told, consume more electricity and will therefore make them to pay more for energy consumed over the same period of time.

5.8.1 Case Discussion

The installation in this community is a collaboration between an international body and a local enterprise without any financial involvement on the part of the government or any of her agencies. This, as shown in Figure 2.7, is one of the financial instruments for off-grid electrification. Similar to the arrangement at Onibambu community, a characteristic of this installation is the robust post installation maintenance by the energy provider. It is also remarkable that technicians used for repairs and maintenance purposes are well-trained and equipped young men of the community. Another notable lesson from this community is the higher tariff paid by rural dwellers to that paid by grid electricity consumers in urban areas. This brings up the issue of appropriate pricing of tariff paid by grid energy consumers in the country. Notwithstanding, it is found that using fossil fuel often cost more going by the exorbitant prices of gasoline and kerosene in rural locations as exemplified by this community. Another lesson learnt from this visit is the manner in which rural dwellers appear to appreciate and embrace the principles of energy efficiency going by their strict adherence to the use of energy-saving lamps rather than the inefficient incandescent lamps prevalent in most urban settlements. Section 5.10 presents further analysis of this study case using indicators scores under Technical Development, Economic/Marketing, Social/Ethical Development, Environmental Impact, and Institutional Development/Government Policies sustainability dimensions.

5.9 Umuode community

Umuode has about 90 households in the community and was also visited in June 2016. The solar PV installation in the community is a bigger version of the one at Umuagwu Village and was installed by the same energy provider company GVE Projects Limited in 2015. It was 83% grant-funded by the US Power Africa Initiative, 9% by the IEEE Smart Village and 8% by GVE Projects Limited. The US Power Africa Initiative is a 5-year United States of America presidential innovation designed as a multi-stakeholder partnership between her government and some African countries including Nigeria. It is aimed at supporting economic growth and development in the African countries by increasing access to reliable, affordable, and sustainable power in Africa. The IEEE Smart

Village is a donor supported signature program of the IEEE Foundation – the philanthropic arm of IEEE - with the goal to deliver basic electrical and educational services to more than 50 million people by 2025.

The solar PV installation in the village has a rating of 10.5kW comprising of 36 units of 295W solar panels and 12 units of 200AH batteries (see Figure 5.26 and Figure 5.27). The installation supplies energy to the households in the community through a ring wiring system which covers the perimeter of the settlement. The official of the Energy Providing Company explained that the success of the implementation of the installation hinged on having access to sufficient financial grants and to a close collaboration of the company with the community. With regards to the latter, he stated that prior to installing the system, the company held a series of meetings with the community to ensure that the installation would meet their expectations thereby promoting its acceptance and sustainability. On being asked why the installation at the two villages are mainly for electricity for domestic use and do not include water pumping for the communities, he explained that most international donor organisations believe that basic lighting and energy to power low power home appliances such as radios and cell phones are the most prevailing energy needs of rural dwellers and therefore adapts their grants for such purposes. However, he asserted that this is contrary to the realities on ground as rural dwellers now seek for more productive and higher level of energy beyond using electricity to see, read or play at night, but also for ironing cloths, for cooling water and drinks, and for other profitable commercial ventures. Furthermore, on the issue of having solar water installation in the community, he stated that since water installations are typically at community level, it may be difficult to implement a water tariff plan based on individual household consumption.

Figure 5.26: Solar Array at Umuode Community

Figure 5.27: Balance of System Equipment in control room at Umuode Community

Moving around the community, it was observed that many homes have basic household electronic gadgets such as small TV sets, radio and electric fan. Members of the 15 households were interviewed by visiting each household during which they generally testified that the availability of electricity in the community provided a new level of comfort, while many of them also regarded the tariff as not too expensive. As stated by one them "the benefits of electricity access as we have in our individual homes outweighs the money we pay for it, and it has more uses than our oil lamps". It was learnt that the local management structure and tariff structure in this village is same as that of Umuagwu community; with similar arrangements of purchasing electricity vouchers by the consumers. Also, a 3-tier maintenance arrangement similar to that of Umuagwu community, with trained locals forming the first tier, exists in the community

5.9.1 Case Discussion

The installation in the village evidences another successful collaboration between indigenous energy company and international donor organisations. This sort of arrangement in which the financial involvement of the energy company is less than one-tenth of the total cost certainly removes a level of financial burden from the company and enables it to concentrate its resources in its area of technical competencies. Also, having been installed 3 years after the one at the nearby Umuagwu village, certain improvements are observed in this installation over the former one. As noted by the official of the energy company, apart from the installation being of a bigger rating, the batteries deployed are of better quality than the previous ones. In addition, whereas the inverter used in the previous installation were imported, the ones used in this community are manufactured by Schneider; an international company that has a Nigerian branch. Hence, the maintenance or replacement of the inverter can be carried out more effectively through the local office of the manufacturing company.

A take-away from these is that indigenous companies can improve their competencies when repeatedly engaged for such deployment. The visit also highlights the commonly-held but not necessarily true belief among donor companies that deployment of solar installations in rural communities should target basic lighting and low power needs of the people. Realities on the ground revealed that though such lighting provisions are valued by the people, they also yearn for higher access to electricity; such that can be used for commercially productive activities. In addition, it is observed that similar to what obtains in Umuagwu community, the installation in this community did not address the equally pressing water needs of the people. As noted by the official of the energy company, this may be because such water installations are typically installed on community level and may therefore be difficult to deploy on a commercial basis. However in the event that such deployment could not be undertaken as a Corporate Social Responsibility (CSR), a way out around this may be to implement a flat affordable tariff rate on all household in the community. Further analysis of this study case and the other ones using Technical, Economic/Marketing, Social/Ethical Development, Environmental Impact, and Institutional Development/Government Policies sustainability dimensions are provided in the next section.

5.10 Presentation of study cases' findings using Indicators Scores

In addition to the discussion on the outcome of the visit to the installation at each of the communities used as study cases, and as stated in section 4.3.6 and Table 4.4, indicators to be used for additional assessment and evaluation of the study cases are categorised into Technical, Economic, Social/Ethical, Environmental and Institutional development and Government policies dimensions, and are awarded numerical scores of "1 = Low", "2 = Medium", "3 = High" and "0 = Absent" in accordance to the level of presence or incidence in each of the study cases as explained in section 4.3.7 0 and Table 4.5. The level of incidence of an indicator is determined based on the information from the field visits (physical evaluation, observation etc.) and interview sessions with stakeholders, and scores are allocated accordingly. Although this proved rather difficult and a bit subjective in a few instances, it nonetheless enables an aggregate measure of each indicator to be obtained. Furthermore, since an indicator may not be applicable to a study case, average scores are obtained in addition to the aggregate scores for each of the study cases to avoid bias against study cases with 'not applicable' (N/A) entries. This is done for all the indicators under the five broad sustainability dimensions as explained in subsequent sections. The average scores are subsequently used for further analysis in CHAPTER 6

5.10.1 Technical Indicators

Ten technical indicators are considered appropriate from the study as shown on Table 4.4. The award of scores for each of these indicators for the study cases are shown in Table 5.1.

From the report of the visits to each of the study locations (sections 5.3 to 5.9), the performance of the installations at Ide I and Ide II could be considered as medium, while the ones at Sagbokoji and Asore had poor performances. In contrast, the installations at Onibambu, Umuagwu and Umuode communities are characterised by high performances. These are reflected in the award of scores of ‘2’ for each of Ide I and Ide II; ‘1’ for Sagbokodji and Asore and ‘3’ for Onibambu, Umuagwu and Umuode installations under ‘Efficiency’. As stated in section 4.3.6.2, the ‘availability of support infrastructures’ were evaluated as at when the installations were functional. Since such supports were not totally absent at Ide 1, Ide II and Sagbokoji communities but were rather weak, these are allotted scores of ‘1’. On the contrary, the presence of such supports could not be found at Asore and was purportedly the basis for the non-functional state of the installation (section 5.6), therefore a score of ‘0’ is allotted. However, the installation at Onibambu manifested a moderate level, while Umuagwu and Umuode possess a high level of such supporting infrastructures. Therefore a score of ‘2’ is allotted to Onibambu while ‘3’ is allotted to each of Umuagwu and Umuode. In the same vein, there appeared to be little daily operational measures incorporated into the running and performance of the installations at Ide I, Ide II, Sagbokoji and Asore communities whereas the presence of personnel that carry out daily checks were noted at Onibambu, Umuagwu and Umuode communities as reported in sections 5.7, 5.8, and 5.9. Hence, whereas the former group of study cases are awarded ‘1’ under ‘daily operation services’, the latter group are awarded scores of ‘3’. However, whereas the availability of such services are quite high at Onibambu and Umuagwu communities, and to a lower extent at Umuode community, they appear not active at Ide I, Ide II and Sagbokoji communities. These are reflected in the scores awarded to each of the study cases under the indicator ‘Availability of Services’. In terms of ‘Incremental Capacity of the system’, this does not exist at Ide I since the residents complained of the inability to obtain water at all times (section 5.3.6) hence a score of ‘0’, whereas the installation at Ide II which serves only five households possesses a high incremental capacity, hence a score of ‘3’. A score of ‘3’ is equally awarded to Onibambu since, as stated by the energy provider in section 5.1.4, *although the installation is rated 37.8kW, the assessed load demand of all lighting and household equipment including refrigerators in the two communities is slightly over 20kW*. Similarly, the installations at Sagbokoji, Asore and Umuagwu have low incremental capacity and are awarded scores of ‘1’ each, while the one at Umuode, which can accommodate moderate increase in loads is awarded a score of ‘2’.

Since the systems at the first four locations broke down within 3 years of their being installed, these are accorded scores of ‘1’ under “Lifespan of the system”. However, this factor could not be graded for the installations at Onibambu, Umuagwu and Umuode since they are still functional and were installed within the past 3 years (see Table 4.1) hence the ‘Not Applicable’ (NA) for the installation at these locations.

From the narratives, the “quality of supply” at Ide I, Sagbokoji and Asore communities could be said to be medium when the installations were functional while that of Ide II could be said to be low (*the residents of the community complained… they have only been using it for water pumping as previous attempts to use the installation for lighting purposes have resulted in the damaging of their lighting fitting* (section 5.4.2). In contrast, the quality of supply at Onibambu, Umuagwu and Umuode are graded ‘high’ with a score of ‘3’ for each of them.

It is also noted that the absence of local skills featured prominently at Ide I, Sagbokoji and Asore communities (score of ‘0”) while at Ide II a resident claimed *to have some knowledge of the installation although he was neither trained by the installer …* (score of ‘1’). On the contrary, Onibambu, Umuode and Umuagwu communities showed a good level of local skills. This was especially manifested at Umuode community, hence a score of ‘3’, while a score of ‘2’ is awarded to the other two communities.

There were no feasible structures that the installations at Ide I, Ide II, Sagbokoji and Asore communities could be said to have directly/indirectly impacted, hence the score of ‘0’ as indicated. However, a low level of commercial impact is observed at Onibambu, Umuagwu and Umuode communities by the opening of cold drinks shops in these communities although this appear more evident at Onibambu community where additional small-scale local business enterprises are hoped to be connected soon. Hence, a score of ‘2’ is awarded to Onibambu and ‘1’ for each of Umuagwu and Umuode.

Considering the remote nature of all the communities (except Asore), and despite the shortcomings observed in the performances of the installations, the choice of solar PV could still be considered practicable since as highlighted in CHAPTER 2 , off-grid energy generation systems based on solar PV technology have often been used to meet the low energy demands of rural areas since fossil-fuel systems come with the challenges of obtaining fuel. Hence, a score of '3' is allocated to all the installations except at Ide II where a fossil fuel system is being implemented and at Asore where a fossil fuel system could be adopted due to the proximity of the community to a major town. Hence a score of '1' and '2' are respectively allocated to these two cases.

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Table 5.1: Technical Indicators

Technical Indicators	**Study Cases** Absent (0); Present: Low (1); Medium(2); High (3)						
	Ide I	Ide II	Sagbo kodji	Asore	Onib ambu	Umuag wu	Umu ode
Efficiency	2	2	1	1	3	3	3
Availability of support infrastructures	1	1	1	0	2	3	3
Daily operation services	1	1	1	1	3	3	3
Availability of services	0	0	0	0	3	3	2
Incremental capacity of the system	0	3	1	1	3	1	2
Lifespan of the system	1	1	1	1	N/A	N/A	N/A
Quality of supply	2	1	2	2	3	3	3
Availability of local skills	0	1	0	0	2	3	2
Development of other infrastructures	0	0	0	0	2	1	1
Practical Technology Choices	3	1	3	2	3	3	3
Cumulative score	**10**	**11**	**10**	**8**	**24**	**23**	**22**
****Average score**	**1.0**	**1.1**	**1.0**	**0.8**	**2.67**	**2.56**	**2.44**

***: The Average score for each column is cumulated over indicators that have entries (scores) i.e. N/A entries are not taken into consideration in obtaining Average Scores*

5.10.2 Economic and Financial indicators

A total of ten indicators (Table 5.2) are considered under Economic and Financial analysis. These indicators are used to establish issues such as the level of financial incentives available for both installers and users, how easy it is for these to be accessed, how the installation has impacted economically on the users, the profitability of an installation etc.

Table 5.2: Economic and Financial Indicators

Economic/ Financial Indicators	**Study Cases** Absent (0); Present: Low (1); Medium(2); High (3)						
	Ide I	Ide II	Sagbo kodji	Asore	Onib ambu	Umuag wu	Umu ode
Profitability	N/A	N/A	N/A	N/A	2	2	2
Low costs for operation and maintenance	3	2	2	2	2	2	2
Share of profit set aside for re-investment	N/A	N/A	N/A	N/A	1	2	1
Share of electricity /water consumed by businesses (income-generating activities)	0	0	0	0	2	1	1
Business development	0	0	0	0	2	1	1
Maximise Opportunities for productive applications	0	0	0	0	2	1	1
Least Cost Design	3	3	3	1	3	3	3
Micro-credit financial incentives available to consumers	N/A	N/A	N/A	N/A	0	0	0
Explore opportunities for international co-financing	0	0	0	2	2	2	2
Proper pricing and affordability of tariff	N/A	N/A	N/A	N/A	1	1	1
Cumulative score	**6**	**5**	**5**	**5**	**17**	**15**	**14**
Average score	**0.86**	**0.71**	**0.71**	**0.71**	**1.7**	**1.5**	**1.4**

The installations at Ide I, Ide II, Sagbokodji are deployed by government agencies on a non-commercial basis and, hence, do not by any means generate earnings to the installers. This is same for the installation at Asore community which is a pilot project between a company and a state government. Contrary, the remaining three installations i.e. Onibambu, Umuagwu and Umuode are commercial undertakings which could be regarded as averagely profitable going by the statement made by the officer of the installing company that the tariff plan will recover the installation over a 15-year period, while the plan of the energy provider that deployed the installation at Umuagwu to independently upgrade the system at Umuagwu community partly from the bills paid by the users also attest to this. Hence they are all scored ‘2’. All the installations except the one at Ide I are ranked medium under “low costs for operation and maintenance” as this characterises solar PV installation. Ide I is ranked ‘3’ under this indicator as it is a battery-free system: a feature which further reduces the operation and maintenance cost. The issue of “share of profit set aside for re-investment” does not arise in Ide I, Ide II, Sagbokodji, and Asore installations since, as explained earlier, these are not commercially-driven systems hence the indicator is not applicable to them as indicated on Table 5.2. This feature is however more pronounced at Umuagwu community where the intention of the energy provider is to independently upgrade the system at the community partly from the bills paid by the users (see section 5.8) and is therefore scored ‘2’, than at both Onibambu and Umuode which are both scored ‘1’.

It is observed at the installations at Ide I, Ide II, Sagbokodji and Asore are not being used for any business or income-generating activities thereby resulting in no business development. Consequently, the score of ‘0’ for the three case studies under “Share of electricity /water consumed by businesses (income-generating activities)” and “Business development”. The level of these two indicators are equally low at Onibambu, Umuagwu and Umuode although it was observed that business activities are a bit more at Onibambu, hence a score of ‘2’ whereas others are rated “1”. In the same vein, whereas the first four locations could not be said explore opportunities for productive applications (hence, a score of ‘0’ at each of them, this is done to an appreciable degree in Onibambu – a score of ‘2’ - but less at Umuagwu and Umuode communities which are both awarded scores of ‘1’.

Being isolated communities with no immediate plan of grid extension, the deployment of solar PV installations to each of the study locations can be regarded as 'least cost design' except in Asore which is proximate to a major town where grid extension is considered more practicable as highlighted in section 5.6.1. Hence, all the locations are rated '3' in this indicator, except Asore which is graded '1'. It is seen that the availability of micro-credit financial incentives is not applicable (N/A) to Ide I, Ide II, Sagbokodji and Asore residents since the installations are not utilised at individual household level. However, while such are relevant at Onibambu, Umuagwu and Umuode communities, they are not in existence in any of these places, hence the scores of '0'. Finally, from the narratives given on each of the installation, it is noted that opportunities for international co-financing were not explored in Ide I, Ide II and Sagbokodji installations whereas these featured appreciably in each of Onibambu, Umuagwu and Umuode installations, giving rise to scores of '2' in each of them. The case of tariff do not arise with respect to the installations at Ide I, Ide II, Sagbokodji and Asore communities as they were deployed on non-commercial basis, hence "N/A" scores. However, against the backdrop of relatively cheaper grid electricity and desires of users for lower tariff structures, a score of '1' is awarded to each of Onibambu, Umuagwu and Umuode.

5.10.3 Environmental Impact Indicators

Though solar PV installations are considered environmental friendly, their physical presence could take up a sizeable amount of land which could make the landscape appear untidy. In addition, their utilisation could lead to the replacement of sources that are less environmental friendly at household levels. Only 3 indicators are evaluated under the environmental impact sustainability dimension as shown in Table 5.3. Since no dispute was recorded with regards to "Land requirements and acquisition" at any of the study locations, and the size of land required appear moderate at each of them, a score of '3' is awarded across board. Also, there was no case or complaints of interference of any of the installation with other utility infrastructures at any of the study locations, hence a score of '3' is also allotted to each of the installations. Although the installations at the first four study cases have become non-functional and not benefiting any member of the communities, it is noted that even when the installations were functional, they did not necessarily replace all other existing means of access. This is the case in Ide I where the residents still do their laundries by the lagoon banks (see section 5.3.1) even when the solar PV installation was functional. A similar situation was recorded in Umuagwu community where residents still resort to the use of local lamps whenever they could not afford to pay for electricity voucher (section 5.8). Hence, the scores for "Households where electricity/borehole water has replaced other sources" are given as '1' for Ide I and Umuagwu communities and '2' for each of the other study cases as shown on the Table 5.3.

Table 5.3: Environmental Impact Indicators

Environmental Impact Indicators	**Study Cases** Absent (0); Present: Low (1); Medium(2); High (3)						
	Ide I	Ide II	Sagbo Kodji	Asore	Onib ambu	Umuag wu	Umuo de
Land requirement and acquisition	3	3	3	3	3	3	3
Non-Interference with other utility infrastructures	3	3	3	3	3	3	3
Households where electricity/borehole water has replaced other sources	1	2	2	2	2	1	2
Cumulative score	**7**	**8**	**8**	**8**	**8**	**7**	**8**
Average score	**2.3**	**2.7**	**2.7**	**2.7**	**2.7**	**2.3**	**2.7**

5.10.4 Social-Ethical Development Indicators

Social ethical development indicators are used to assess the level of impact of the solar PV installations on the social lives of the users: in what way and to what degree it has impacted on daily activities. A total of eight indicators are considered under this category as shown on Table 5.4. At all the study locations, there appears to be a good degree of acceptance of the installations by the residents although the same may not be said in terms of political (government) acceptance. This may have been the reason behind the non-replication of the pilot installation at Asore community across the state by the government as originally intentioned in the joint programme with Schneider Electric (see section 5.6). Another indication of low acceptance on the part of the government is the decision of the Lagos state government to revert to the use of diesel-powered generators due to the recorded high failure rates and poor performances of solar PV installations in the state as highlighted in section 3.5.1. Hence a score of '2' is awarded across the all the installations under ‘public and government acceptance’. On the indicator “Share of health centres and schools benefitting from installation”, it is noted that health centres and schools do not directly benefit from the installations at all the study locations while neither a health centre nor school exists at Ide II, hence, a score of ‘1’ is allocated to each of them except at Ide II where it is not applicable N/A. Also, since the installations at the first four study cases have become non-functional and non-beneficial to any member of the communities, the score of ‘0’ is awarded to each of them under “Share of population with access to water/electricity” while a score of ‘3’ is awarded to each of the remaining communities since the services rendered by the installations in the respective places are accessed by virtually every member of the communities

Table 5.4: Social-Ethical Development Indicators

Social-Ethical Development Indicators	**Study Cases** Absent (0); Present: Low (1); Medium(2); High (3)						
	Ide I	Ide II	Sagbo Kodji	Asore	Onib ambu	Umuag wu	Umuo de
Public and political acceptance	2	2	2	2	2	2	2
Share of health centres and schools benefitting from installation	1	N/A	1	1	1	1	1
Share of population with access to water/ electricity	0	0	0	0	3	3	3
Non-cultural conflict	3	3	3	3	3	3	3
Social equity in the deployment of RETs	3	1	3	3	3	3	3
Level of satisfaction with services	2	2	1	1	3	2	2
Awareness of users on potentials and limitations of the Technology	1	3	1	3	3	3	3
Active participation of all stakeholders in the choice/deployment of Installation	2	2	3	2	3	3	3
Cumulative score	**14**	**13**	**14**	**14**	**21**	**20**	**20**
Average score	**1.75**	**1.86**	**1.75**	**1.75**	**2.63**	**2.5**	**2.5**

Additionally, there was no case of conflict between an installation with the cultures or beliefs of the users at any of the study cases, hence, a score of ‘3’ is allotted across board under the indicator “Non-cultural conflict (i.e. does it have cultural acceptability?) With regards to “Social equity in the deployment of RETs”, a case of bias appears plausible in Ide II going by the size of the installation in relation to the number of residents in the community, and by the fact that it was deployed earlier than the one at Ide I as stated in section 5.4.2. Hence, whereas a score of ‘3’ is allotted to other study cases where no such bias is asserted, Ide II is allotted a score ‘1’.

Going by the narratives of the visit to each of the study cases as earlier reported in this chapter, the various scores allotted to each of the study cases under “Level of satisfaction with services” of the various installations are as shown on the table; these were gauged as at when the installations were functional. It is reported and observed that while the residents at Ide I and Ide II were moderately satisfied ith the services of their installations, those at Asore and Sagbokodji were less satisfied. Hence, a score of ‘2’ is allocated to the former two, while a score of ‘1’ is allocated to the latter two installations. Also, a score of ‘3’ is allocated to the installation at Onibambu where a high level of satisfaction was attested to by the residents (section 5.7), and score of ‘2’ at each of Umuagwu and Umuode where the level of satisfaction can also be adjudged to be moderate. A case of low ‘Awareness of users on the potentials and limitations of the Technology” was apparent at Ide I and Sagbokodji study cases where, respectively, the resident wanted water from the installation at all times (section 5.3.6) and there were allegations of attempts to tap electricity to individual homes (section 5.1.3). Hence, these two study cases are awarded a score of ‘1’ while a score of ‘3’ is allotted to the other study cases where such ignorance were not displayed by the users. Finally, it is observed that there was “Active participation of all stakeholders in the choice/deployment of Installation” of the installations at Sagbokodji, Onibambu, Umuagwu and Umuode, hence a score of ‘3’ for each of these study cases and a score of ‘2’ for Ide I, Ide II and Asore study cases which do not reflect such a widespread of stakeholders’ participation.

5.10.5 Institutional Development and Government Regulation Indicators

As stated in section 4.3.7, indicators relating to Marketing, Institutional development and government regulation can be regarded as general indicators in the context of this study since their effect would, to a large extent, be the same across all study cases and, as such, would not warrant a case study-by-case study evaluation. For example, relating to the issues of tax incentives/waivers, it is seen that such incentives are only partially available to solar panels and not extended to other batteries and other balance of system equipment (see section 5.1.4), hence . Similarly, on the indicator “competitiveness of current energy market prices”, it is noted that current energy market prices for grid electricity are far lower than the tariff paid for electricity produced by solar PV systems (see section 5.8) and, therefore, do not present the latter as competitive. A direct fallout of such disparity, in addition to absence of government incentives to involve the private sector in RETs deployment and diffusion, could be the discouragement of foreign investments and low degree of private sector participation in the sector since such investments would not be seen as profitable undertakings. Likewise, the absence of ‘legal/regulatory frameworks’ to enhance the use of RETs is reflected in the profoundly low contribution of solar PV installations to rural and urban electricity supply in the country as shown on Table 3.5. Similarly, there are no existing ‘standard and codes and certification’ for solar PV installations in the country even though government agencies (e.g. the Ministry of Rural Development) may have developed individual ones they follow. Finally, there appears to be no ‘regulation on use of local resources’. It is therefore seen that the impact of institutional development and government regulations indicators on the sustainable existence and performance of solar PV installations in rural communities have been quite low. Consequently, a score of “1” is allocate to them as indicated in Table 5.5.

Table 5.5: Institutional Development and Government Policies Indicators

Indicators	**Score**
Competitiveness of current energy market prices	1
Availability of Policies to reduce Trade Barriers	1
Degree of foreign investments in solar PV market	1
Opportunity for private participation	1
Legal/regulatory frameworks to enhance the use of solar PV systems?	1
Availability of standard and codes and certification	1
Regulation on use of local resources	1
Cumulative score	**7**
Average score	**1**

5.11 Discussion of findings from Case Studies

The average scores of each of the study cases across the five core sustainability dimensions employed in the study as obtained earlier are presented in Table 5.6. An analysis of the scores brings out a sharp difference between Ide I, Ide II, Sagbokodji and Asore as one group, and Onibambu, Umuagwu and Umuode as another. This can be attributed to the consistent low scores of the former group on many of the indicators in comparison to the latter as shown on the table. As highlighted earlier in this study (see sections 1.3, 2.4, 5.5.2 etc.), a series of low scores under technical indicators by an installation could suggest poor performances and low sustainability index of such installation. This is seen to characterize the first four cases in Table 5.6. It is pertinent to know though that such low scores in technical factors may not necessarily be due to the physical components that make up the system but could be the absence or limited presence of associated services that ensure effective functionality of such components. A case of this is the absence of skilled personnel and lack of training of local hands at Ide I, Ide II, Sagbokodji, and Asore communities.

Table 5.6: Average Scores of Indicators across Study Cases

	Indicators				
Study Case	Technical	Economic and Financial	Environmental Impact	Social-Ethical	Government Institutions
Ide I	1.0	0.86	2.3	1.75	1
Ide II	1.1	0.71	2.7	1.86	1
Sagbokodji	1.0	0.71	2.7	1.75	1
Asore	0.8	0.71	2.7	1.75	1
Onibambu	2.67	1.7	2.7	2.63	1
Umuagwu	2.56	1.5	2.3	2.5	1
Umuode	2.44	1.4	2.7	2.5	1

Economic and Financial indicators also reveal low average scores for Ide I, Ide II, Sagbokodji, and Asore communities in comparison to Onibambu, Umuagwu, and Umuode installations. As highlighted in section 5.10.2, since the former group of installations are not designed to be financially self-sustaining, the issues of profitability, share of profit set aside for re-investment, or share being used for businesses or income-generating activities are not applicable to them. In essence, the bulk of the financial requirements for maintenance, repair or replacement may still need be borne by the installing agency which in the cases of Ide I, Ide II and Sagbokodji installations are government agencies while Asore is a collaboration between government and an international company. However, as has been pointed out earlier, such government agencies often operate within fixed and limited budgetary allocations (see sections 2.3 and 5.1.1.1) which may not fully include provisions for the repair or maintenance of installed installations. In cases where such provisions are made, the financial allocations are often not released when they are due (see section 5.3.4). In addition, as highlighted in section 2.3, the support of donor agencies often terminates after the completion and donation of such electrification projects and most often do not involve post installation maintenance activities of the projects. A related issue to these is that the installations at Ide I, Ide II, and Sagbokodji are government-deployed installations that do not involve access to loan or credit facilities either to the installers or users. In contrast, the installations at Onibambu, Umuagwu and Umuode communities were carried out by private organisations through loans and grants made available by national and international bodies. The fact that 80% and 20% of such installations were funded by international and local donor agencies respectively (see section 5.8), suggests that local energy providers may not be able to accomplish much on their own without such financial backing.

The issue of proper electricity pricing and affordability of tariff appears contradictory. While it is established that appropriate tariff needs to be charged for investments in commercially-deployed installations to be profitable, it is equally necessary that such tariffs should be affordable by the users. However, while the energy providers are of the opinion that appropriate tariffs are being charged for both the profitability and sustainability of the installations (sections 5.1.4 and 5.8), the users at Onibambu (section 5.7) and Umuode (section 5.9) consider it affordable, but those at Umuagwu (section 5.8) consider it unaffordable. This is despite the fact that the tariff at Umuagwu and Umuode are comparable, and the two communities are neighbouring communities having residents with comparable occupation and social status. However, a related issue to this is the disparity between the tariff the rural dwellers pay for solar PV electricity and that being paid by urban consumers of grid electricity as highlighted in section 5.10.5. It is further noted that one of the causes of the wide gap presently existing between the price of grid electricity and that of solar PV is that current government subsidies in the former are not extended to the latter hence, solar PV electricity appears comparatively over-priced. A consequence of such disparity in prices is that rural dwellers, to whom the use of solar PV system may remain the only viable electricity option, may not be able to afford the cost of such systems while urban consumers, who are more likely to be able to afford such systems, may not consider it a necessity since the available grid electricity is much cheaper. Additionally, whereas the pricing of solar PV electricity appears deregulated such that individual energy provider sells electricity at a tariff considered profitable to the organisation, this is not same in the sales of grid electricity which is largely regulated by the government through the activities of the Nigerian Electricity Regulatory Commission NERC (see section 3.3.7). This may also suggests ambiguity about legal position for off-grid electricity in the country. It is therefore evident that private investors' participation in RE electrification programmes may not thrive under a purely deregulated solar PV market if grid electricity consumers continue to benefit from government subsidies that allows them to pay considerably lower tariffs those using off-grid electricity.

While solar PV installations are known to be quite environmental friendly due to their non-exhaustive nature, they could still have some negative environmental impact due to the amount of land required. The high scores obtained by each of the study cases against the indicators considered under environmental impact sustainability suggest that they do not possess any significant level of threat to the environment. However, an important issue which could not be assessed in the study is the environmental effects posed by old and unusable batteries such as the ones in ide II (see Figure 5.13) if not properly disposed of.

The social-ethical impact of solar PV installations is reflected in that using Solar PV installations for the provision of basic amenities like water and lighting in rural communities has been found to be beneficial to the village dwellers. Although there exist some disparities in the level of satisfaction in the services provided by each of the installations in the study cases as shown on Table 5.4, the fact that each provided a level of comfort to the rural dwellers is evident going by the testimonies of the residents *"It's a life changer"*(Section 5.3.1) and their disappointment as they recount their frustration over the non-functionality of the installation *"the installation functioned for barely 3 months after it was installed before it developed problems and ceased to function"*(Section 5.5.2). Despite this however, it is apparent from the study that, if properly managed, solar PV installations appear to be a better option than diesel generators. Reasons for this preference include the persistent challenge of accessing fossil fuel for generators as encountered in Ide (Section 5.3.1) which is not associated with solar PV installations. Similar expressions of frustration about the inability to obtain fuel when needed were encountered in Sagbokoji village where such generator-powered boreholes are found thereby putting additional financial burden on the users (section 5.5.2). The situation at Ide II where the solar PV installation has been abandoned and a fossil fuel generator borehole is being constructed may therefore not be considered an appropriate decision. However, consistent poor performances of solar PV installations as encountered in the cases of installations at Ide I, Sagbokoji and Asore communities may tend to make such expensive decisions inevitable. In addition to this is the perceived inequity in the deployment of the installations to rural locations as typified by the cases of Ide I and Ide II (section 5.4.5). This can be regarded as social injustice which could have dire outcomes.

As noted earlier, the impact of the Institutional Development and Government Regulation Indicators cut across all the study cases to the same degree. Comparing the Nepal and Bangladesh examples of National Rural Electrification programmes as highlighted in section 2.6 with the review of issues of the Nigerian energy and water status in CHAPTER 3 , and also the findings from this study, it appears Nigeria is yet to have an effective institutional and regulatory system in place that could support the widespread uptake of solar PV electrical solutions by rural dwellers.

Finally, it is important to note that there is no correlation between the failed systems and the type of installation (water, electricity, or water and electricity) as Table 4.1 tends to portray. Factors that contributed positively to successful systems will most likely have the same positive influence on failed systems had they been present. It however appears that private energy providers are more involved in the provision of electricity to rural communities due to the relative ease to provide and to meter electricity usage on a household-to-household basis whereas most water installations are provided on community scale and not on individual household basis. A factor that may also be related to the lower commercial viability of water installations to private energy providers is that most rural communities often possess alternative – though less hygienic – sources of water in the forms of hand-dug wells, streams etc which the provision of water installations on a commercial basis may not totally replace.

5.12 Chapter Summary

From the perspectives of different stakeholders, this chapter reveals the procedural stages, peculiarities and challenges involved in the process of deployment and utilisation of RE installations in rural locations, and also presents the outcomes of the visits to each of the study cases. Specifically, it highlights the factors that are involved in the process of determining the choice of locations for deployment of solar PV installations to post-installation maintenance procedures put in place by government agencies or private bodies. It further reveals the viewpoints of local contractors, energy providers and technical partners with regards to diverse issues impacting on the solar PV sector in the country. The chapter also details the findings from each of the study cases and presents these under five core sustainability dimensions of Technical, Economical/Financial, Environmental Impact, Social-Ethical Development, and Institutional Development and Government Policies indicators. The level of impact of constituting indicators under each of these sustainability dimensions are further evaluated and presented as on a 4-tier scoring system as Absent (0), Low (1), Medium (2) or High (3) based on the degree of incidence or occurrence of the indicators in each of the study cases. It is found that while the installations at Ide I, Ide II, Sagbokodji and Asore are characterised by low scores under Technical and Economic/ Financial indicators, those at Onibambu, Umuagwu and Umuode communities have consistently high scores. However, whereas there are also disparities in the cumulative scores obtained by these two sets of study cases under Socio-Ethical and Environmental indicators, these are not as profound as in the Technical and Economic/ Financial indicators. Finally, it is highlighted that the effect of Institutional Development and Government Regulation indicators cut across the study cases to the same depth, hence, they are discussed as such and not aggregated on a case-by-case basis. Finally, it was highlighted that there is no definite relationship between failed or successful installations and the type of installation.

The outcome of this chapter as presented form the basis from which further analysis and integration is carried out in the next chapter.

CHAPTER 6 Integration of Findings and Development of Framework

In the light of the outcomes of the interview sessions held with various stakeholders involved in the deployment of solar PV installations, and the findings from the study cases as detailed in the last chapter, this chapter will integrate and correlate these together along common themes. This will help to generate the factors that constitute a framework for, and underpin recommendations about, solar PV installations in rural locations in Nigeria. The outcomes of these will form the basis of an improved framework and set of recommendations that can aid the effective deployment and performance of the installations in rural location in Nigeria.

6.1 Discussion and Integration of Findings

As seen in sections 5.2 to 5.9 and highlighted in section 5.11, the study cases can be grouped into two: the installations which were deployed by private energy providers through collaborative efforts of national and international funding organisations on commercial (i.e. income-generating) basis which are noted to have been quite successful, and those deployed solely by government agencies on non-commercial basis either directly or through government contractors and have been found to be less successful. This former group can be related to the Nepal rural electrification efforts in which the deliberate attempt by government to involve the participation of the private sector, in addition to providing varied forms of financial incentives and subsidies as highlighted in section 2.6.1 are regarded to have contributed the success of the programs. In the case of Bangladesh as highlighted in section 2.6.2, the formation of strong and functional institutions played a major role in the recorded success. This is specifically seen in the role played by the Infrastructure Development Company Limited (IDCOL) which supervised the implementation and operation of off-grid renewable energy projects being carried out mainly by Non-governmental organisations (NGOs) and Partner Organisations (POs), while the POs were additionally financially empowered through soft loans from international donor organisations and equity funds from the government. However, the review of the Nigerian renewable energy situation in CHAPTER 3 and the study cases reveal that such efforts are, at best, weak where they exists at all in the country. Whereas government organisation such as Rural Electrification Agency (REA) and the Ministry of Rural Development (MRD) exist in this respect, they appear to be more involved in awards of contracts while many of the projects handled by the REA appear to be electrification through grid extension or diesel generators, and distribution of transformers (see section 3.4.1).

The following sections discuss in more depth the attributes which may have influenced the performances of the installations at each of the study cases.

6.1.1 Factors influencing the performance of Installations

A plot of the average scores of the study cases as presented on Table 5.6 is shown in Figure 6.1. It reveals that for each dimension, the scores are much higher for Onibambu, Umuagwu, and Umuode study cases compared to those of Ide I, Ide II, Sagbokodji, and Asore. The factors that may have influenced such disparities are discussed below.

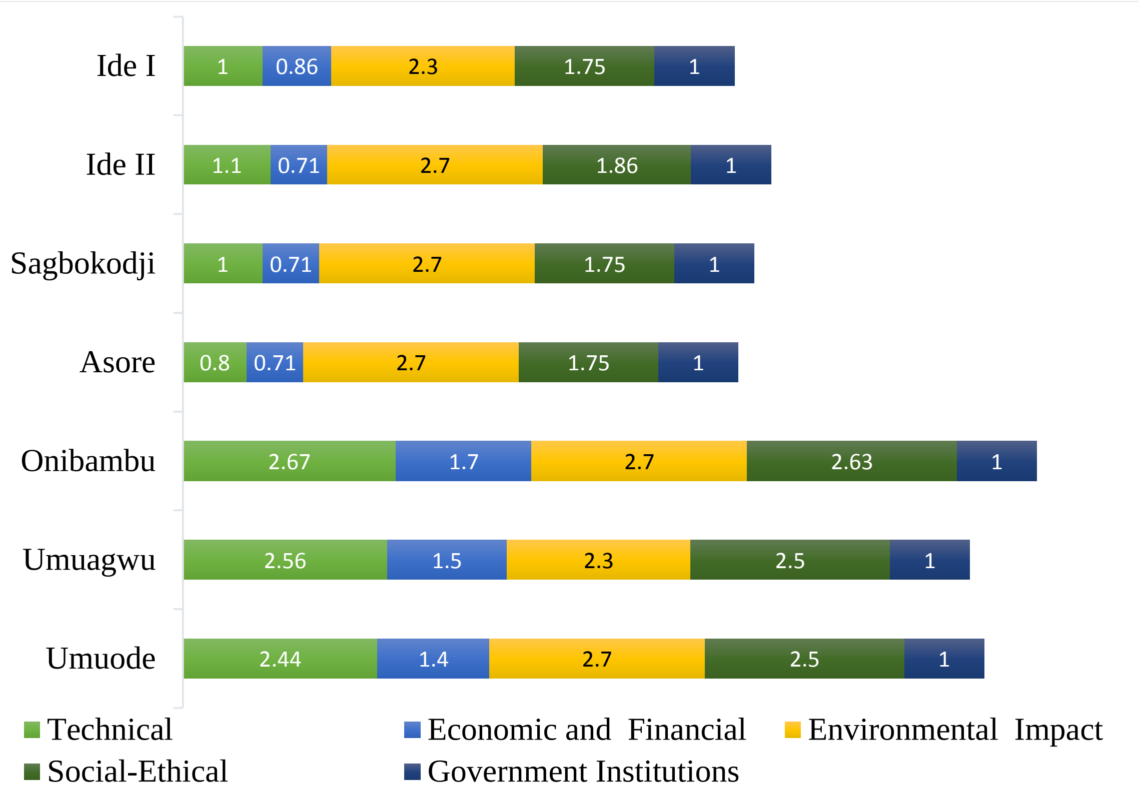

Figure 6.1: Plot of Average scores of study cases on all indicators

i. *Provision of Effective Post-installation Maintenance Arrangement*: The evidences at the study locations align with the findings from the review of some solar PV rural electricity projects (sections 3.5) and discussion with officers of the Lagos State Electricity Board LSEB (section 5.1.2) where the absence or inadequate post-installation maintenance is noted as one of the reasons for failed solar PV projects in the country. A major feature of the more successful installations is the implementation of effective and long-lasting post installation maintenance arrangements. These, in each of Onibambu, Umuagwu and Umuode involved a 3-level arrangement involving locals to take care of minor faults, technical personnel who reside in proximate towns for major faults, and technical partners for more complex faults (see section 5.1.4). The structure ensured that faults are effectively attended to as they occur thereby reducing the down time[1] of the installations and improving customers' satisfaction. On the contrary, it appears that the absence of such concrete maintenance arrangements and slow response to faults contributed to the failure and eventual breakdown of the installations at Ide I, Ide II, Sagbokodji and Asore communities as reported in sections 5.3 - 5.6. Also, evidence of active involvement of locals in carrying out basic installation and repairs exists in Onibambu and Umuode communities (see Figure 5.23), and the initiative has proved effective. In addition, locals can be taught how to exploit modern technologies to reduce the down time of an installation. This could be as basic as using the camera features of mobile phones to take pictures of an installation when it has visible faults and sending these to the supervising agency using the Multimedia Messaging Service (MMS), rather than making voice calls only. Similar applications of mobile phone technology have been adopted by farmers in rural India to help ease their workload by enabling them to turn on the water pumps which irrigate their crops without having to walk miles to the location of the pumps (BBC, 2012). A system in which solar photovoltaic systems in rural locations can be remotely monitored using GSM voice channel is presented by Tejwani et al., (2014). In reference to the study locations, the time lost by the technician having to go for the right tools after appraising the faults on the installation at Ide I village (section 5.3.1) could have been avoided.

Nonetheless, it appears that slow response by government agencies to issues regarding maintenance is not peculiar to RE installations as observed in the case of Ide I where

[1] The period of time an equipment is not available for use due to maintenance or breakdown.

renovations of a block of classrooms and part of the staff building were carried out in 2013 with a 2011 budgetary allocation.

ii. Type of Business Model/ Manner of Private Sector Participation: The three installations that appear to have better overall performances are commercial-based ones deployed on a *financial institution and energy company partnership* business model as highlighted in section 2.3.3.2. As stated on Table 2.3, an advantage of this model is that each partner is able to focus on core competencies, and also to pool resources for improved services. In this regard, it is also seen that since the profitability of an installation is based on the reliability of its functionality, the likelihood is that the energy provider will continually see to it that such installations remain functional by providing effective post-installation maintenance to maximise income. This is in contrast to government-deployed installations where, in most cases as typified by Ide I, Ide II and Sagbokodji installations, consumers do not pay for the service. In such cases, the human and financial resources requirements to ensure continuous functioning of the installation remain government-dependent. However, this is often not available, slow to arrive, or available for only a short-term.

The characteristics of the three successful installations and three non-successful ones as revealed from the study cases are shown on**Error! Reference source not found.**

Table 6.1: Features of Business Models of Study Cases

	Financial Institution Partnered with Energy Enterprise (Onibambu, Umuagwu and Umuode)	**One-Stop-Shop** (Ide I, Ide II and Sagbokodji)
Financial Commitments	A level of financial commitment by the energy provider while donor organisations provide the major part	Low level of financial commitment on the part of the contractor. In most cases, contractors are wholly mobilised financially by the agency awarding the contract
Profit-taking	Not immediate. Often a number of years after completion	Immediately after completion of project
Post-Installation Maintenance	Provision of standard post-installation maintenance enhances profit as profitability of an installation is tied to its performance.	Provision of standard maintenance may not be embedded in the contractual agreement and does not influence profit
Risk Sharing	Joint risk shared between Energy Provider and financing bodies	Risk is not borne by the contractor in the case of failure of the installation

Another noted feature relates to the manner of involvement of the private sector between the failed installations and the successful ones. This is typified by the failed Sagbokodji and Ide II installations which were deployed by the private sector as contracts awarded by government agencies (see section 5.1.3 and Figure 5.12). Under this arrangement, the contractor is often paid off after the successful completion of the project, hence 'profit-taking' on the part of the contractor is not dependent on a long-term functioning of the installation. Hence, while it may not be practicable for government supervising agencies to have personnel in all remote rural locations, they could develop scheduled preventive maintenance visits to RE systems installed in these places. In addition, post-installation maintenance agreements can be included as part of the contractual terms in the award of these solar PV installations to contractors. Such agreements could require contractors to carry out both preventive and corrective maintenance on such systems for specified periods after installation. This appears not to be the practice presently as affirmed by a contractor (section 5.1.3) who stated that the MST did not enter into any maintenance contractual arrangement with him.

The success and failures of solar PV installations in a number of countries including Nepal, Bangladesh, Mali, Senegal, and Kenya which were presented in section 2.6 highlighted the roles played by different institutions including government, private investors and international donor organisations, and the different business models employed in each case. Whereas, as stated in section 2.7, there appears to be no standard approach for rural electrification that could be employed across countries, specific lessons can be learned from each case and, where applicable, introduced into the Nigerian context. The successful deployment and performance of RE installations in Nepal, Bangladesh and Mali are notable examples of the vibrant roles that can be played by the private sector and donor organisations. In Nepal, the waiver of official licencing fees for private investors' participation, and the introduction of various forms of subsidy, equity and credit mechanisms led to the wide spread take up of RE in rural locations. In the same vein, the success in Bangladesh was largely due to factors such as the setting up of a strong institutional framework and the development, implementation and adherence to standardized procedures and practices that enabled active participation of partner (private) organisations. Similarly, in Kenya, active private sector participation was buoyed by significant government involvement in terms of policies and indirect participation such as price and foreign exchange control, reduction of import duties on photo-voltaic modules, and removal of value added tax (VAT). In contrast, the failed cases in this study are fully government-funded projects where the private sector only played the role of the contractor. It is argued (see section 3.3.1) that where government has been the sole financier in rural electrification projects, the desired results have often not been produced. Therefore, a departure from such an approach to another model that would involve the active participation of both the private sector and foreign investors in rural electrification may be considered.

While the Nigerian government has recently initiated some measures relating to the de-regularisation of the electricity sector and this has led to the participation of the private sector and enhanced urban electrification, there has not been commensurate improvement in rural areas. The uneconomic features of rural locations such as low level of consumption, and lack of industrial load make them unattractive to private investors. Hence, there is the need to develop and implement specifically targeted additional actions such as improved tax rebates to stimulate rural electrification development. In addition, although Nigeria has relatively low taxation which private investors could find attractive (with VAT at just 5%), other prevailing issues such as threats to political stability, and risks of terrorism - Islamic insurgency in the North and militancy in the Niger Delta region - (see section 2.4) can harm investors' confidence. This may need to be addressed to stimulate the improved participation of both the private sector and international donor organisations in the deployment of solar PV systems to rural locations that is commensurate to the levels experienced in Mali and Bangladesh.

iii. Non-existence of local representative authorities and failure to train local residents on basic maintenance:

A notable difference between the successful and the failed cases is the existence of vibrant Community Development Associations (CDAs) coupled with the participation of trained local residents to carry out basic maintenance works. Whereas MRD officials highlighted the necessity of Community Development Associations CDAs that could serve as representative bodies and communication channels in matters between the communities and the MRD (section 5.1.1.1), such associations do not exist in Ide I, Ide II, and Asore communities. As seen in the Bangladesh rural electrification scheme, the formation of CDAs could be a main driver for the widespread of *individual household* solar PV systems such as the Solar Home Systems (SHS). Such a properly structured body constituted and run by community members provides a platform for proper local maintenance and administrative activities which are crucial to the performance of the installations in Onibambu, Umuagwu and Umuode communities, and could also enhance private ownership of household installations through the provision of loans as seen in the Bangladeshi case (section 2.6.2). The relevance of such local bodies in the form of cooperative groups in rural electricity services is further highlighted in a study by Yadoo and Cruickshank (2010) which recognises their existence as an efficient and effective means of extending and managing rural electricity services.

iv. Incorrect design and incompetent contractors

The interview session with the officers of the Lagos State Electricity Board LSEB (section 5.1.2) revealed a challenge with respect to a scarcity of well-trained and competent contractors that understand the intricacies of RE installations. While this challenge was not directly highlighted by officers of the Ministry of Rural Development MRD (Section 5.1.1), it appears that the award of RE installations to contractors by the Ministry is skewed mainly towards the economic considerations rather than the technical competence of the bids submitted by them. This can be deduced from the explanation of the MRD officials that *in most cases, the contractor with the lowest financial bid is awarded the contract* (section 5.1.1.2). A general effect of poorly designed installations, or the use of incompetent contractors is the underperformance or failure of such installations. Such underperformances or failure tend to give credence to existing prejudices against solar PV installations, such as that shown by the Lagos state government in reverting to power streetlights on major roads in the state by diesel-powered generators after the earlier failed attempts to power the streetlights from solar PV systems (see sections 3.3.1 and 5.1.2).

v. Distorted decision process and absence of equity in deployment process

Whereas the MRD appears to have a robust decision process for deployment of installations to communities, this seems not to be followed strictly as seen in the case of Ide I community (Section 5.3) and Ide II community (Section 5.4) which were both handled by the MRD and in which the latter got a bigger installation deployed to it earlier than the former. While such allegation may not be founded, the absence of transparent standards (or failure to adhere to them where such exist) in the deployment of RET installations could breed resentment and envy among erstwhile peaceful neighbouring communities; the outcome of which may negate the positive objectives such installations were meant to achieve. In addition, such political interference and influences could harm the confidence of private investors and donor organisations, and thereby discourage them from actively participating in the renewable energy sector.

vi. Limited understanding by users of the potential and limitations of the installation

A related issue to the training of locals in basic maintenance activities of solar PV installations is the need for clear operating instructions and guidelines for the efficient operation of the installations. This is exemplified by the Sagbokoji settlement where alleged misuse through illegal connections by the residents may have led to the repetitive faults on the installation in the community. This presumption is based on recurrence of the fault each time the installation was repaired (section 5.5.2), and also on the findings of the contractor (section 5.1.3) which alluded to such actions by the residents. It is apparent that the absence, or inadequate dissemination, of such instructions may cause the users to take actions that could impact negatively on the system. It is also important that users are informed about the rules and safe practices with regards to the installation in their communities. This is especially so when the users are rural dwellers who may not know why, for example, actions such as the illegal connection of electricity to their homes could negatively impact on the installation by reducing its efficiency or resulting in its breakdown as was allegedly the case in the Sagbokodji community.

vii. Overlapping functions of government agencies

From the study cases, it appears that government agencies work discordantly while attempting to achieve the same goal of improved water and energy access to rural locations. A case of this is reported in section 5.5.2 where the solar PV installation, and the two other borehole projects in the community were handled by different government agencies.

While it is understandable that a separate agencies may be necessary to handle rural and urban installations, rather than having a number of independent government bodies involved in the deployment and installation of solar PV systems to rural locations, a more practical and more efficient approach could be to merge the individual resources of theses bodies to augment one another in a single central body that regulates the implementation of such installations. Whereas the Rural Electrification Agency (REA) is set up to play this role, it is seen that a number of rural electrification projects are being executed without the involvement or coordination of the agency; example of these are the projects handled by the Bank of Industry (BoI) across the country. One possible effect of this is a lack of standardization in deployed projects and inadequate or unrealistic data to make strategic decisions. In addition, under such an improved approach, a body such as the Ministry of Science and Technology (MST) may not get involved in the direct installation, but could provide technical-related expertise to the regulating body. Alternatively, forums where the agencies could collaborate and share ideas for joint improvement may be set up. This is exemplified by the Lagos State Electricity Board's criteria and standards for solar installations and the introduction of standard practices to be adhered by both contractors and end users in order to improve systems' design and performance (section 5.1.2). While the existing criteria and standards are for urban electrification projects, they could be modified and adopted for the rural energy sector.

viii. Non-involvement of end users in decision process

There is no indication in any of the study cases that the residents were consulted prior to having the solar PV installations deployed in any of the locations where the installations failed. While this may be attributed to the fact that the installations were not for commercial purposes, the benefit of such an exercise could be ascertained from suggestions raised by the residents with respect of location of systems and location of taps (sections 5.1.1.3; 5.3.4). Hence, holding regular forums between supervising agencies and end users for the purpose of sharing and gathering of constructive opinions may lead to the improved performance of local solar PV installations, and also enhance the bond between the installing agency and the community.

ix. Weak implementation and low success of Government policies

Although the country has developed a number of policies designed to increase total electricity generation, and raise the contribution of renewable energy in the energy mix, realities on ground show that the strategies towards these objectives are often not being totally implemented. Whereas the "Renewable Energy Policy Guidelines of 2006" *recognise that a large percentage of rural areas will remain without electricity even with increased power generation from conventional sources and grid extensions, and further states that, "accelerating rural electrification coverage will require an aggressive deployment of multiple supply options and business delivery systems*" (section 3.3.8,) findings from this study do not reflect such an aggressive deployment of such supply options and business delivery systems of the types encountered in the cases of Bangladesh and Kenya (sections 2.6.1 and 2.6.2 respectively).

While noticeable achievements are being made towards improving grid electricity from conventional sources through on-going deregulation and the subsequent opening up of the sector to private investors (section 3.3.1), the efforts at improving rural electrification are considerably weaker. This gives credence to the opinion of Cherni and Preston (2007) that the provision of electricity to rural areas has often been neglected during the privatization and liberalization of the electricity sector.

Hence, there is need to align policies with concerted efforts and practices to enhance rural electrification, especially renewable energy and solar PV systems. In addition, the Presidential Task Force on Power (see section 3.3.8) needs to ensure, and monitor, the implementation of the various reforms in the country's power sector. Such a necessity is illustrated in the interview sessions held with the personnel of the MRD in section 5.1.1 which highlights the pre and post-installation decisions and actions taken by the agency towards the deployment and performance of solar PV installations to rural locations in the country. However, the two case studies involving the MRD revealed that not all pre and post deployment processes enumerated by officials are either present or undertaken by the agency in the deployment of RE systems in rural communities. This is seen in the absence of trained locals for basic maintenance purposes as reported in Ide I (section 5.3.2) and in Sagbokoji community (section 5.5.2) while the assertion by many residents of Ide I regarding the ownership of the installation in the community (section 5.3.2) suggests that the MRD either did not carry out such transfer, or it was not publicly done, in contrast to earlier assertion by officials of the agency.

In addition, it is important to note that the factors listed above as influencing the performance of installations may have varying effects, hence it may be necessary to provide an indication of the relative importance of these factors in terms of their effectiveness against the cost/efforts required to provide them towards improved and sustained performance of installations; an indication of this is provided in Figure 6.2.

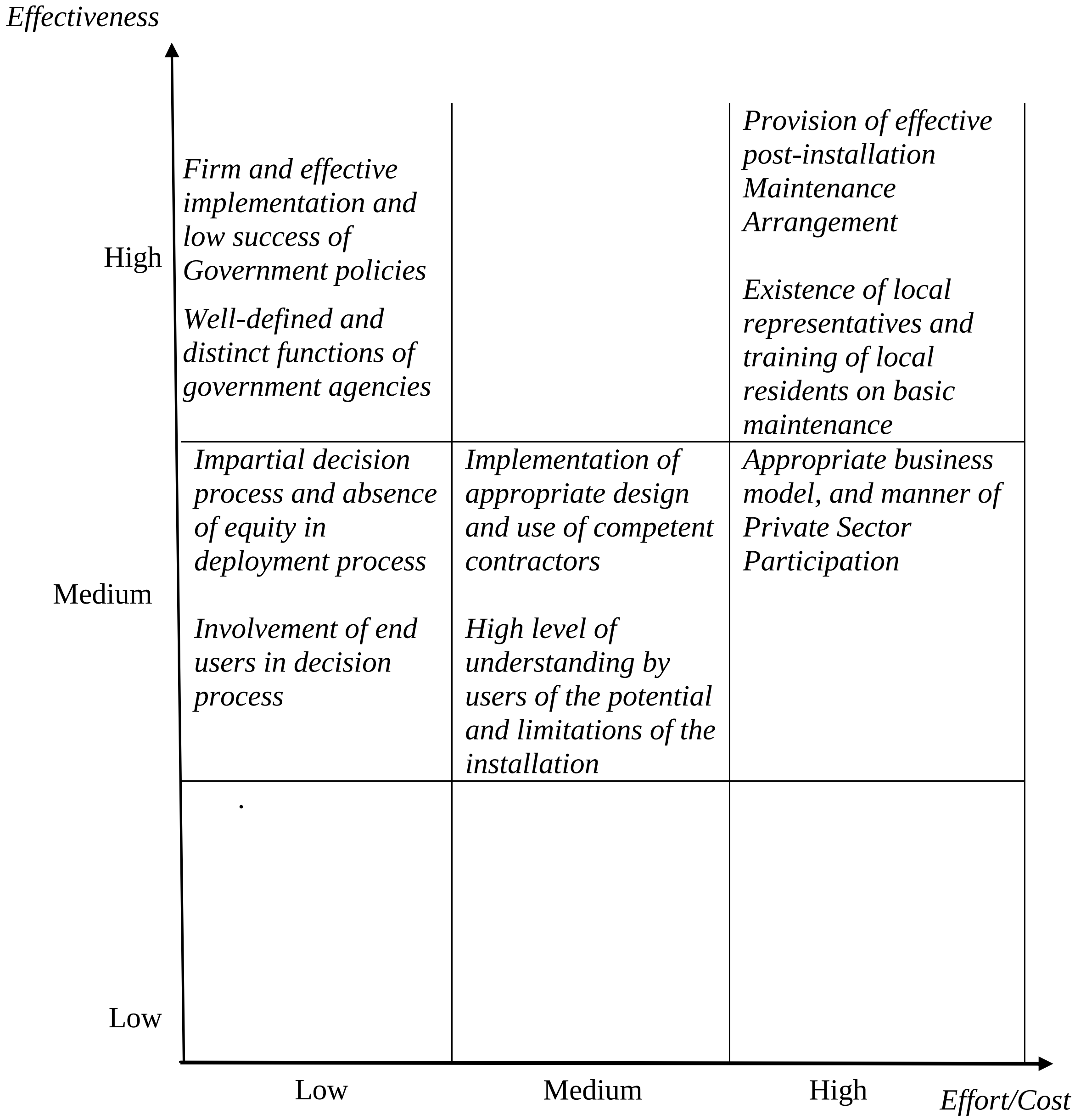

Figure 6.2: Relative importance of factors influencing systems' performances

Nevertheless, it is equally important to emphasize that all the factors work in harmony for a successful system, hence the implementation of all of them is key. In this regard, the absence of a factor can trigger a chain reaction that could lead to the underperformance of an installation. This is further discussed in section 6.3 and depicted by Figure 6.3**.**

6.2 Analysis of current situation by Sustainability Dimensions

From the discussion and integration of findings in the previous section, it is observed that the positive effects of using solar PV installations in the provision of basic amenities such as water and lighting to rural communities have both been aided and impaired by a myriad of technical, human, economic issues, and governmental factors. It is also revealed that these factors can be influenced by government and consumer actions and could therefore contribute to the framework for improved deployment and performance of solar PV installations. This is presented in Table 6.2, and subsequently used to support additional recommendations for improved performance.

Table 6.2: Recommendations for Effective Deployment and Performance of Rural RE Installations

	Inquiry	Finding/current status	Recommendation
Technical Indicators	Is there sufficient local knowledge and skills to implement, maintain, and repair RE infrastructures?	Lack of local knowledge and skills to implement maintenance and repairs (sections 5.3)	Only contractors with technical competence will carry out installation of RE installations. Training of local maintenance and repairs committee members must be embedded in the contractual agreement of engaged contractors.
	Is the Technology simple and technically feasible?	Though PV Technology appears simple, it often requires additional hardware such as battery and inverters (section 2.2)	Where feasible, battery-free (dc) systems should be considered (e.g for water pumping) over ac systems, while the latter is used lighting purposes
	Does the present arrangement facilitate fast response to faults? Are the materials required for implementation and repairs available?	Response to fault is slow; materials required for repairs and maintenance is not readily available (section 5.3))	Provision of materials necessary for regular maintenance and repairs must be made available at local government levels
	Are there appropriate technical standards for RETs to be deployed to different communities?	Technical specifications exist based on population of communities (section 5.1.1.1) but these are not being rigidly implemented (section 5.4.5)	The technical specifications of RETs deployed must be proportionate to population sizes of communities
Financial/Economic	Financial incentives (e.g. access to loan, credit facilities) available to consumers?	Absence of financial incentives that could enhance individual ownership of SHS by rural users (sections 2.4.1 and 3.5.3)	Credit and soft loan facilities should be provided for rural users to encourage ownership of SHS. Creation of enabling financial environment, introduction of incentives such as import duty waivers and tax concessions to stimulate private sector participation
	Are there measures to reduce the cost of RETs e.g. reduced taxes on imported RETs hardware?	Absence of measures on reduction of cost of solar PV hardware (section 5.5.3)	
	Are the current energy market prices competitive?	Current grid electricity prices are unrealistically low due to prevailing subsidies. This puts PV energy cost at disadvantage (sections 2.4 and 5.8	A gradual removal of subsidy on grid energy; conversely, an introduction of subsidy on PV energy needs to be implemented

	Does the market encourage foreign investments and private sector participation?	The present market does not encourage foreign investments; neither does it encourage private sector participation in rural deployment of PV technologies (section 5.10.5)	A liberalised market with prospects for profit- making is necessary
Socio-cultural /Ethical	Does it have any harmful effect?	PV technology does not present any harmful effect to the community where it is being utilised, neither does it possess any known cultural intolerance (section 5.3.6)	Based on cultural considerations, solar PV technology may have a better cultural receptivity over other forms of RE technologies since it has no known cultural conflict with the users
	Does the use of the RETs conflict with the culture of the users (i.e. does it have cultural acceptability?)		
	Is there social equity in the deployment of RETs (such as not to breed animosity between communities)?	Lack of equity exists in the deployment of solar PV installations to rural locations (section 5.4.5)	Laid down guidelines based on unbiased set of decision process must be employed in the deployment of RETs
	Is there appropriate information and awareness on the potentials and limitations of the Technology?	Low level of awareness by rural users about PV installations (section 5.5.3)	Appropriate information provided about the potential and limitations of RETs
	Is there active participation of all relevant actors/stakeholders in the deployment of RETs?	Not all relevant actors are involved in the decision process (section 6.1.1)	The opinions of all relevant actors must be sought and considered in the development of decision processes.
Government Policies	Are legal/regulatory frameworks to enhance the use of solar PV installations available?	Existing regulatory and legal policies to increase the use of solar PV systems are weak (section 6.1.1)	Further development and implementation of policies that imparts positively on rural electrification
	Are there policies/political support to encourage the use of RETs?	RE policies exist (section 3.3.2) but political support is low	Political support must be given to existing RE policies to facilitate their implementation
	Do government agencies have well-defined responsibilities with respect to the take-up of RE technologies?	Overlapping of functions exist among government agencies in addition to absence of collaboration (section 6.1.1)	Government agencies must possess well-defined roles and responsibilities to enhance the spread of RETs. In addition, collaboration among various government agencies must be encouraged.

Another important feature that can be obtained from the study as discussed in section 2.4.1 is the connection and inter-relationship among the various factors discussed above and how they influence one another. This could aid the development of a robust framework for improved deployment and performance.

6.3 Interconnection between factors - towards an evaluative framework for RET performance

Apart from determining the specific factors that have negatively affected the diffusion and performance of solar PV installations in rural Nigeria as highlighted in the previous section, it is also necessary to note that many of these factors are inter-connected, such that the presence of one or more of them could trigger some other ones into existence or non-existence, and these could combine to positively or negatively influence the performance of such installations.

A case of such interconnections is observed in the politically influenced installation at Ide II (sections 5.4) which created a level of bitterness and jealousy among the residents of the Ide I. In this same vein, failure to provide fast and effective maintenance could have led to the installation to be vandalised as in Sagbokoji (section 5.5). However, a number of interconnected factors may impact more directly on the uptake, rather than the performance of RETs. As noted in CHAPTER 2 and section 6.1.1, favourable government policies such as appropriate investment in RE technologies, waiver of income tax on RE materials, accessibility to low-interest loans, etc., could bring down the cost of solar PV systems and make them more affordable to rural dwellers; thereby leading to the widespread uptake of such systems. In addition, it is observed from the study that the support of local financial bodies and international donor organisations enabled more pragmatic and successful participation of the private sector as demonstrated by Onibambu, Umuagwu and Umuode installations.

The need to study the interrelationship between various factors highlights the importance of systems feedback (vicious and virtuous cycles) and the existence of various unintended consequences (Lemon, 1999). Figure 6.3 depicts three loops of such interconnections of some of the factors that have been revealed to influence the low take-up and poor performances of solar PV installations as encountered in the study. The upper loop portrays the findings at Sagbokoji village where the absence of effective maintenance/support infrastructures led to the withdrawal of the local security arrangement and the subsequent damage/sabotage of the installation as represented by blocks 1, 2, and 3. As mentioned in sections 3.3.1 and 5.1.2, the underperformance and failure of solar streetlights installed by the Lagos state government discouraged further investments in such installations by the state government (block 4), which could lead to a low spread of RE systems (block 5). One possible effect of such low spread of RE installations is the unavailability of qualified technicians (block 6) and the subsequent use of unqualified ones, leading to wrongly-installed systems (block 7); these are depicted by the middle loop. Finally, as earlier discussed, unfavourable government policies (block 8) such as the absence of incentives (e.g. absence of import duty waivers on component parts of RE installations) may lead to high cost of RE systems (block 9) and also dicourage active participation of the private sector. These may combine to further result in a low spread of RETs (block 5) – a possible effect of which has been discussed earlier -, while such low spread may, inturn, contributes to their high cost. Such interrelations are represented by the last loop.

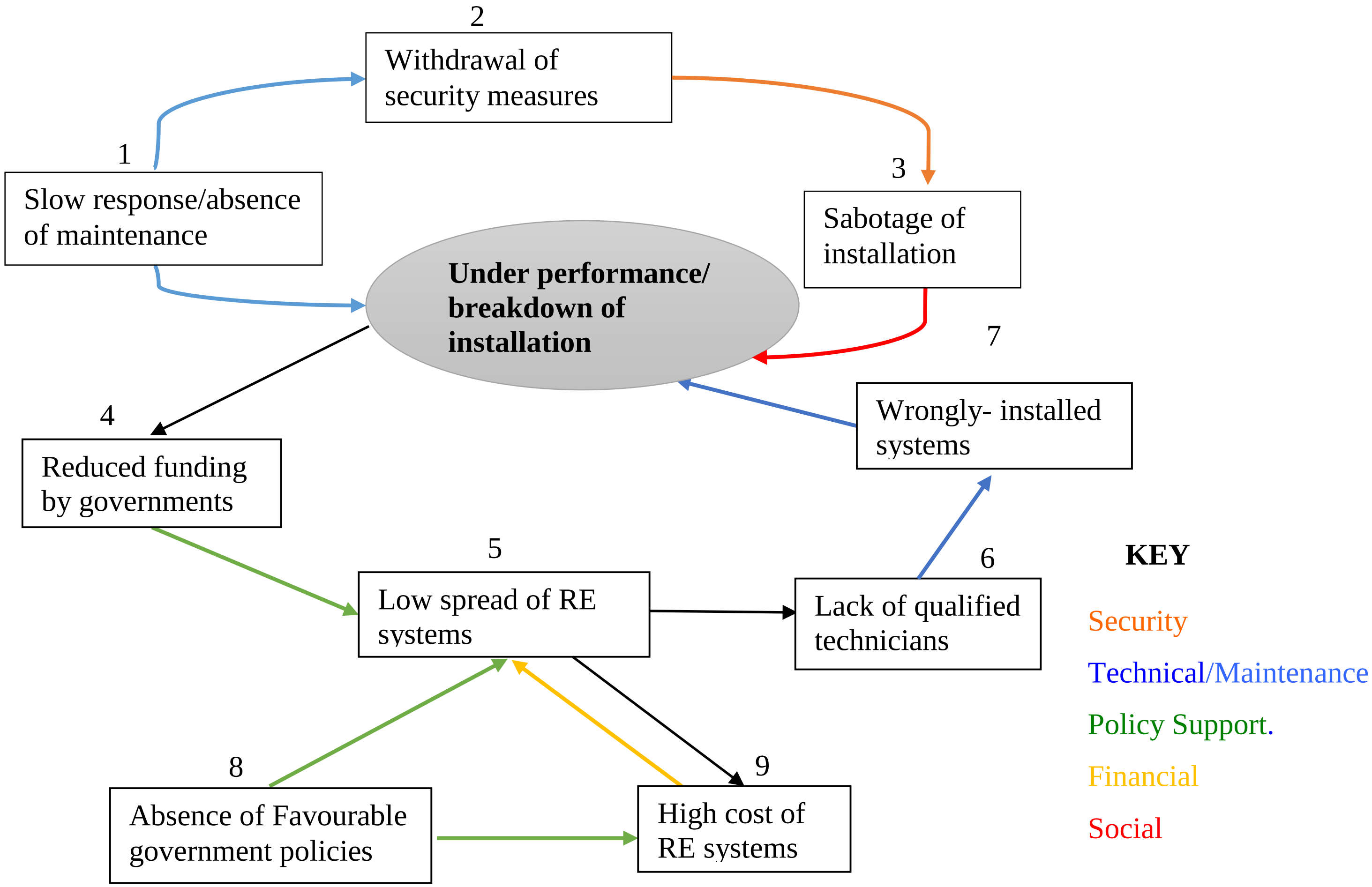

Figure 6.3: Interconnection of factors against the uptake and performance of Rural Solar PV Installations

6.4 Development of Framework

The findings from this study have revealed varied factors which aid and impede the effective deployment and efficient performance of solar PV installations in rural communities in Nigeria and their interrelationship, and as such, could provide a basis for the development of a framework for improved performance.

A main finding of this study is that the involvement of private energy providers in the deployment and running of solar PV installations in rural communities in the country tends to be more effective than the sole involvement of government agencies or contractors due to the provision of close monitoring, control and other post-installation maintenance activities by the energy providers. It was also revealed that the existence of strong institutions is fundamental to improved performances of solar PV installations in rural communities. Government institution and regulations in particularly are likely to influence other indicators in technical, economic, financial, and social-ethical dimensions. This can be seen from the fact that indicators such as the competitiveness of current energy market prices, availability of policies to reduce trade barriers, encouragement of foreign investments, opportunity for private participation, availability of legal/regulatory frameworks to enhance the use of RETs, and availability of standard and codes are all, to a large extent, dependent on the existence on strong government institutions and regulations. Hence, while the roles played by government and other stakeholders have mutual objectives, many of the roles played by other stakeholders such as private investors and international donor organisations are largely determined by government decisions. On the other hand, the behavioural patterns and other activities of the end users (consumers) – rural dwellers in this study – have been seen to equally influence the performance of the installations (see sections 5.1.3, 5.4.1, 5.5.1, etc). The framework as shown in Figure 6.4 is therefore developed along two paths: government roles and consumers' roles.

6.4.1 Role of Government: Formation of Strong and Transparent Institutions

The literature review and case studies presented above have identified a number of diverse factors that interplay towards achieving effective diffusion of RE installations to rural locations. The establishment of strong institutions are found to be a fundamental function of the government.

The framework for the effective deployment, diffusion, and performance of RETs in rural off-grid locations in Nigeria, as presented in Figure 6.4, is developed based on the findings that the roles of government, private sector and NGOs, and consumers are pivotal to the success of such undertakings as highlighted in section 6.1. Hence, in the framework, the development and implementation of required measures are premised on these roles - which are respectively shown as blocks A,B and C. It is from these three that all other requisite actions emanate.

As noted earlier in section 2.6.4, electricity levels are often more strongly related to government effectiveness in sub-Saharan African countries than other countries on the continent. Also, total foreign investment is greater in countries with good governance and characterised by low corruption indices and high political stability indicators (Morrissey and Udomkerdmongkol 2012). Hence, it is seen that such involvement is tied to the existence of strong and functional institutions such as a vibrant capital market and effective regulatory and legal structures that will not only improve the profitability of investments, but also provide assurance that appropriate fiscal guidelines for grants will be followed. The establishment of such functional institutional structures is a basic function of the government and is shown as block 'D' of Figure 6.4.

While reforms in the Nigerian energy sector as presented in section 3.3.1 has brought about the creation of various institutions including the Nigerian Electricity Regulatory Commission NERC, Rural Electrification Agency REA, and Presidential Task Force on Power PTFP, their activities in the rural electrification sector, especially in the use RE systems, have hardly been evident. Hence, related issues relating to policies (section 3.3.2), and tariffs (sections 5.8), legal and awareness that need to be objectively determined and implemented with a high level of transparency are represented in blocks G, H, I, and J. Typical consequences relating to poor transparency have been discussed in section 6.1. An example of such a situation is seen in the discontinuation of pre-paid meters to consumers by new investors in the electricity sector despite the fact that the pre-paid meters ensure consumers only pay for the units of energy consumed (section 3.3.1).

Specific functions of blocks G, H, I, and J are contained in G_1, H_1, I_1 and J_1 respectively. These functions are detailed in Table 6.3; they include the development and implementation of ethics, standards, specifications and policies that could impact positively on rural electrification, and would ensure that all standards and guidelines relating to rural electrification are strictly adhered to by all players in the sector. The role a regulatory and monitoring institution (block G) can play is seen in the case of the divergence between policy objectives and practice as highlighted by the failure of government agency to transfer ownership of installed RE system to benefiting community (section 5.3.6).

The financial and market institution (block H) recommends the creation of an enabling environment that could encourage the participation of the private sector and attract foreign investors as discussed in section 6.1. Such an institution would also develop financial facilities that could make the uptake of RE technology options more affordable to the end users. Hence, specific functions of the financial and market institutions will be to recommend the development and implementation of financial incentives such as import duty waivers on component parts of RE installations, tax concessions to firms involved in the deployment of RE installations to rural locations, liberalised financial market and facilitation of soft loans to low-income consumers (block H_1 in Figure 6.4).

Furthermore, a primary concern of foreign investors is the safety of the investments provided by the legal systems of the host country (Czinkota and Skuba 2014). Hence, the establishment of a legal institution is represented in block I while the functions of such an institution in the provision of a legal framework that would attract and protect foreign and private participation in the widespread adoption of RETs in rural locations are represented by I_1. However, while the legal system in itself is of crucial importance, it is often the absence of laws or a lack of enforcement that have the greater impact on investors (Czinkota and Skuba 2014).

In the study, it was observed that training exercises on the working principles, and dissemination of information on the limitations of installations need be undertaken with the aim of discouraging consumers from engaging in practices (including acts of sabotages) that could adversely affect the performance of such installations. A case of this is the illegal connections made by the residents Sagbokoji on the installation in the community which purportedly contributed to its breakdown (see section 5.5.2). Hence, these training exercises, which are to be carried out by the Promotion and Awareness Institution (block J), are listed as J_1. The dissemination of such information could also be incorporated into the regular forums between supervising agencies and rural consumers.

As observed in the Bangladesh and Mali cases (sections 2.6.2 and 2.6.4), a central feature of successful rural electrification programs is the existence of an organisation which has the expansion of rural electrification as its main objective. In Nigeria, such a body is represented by a Ministry of Rural Development (MRD). However, while the MRD has developed sets of procedures for deployment and post-installation of RE installations (section 5.1.1), some of these are either not being adhered to, as observed by the absence of Community Development Associations in the study cases, or are being influenced by external factors, exemplified by the political influence in the deployment of installation to Ide II in section 5.4. It is also important that the body must not see the deployment and subsequent installation of RE systems to rural communities as an end to its function; rather, this should be followed up with the provision of appropriate maintenance mechanism as suggested earlier. In addition, more frequent checks can be made to installations in communities where no member had been trained. The functions of such an agency are shown in K_1 of Table 6.3.

Alongside the role of government, the contributions of consumers to the success of rural electrification programmes can also be significant as seen with the successful community associations in the Bangladesh rural programmes that were introduced in section 2.6.2. Nevertheless, as highlighted in section 2.7, it is important to emphasize the appropriate solution is that which addresses the peculiar and common attributes of the inhibiting factors against rural electrification in a country and aligns the characteristics of the technology with the local context into which it is to be introduced.

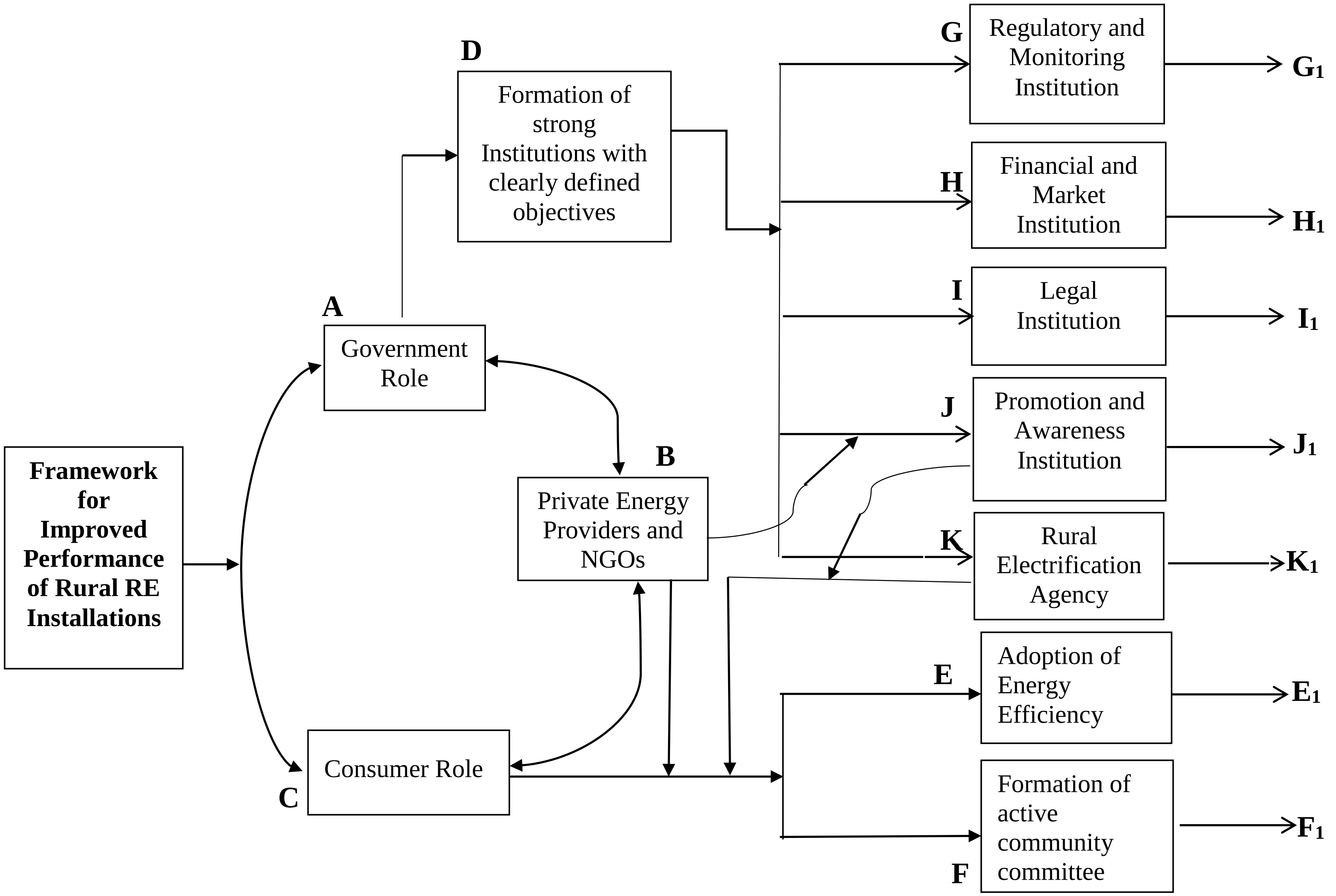

Figure 6.4: Framework for Effective Deployment of RE Installations to Rural Locations

Table 6.3: Functions of Framework Delivery Blocks

Block	Functions
E_1	▪ Utilisation of energy saving lighting and home equipment ▪ Strict use of electricity only when required (discourages wastefulness)
F_1	▪ Provision of security for the system ▪ Training and holding of regular meetings to enlighten users Appraise complaints from users and recommends actions ▪ Establish strong link with government institutions and other sponsors/players
G_1	▪ Development and implementation of policies that impact positively on rural electrification ▪ Develop standards, specifications, and ethics to be obeyed by all players in the sector ▪ Ensure that all standards and guidelines are strictly followed/implemented
H_1	▪ Creation of enabling financial environment for private sector participation ▪ Provide necessary incentives such as import duty waivers and tax concessions ▪ Creation of access to soft loan and facilities to rural dwellers ▪ Develop business models for private sector participation
I_1	▪ Provide legal framework that protects both investors and consumers ▪ Establish guidelines for settling disputes ▪ Create level playing field for all participants ▪ Provide regulations for sensitive issues like tariff and metering equipment
J_1	▪ Create awareness of negative health and climatic effects of usage of diesel/gasoline and biomass ▪ Enlighten users on the limits in the use of solar PV ▪ Assures communities of transparency in deployment process; discourages jealously and vandalism ▪ Highlight the benefit of community committee and encourage its formation
K_1	▪ Appraise rural communities and determine locations for RE installations based on transparent guidelines ▪ Enter into collaborative efforts with private sector and donor bodies ▪ Ensure the formation of Community Development Associations (CDAs) in benefiting communities, and develop viable communication channels with them ▪ Develop and implement effective post-installation monitoring and maintenance strategies

6.4.2 Role of Private Sector and NGOs

As revealed in the study, the roles played by the private sector and NGOs are intertwined with those of government and consumers; this is represented by the connection of block B with blocks A and C in **Figure 6.4**. It was seen that private sector can contribute to the promotion and awareness of the relevance of solar installations in rural communities through their deployment of such installations as encountered in Onibambu, Umuagwu and Umuode communities - as depicted by the linking of block B to J. Similarly, the study cases handled by the private sector witnessed a more active participation of the local people in the running, maintenance and repair of the installations through formation of active community committees, and a higher inclination towards energy efficiency practices through the use of energy saving bulbs. These are depicted by the connection of block B to blocks E and F.

6.4.3 Role of Consumers

The role of consumers is well documented in the study both from the literature and the case studies. Consumers are physically closest to the installation and could provide monitoring data which may be difficult for the installers to obtain. Hence, some day-to-day processes and practices that could contribute to the enhanced performance of such installations may be better undertaken by them. A case of this is the notification made to the supervising agency by consumers about the leaking water pump at Ide I village. Additionally, limited knowledge or awareness on the limitations of installations by consumers have been seen to contribute to the reduced performance of the installations. Two prominent roles on the part of consumers that could contribute to the enhanced performance of installations are discussed below.

6.4.3.1 Formation of active community committee

Active community-based committees could form an integral part of the RET installations roll-out as observed in the case of Bangladesh in section 2.6.2. However, these were absent in Ide I, Sagbokoji and Asore communities; a factor that may have contributed to the failed installations in these places. Apart from acting as a link between government institutions and communities/consumers, such community-based committees could develop a structure for the effective security and monitoring of the installations, in addition to providing basic maintenance and repairs. Even when a committee cannot carry out such repairs, complaints received or observed by it can be routed to the relevant government agency. In addition, such committee can be used by the Promotion and Awareness Institution to enlighten consumers on the limitations of the installations, and best practices relating to their use. The formation of such a committee is represented by block F in Table 6.2 while its functions are shown in F_1 of Table 6.3.

6.4.3.2 Assimilating the principles of Energy Efficiency

In addition to the fact that energy efficiency policies require a high level of co-ordination between government agencies (IPCC, 2013), countries with low levels of access to modern energy services - such as Nigeria - rarely concentrate on energy efficiency as they are faced by other more pressing challenges. However, the adoption of energy efficiency principles by consumers, for example, through the utilization of energy-saving lighting can lead to an increment in the number of users that have access to available units of electricity from an installation, and also lead to reduced cost of energy consumed by households Such advocacy for the uptake of energy-saving principles can be carried out by the Promotion and Awareness Institution through education about the positive effects of such practices as encountered in Umuagwu community (see section 5.8). This can further be encouraged if the cost of such energy-saving fittings are subsidised by the government. On the other hand, the adoption of such practices by consumers may not be seen as important or necessary if electricity is free or if they have been able to devise means of evading payments for units of electricity consumed since ‘efficiency’ may not appear relevant at a personal level.

However, as shown in section 3.3.8, although the adoption of an energy efficiency culture by the consumers is beneficial and should therefore be pursued, its adoption by them may be dependent on other related issues. These include ensuring the implementation of appropriate and transparent tariff structures, creating increased awareness on the benefits of energy efficiency practices, and subsidising the cost of CFLs and other types of energy-saving bulbs. In particular, the implementation of a pre-paid metering system which enables consumers to purchase blocks of energy as they could afford could also encourage the uptake of energy efficiency practices by the consumers (as it discourages wastefulness), in addition to providing income that could be used to maintain/expand the system as witnessed in the successful case studies in sections 5.7, 5.8, and 5.9. Such energy efficiency practices are designated as E_1 in Figure 6.4.

6.5 Summary of Recommendations

The role of government is fundamental in creating an effective RE energy sector, with the success of many other players and actors being dependent upon it. Furthermore, it was seen that a more result-oriented approach is for government to focus more on the creation of conducive environment, without necessarily getting involved directly in the deployment of such installations as is often the practice presently. In addition, while environmental concern and energy efficiency appear not to be issues of pressing concern on the agenda of regulating bodies in the Nigeria’s electric power sector, on-going reforms in the sector do present an opportunity for the government to introduce these into the country’s energy mix through the development and deployment of RETs (section 3.3.2).

Whereas the various energy policies cover a substantial number of well-intentioned objectives, realities on the ground over the past ten years and encountered during the course of this study, have not been in accord with these. For example, although the National Energy Policy 2003 (pg. 29) states that: *The nation shall aggressively pursue the integration of solar energy into the nation's energy mix,* and that *the nation shall keep abreast of worldwide developments in solar energy technology*, the integration of solar energy over the last decade has lacked assertiveness. Whereas the provision of electricity to rural communities worldwide has continued to become more affordable and diversified in both application and size as technology has advanced and prices have decreased over the last decade (Lins and Murdock, 2014), these attributes have been largely absent in the Nigerian experience as encountered in this study. Similarly, the positive effects of advances in managing energy systems and the use of mobile phone technology, such as remote monitoring and payment have been limited in the country.

A summary of policy-related recommendations derived from the study is presented below.

- A comprehensive review of the National Energy Policy to set realistic short, medium, and long-term goals towards the electrification of rural location.
- Formation of strong independent regulatory and monitoring institutions and processes to support proper implementation and compliance of policies

- A policy shift from solely government-deployed to collaborative efforts between government, private sector and donor bodies.
- The development of appropriate policies to elicit active private sector participation must be incorporated into the country's Energy Policy. This could be in form of tax waivers on imported RE parts and equipment and the introduction of other forms of subsidies as may be necessary.
- Development of business models that align with the peculiarities of the Nigerian situation.
- Efforts must be made to encourage international donor organisations and NGOs to play complementary roles in the deployment of solar PV installations to rural communities as is being witnessed in some other developing countries. Equally, access to low-interest loans spread over a number of years must be made available to rural dwellers so that easy take-up of solar home systems can be enabled.
- An improved level of awareness needs to be created among rural dwellers on the benefits as well as the limitations of RE Systems. In addition, awareness of the benefits of energy efficiency practices must be created, such that consumers can develop a positive behavioural change towards their adoption in their daily activities.
- Pre-installation and post-installation guidelines for standards and practices for contractors and end users in the deployment and utilisation of the installations must be developed. In addition, the various Government agencies in the RE sector such as the Ministry of Rural Development, Lagos State Energy Board and Ministry of Science and Technology must share relevant information that could improve services.
- Capacity building of indigenous manpower in the design, deployment, monitoring and maintenance of solar PV installations must be developed through training and development programmes.
- The policies of bringing electricity and water services to rural areas should move beyond the meeting of basic needs such as lighting and charging of phones as encountered in many of the study cases to providing sufficient power to facilitate economic activities to create employment and increased incomes.

It is however noted that platforms to implement some of these recommendations may already exist but could need to be augmented. An illustration of this is the commissioning of the Lagos State Energy Academy in October 2014 (Lagos State Electricity Board, 2014). The Academy, which is under the auspices of the Lagos State Electricity Board was set up to provide training in metering, solar energy, and various aspects of generation, transmission and distribution of electricity in a bid to produce the necessary qualified personnel for the sector. With such an academy in place, the technical staffs of potential government contractors could be mandated to undergo training as part of pre-qualification conditions for the award of contracts. In addition, the existence of such an academy could create a platform for collaboration in pursuit of a common goal among different government agencies such as the MRD and the LSEB.

It is also important to note that policies that have been successfully implemented by investors in other regions of the world may not automatically be effective in Nigeria due to local peculiarities (Asiedu, 2002; Davidson et al., 2003). Hence, the effectiveness of 'imported' policies may need to be tested and verified against existing local peculiarities before being implemented on a large scale.

6.5.1 Processes for system planning, installation and utilisation

Apart from generating a framework for the improved deployment and performance of solar PV installations in rural locations as developed in **Figure 6.4**, it is equally necessary to develop practical processes that could aid its implementation. As encountered in the study, while Figure 5.1 depicts existing steps involved in the deployment process as being implemented by the ministry of rural development (MRD), findings from the study revealed the necessity of inculcating additional measures towards achieving improved deployment, and enhanced performance of solar PV installations in rural Nigeria. In particular is the need to include post-installation maintenance practices. Figure 6.5 therefore depicts such an arrangement which provides a practical process that could be used alongside with the framework and referenced by all relevant agencies/stakeholders involved in the deployment and running of such installations. It integrates a feedback loop that introduces post-installation maintenance activities whenever an installation develops a fault. It further ensures that adequate competencies of personnel of government agencies are developed in cases when deployments are to be carried out by them.

While not indicated, it is expected that in deployment of installations to be handled by contractors, the contractual terms of such awards should involve preventive and corrective maintenance post-installation maintenance agreements for (initial) specified period after such deployments. This appears not to be the practice presently as affirmed by a contractor (section 5.1.3) who stated that the MST did not enter into any maintenance contractual arrangement with him.

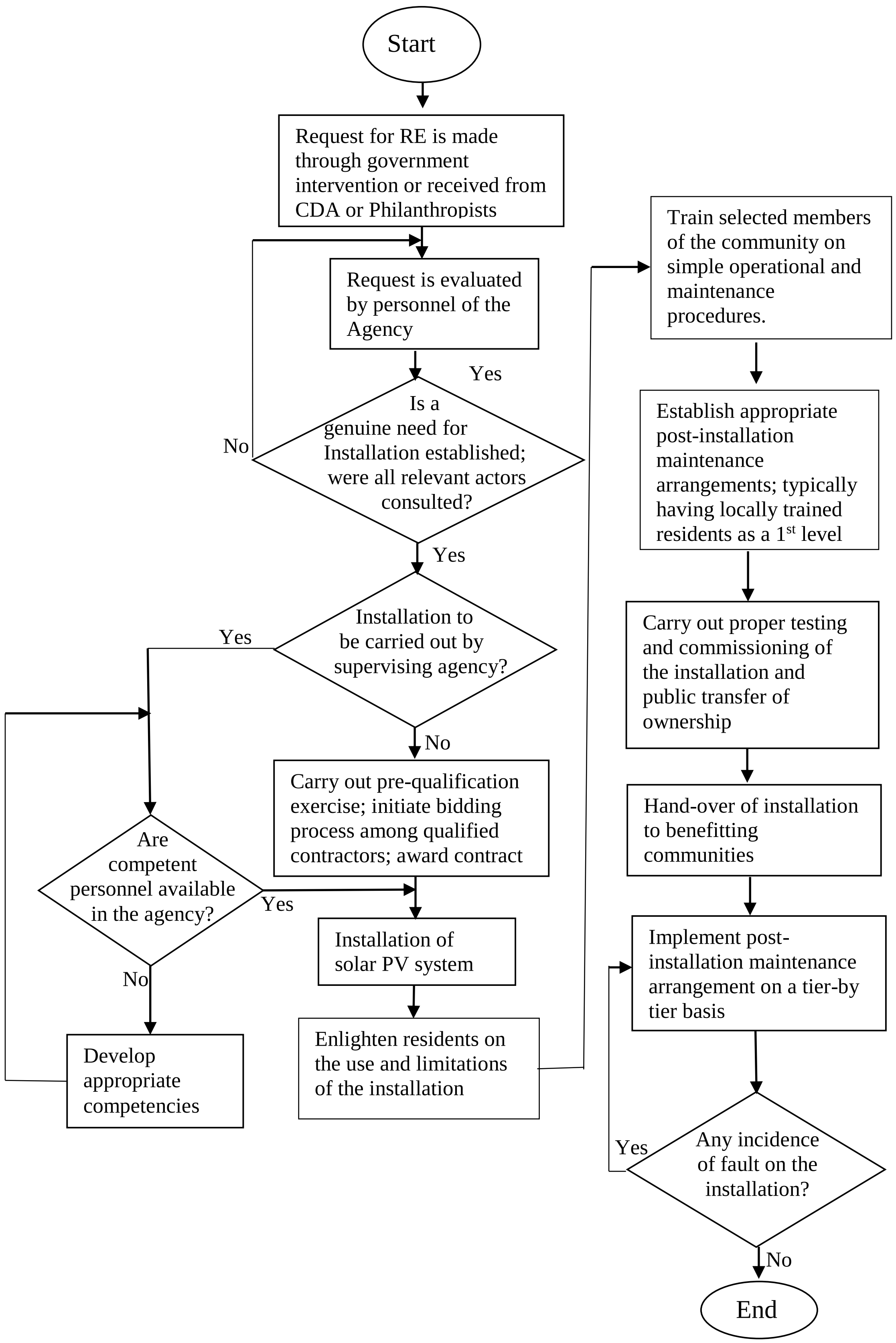

Figure 6.5: Process leading to effective deployment of solar PV Installations

6.6 Feedback from Stakeholders

The opinions of some stakeholders were sought to critique the findings of the study - particularly the developed framework and set of recommendations. For this purpose, one interview session was held with two officials of the Ministry of Rural Development - one of these had previously been interviewed during the course of the main study (see section 5.1.1). In addition, interview sessions were held with a government contractor, and an officer of the Lagos State Electricity Board (LSEB) respectively. Furthermore, the views of rural dwellers at the case study locations were also obtained. Excerpts from the sections of the study which cover the derived framework and recommendations- mainly sections 6.2 and 6.5 - were printed out and discussed with the stakeholders.

The officials from the Ministry of Rural Development agreed that a more aggressive approach needs to be adopted by the government in order to achieve more successful implementation of RETs to rural locations. Specifically, they agreed that widespread RET diffusion would involve significant capital which would normally be beyond government's budget, and may require the involvement of international donor organisations. They also agreed that private investors are not attracted to rural electrification projects; hence, government may need to devise profitable platforms that could stimulate their active participation. However, they disagreed on the findings that government needs only to provide the right conducive environment such as legal, financial and regulatory platforms for private investors, and to play only supervisory roles in the deployment of solar PV installations to rural locations. Rather, they asserted that government agencies can equally play strong roles in the direct deployment of such installations provided necessary provisions are put in place.

There was consensus over the necessity for community committees. They affirmed this as a main objective of the MRD that has been difficult to achieve due to a lack of receptivity on the part of the rural dwellers and the challenges often encountered in forming a committee. They explained that the MRD presently aims to be in contact with, at least, one resident in each community where the installations are located.

Regarding the performance of the installations, the officials recommended a strict adherence to high-performing components such as solar panels and batteries for solar PV installation, although these often cost more. They suggested however that the use of independent contractors could be discontinued if the size and technical competence of the staff of the MRD were improved upon. This, they opined, will necessitate improved remuneration and periodical training of the staff. Overall, they asserted that a high degree of government commitment is required to implement the framework and set of recommendations, and affirmed that such commitment would result in widespread diffusion and improved performance of RE systems.

At the Lagos State Electricity Board, only one official was available to appraise the framework and recommendations. He noted that, as highlighted, the Board regards the pursuit and uptake of the principles of energy efficiency as a cause that should be taken on board by both the energy producers and consumers in the country. While stating that the board is not directly involved in rural electrification projects, he suggested that government agencies could learn from one another's experiences, while also noting that some suggestions, such as the need for increased financial support for RE projects by the government relates equally to urban projects as well.

When the framework and set of recommendations were presented to a contractor, he immediately pointed out that the role of energy contractors are not highlighted. It was however clarified that while the roles of contractors are not explicitly highlighted, they are embedded in the role of government represented by the formation of strong institutions with clearly defined objectives (Block D) and their respective sub units (Blocks G,H,I,J). He still contended that the role of contractors ought to be separately highlighted on the framework since, according to him, "government agencies will need to deeply involve the use of contractors if the widespread of RE installation to rural locations is to be achieved". The contractor argued that the major factor acting against the widespread take-up of solar PV and other RE technologies in the country is the high initial cost of such installations. He considered the implementation of processes that could achieve a drastic reduction in the cost of such installations as an issue that should be the prime concern of government. In addition, he emphasised the importance of ensuring that only competent contractors are awarded government projects on an ethical and unbiased basis. Finally, he suggested that independent contractors could be engaged to carry out periodical assessments and maintenance of installations.

At Ide I and Ide II communities the users agreed with the factors revealed in the study as influencing their performances of the installations. Nonetheless, they consider slow response by the installing agency as the biggest challenge they encounter in the efficient functioning of the installations. Conversely, they do not regard the non-existence of established cooperative groups as impacting negatively on the performance of the installations, noting that they already have members who act as the link between them and the installing agency.

While residents at Sagbokoji community also agreed with the findings of the study, they pointed out that poor performance or breakdown of an installation could also affect the existence of a cooperative as had happened in their own case. This claim by the residents of the community further asserts the inter-relationship that could exist between various factors and actors in the RE sector, and the possible ‘ripple effect’ that could emanate from them as highlighted in section 6.3. A significant lesson therefore is that a framework may not achieve the expected result unless all factors incorporated into it are appropriately implemented, and all actors (e.g., government institutions, consumers, etc.) play their roles effectively.

CHAPTER 7 Conclusion

7.1 Summary of Study Findings

This study appraises the global energy situation, the energy scenarios in developing countries in general and Nigeria in particular; from which the challenging electricity situation in both urban and rural regions in the country is revealed. Although grid extension is regarded as favourable for rural locations that are close to existing networks, standalone RE sources such as solar PV and wind are oftentimes more feasible on economic and technical grounds for remote locations that have a low probability of grid extension in the foreseeable future. In Nigeria, there has been a number of attempts to provide isolated rural communities with solar PV installations for both electricity and water pumping services, and these have resulted in divergent outcomes. This study set out to reveal the underlying factors behind both failed and successful cases, and to develop an approach that may lead to the provision of improved water and energy access.

Although an Action Research approach was initially adopted for this study, the limitations of the approach became apparent since the implementation of the interventions that form the basis for many of the findings in this study were beyond the influence of the researcher and had already taken place. This notwithstanding, multiple methods of observation, interviews, discussions with relevant stakeholders, and evaluation of case studies are adopted in the study. Through reviews of renewable energy case studies from the literature, and a number tools used for evaluation and assessment, 5 core sustainability dimensions (Technical, Economical/Financial, Environmental Impact, Social-Ethical Development, and Institutional Development and Government Policies) cutting across 38 indicators evolved as appropriate for this study. These defined the course for the investigation and analysis of case studies, and assured that the first objective of the study "*to develop a systematic approach and associated indicators for analysing PV installations in isolated areas*" was met. Furthermore, in accordance with the second and third objectives which dwell on analysing previously documented Nigerian case studies, interviewing stakeholders and evaluating solar PV installations in isolated communities as study cases, a number of documented cases in the country were analysed and the reasons for their successes and failures revealed. In addition, drawing on formal and informal interactions with personnel from rural electrification agencies, energy contractors and end users; a physical evaluation and performance assessment of seven case studies of installed solar PV systems in rural communities in Nigeria was undertaken. Adopting a case study approach and the associated observation of people in these communities enabled the identification of specific factors that influence the deployment and performance of solar PV installations in rural communities, and the relationships that exist between them. The field studies generated valuable experiences regarding the collection of data for evaluation of the indicators and illustrate some difficulties associated with such undertakings. While the use of seven case studies in a study of this nature may be regarded a small number from which general conclusions may not be made, it enabled a more in-depth appraisal of the topic (see section 4.3.1). A number of findings in the study are supported by the literature and documented cases within Nigeria and beyond.

For the cases analysed, installations deployed by private energy providers in conjunction and support of local and international donor bodies, and deployed on a commercial basis, tend to perform better over the long term than those deployed solely by government agencies on a non-commercial basis – the latter were found to be unsustainable. The various findings further revealed that failures on the part of both the government and the end-users contributed to the initial failure and eventual breakdown of some of the installations, which cut short the relief the installations brought to the dwellers (see sections 5.3.3 and 5.5.2). In particular, as highlighted in section 6.1.1, these factors include:

- Absence of effective post-installation maintenance arrangements
- Type of business model/ manner of private sector participation
- Non-existence of local representative authorities
- Inappropriate design and lack of qualified contractors
- Failure to train local residents on basic maintenance measures
- Limited understanding of the capability of the installation by the users
- Weak implementation of strategies and low success of government policies
- Absence of strategy to improve the post-deployment monitoring and evaluation of rural solar PV installations

In addition to revealing the above limiting factors, the study provides causal insight and appreciation of the interrelationships between the factors (section 6.3) and suggestions on how their effects could be mitigated or eliminated (section 6.2). It proposes that the factors need to be addressed through appropriate, context specific approaches based on the *holistic* implementation of the framework (Figure 6.4) and a set of recommendations (section 6.5) developed in the study. The framework, which is developed from an integration of the first three objectives, is grounded on specific roles of government and consumers, which are considered pivotal to effective deployment and performance of RE installations. The role of government included the formation of viable and relevant institutions with clearly defined objectives, and the development of appropriate policies such as those for regulating and monitoring all players in the renewable energy sector, establishment of enabling financial and market environment, promotion and creation of awareness of the benefits of renewable energy technologies, and the provision of a legal framework that protects both investors and consumers.

The role of consumers centred on the adoption of energy efficiency practices, and formation of an active community committee to facilitate active local management of installations. The existence of such committees could also provide a communication channel for funding organisations on such issues as the provision of loans for individual household solar PV systems as highlighted in section 6.1.1. The development of an integrative framework (Figure 6.4), set of recommendations (section 6.5), and practical tool that can be employed for effective deployment and performance of solar PV installations in rural Nigeria (Figure 6.5) through the linking of the findings of this study underscore the achievement of the fourth objective of the study and affirmed that the aim of the thesis which is *to develop a generic framework for the implementation and sustained performance of solar PV systems for water pumping and electricity services in rural areas of Nigeria* was met, and a clear and practical contribution to knowledge made.

A prominent revelation of the study is that rather than government playing direct role in the deployment of solar PV installations to rural areas, its efforts may be more effectively directed at providing a conducive environment that could attract private sector participation, international investors and donor organisations, although this tends to contrast the opinion of officials of government agencies and contractors. Subsequently, the study reveals that while drawbacks certainly exist, there has only been a limited participation of the private sector in the Nigeria RE energy sector. This is contrary to the situation in some developing countries including Nepal, Bangladesh and Mali (section 2.6) and may be due to the current limited motivation for such participation and the bureaucracies involved in running private enterprises in Nigeria, and may be reflective of the country's rank of 169 out of 189 countries in the "Ease of Doing Business" assessment report by the World Bank (World Bank, 2015). In addition, as highlighted in section 6.1, rural electrification projects do not appear profitable relative to urban electrification projects due to factors such as low population densities and low income levels and hence, may not follow a purely commercial model. It is therefore important that rural electrification policies cover appropriate technical and business models such as technical assistance and capacity building of indigenous manpower, Public-Private partnership (PPP), and well-targeted financial support, as indicated in the framework of Figure 6.4. Even against the possibility of reduced profit margins, a more active participation of the private sector in rural electrification programmes may be achieved through legislative means that mandates them to do so in parallel with urban electrification highlighted in section 3.3.

Furthermore, a noticeable feature encountered in the study case (with the exception of Onibambu) is that the provision of electricity and water services appears to target only the domestic comfort of the dwellers. While it could be argued that the provision of such improved services in rural areas could free more time for economic activities for the rural dwellers, eradicating poverty should be a central and underlying aim and not 'merely' an offshoot of such interventions. Hence, as much as possible, such intervention projects should target to positively impact the economic livelihood of beneficiary communities. For example, in a fishing community, the aim of such intervention projects should move beyond providing electricity for lighting purposes in individual homes to one that could, say, introduce methods of preserving fish or improve on existing ones. In addition, such economic empowerments of the users would make the energy more affordable to them, and thereby self-sustaining.

It is hoped that this study would positively alter the perception of policy makers in the country about solar PV, and renewable energy technologies (RETs) in general, enabling rural dwellers to benefit from improved services. The deployment of RE installations to rural communities should not be regarded as an end to itself, but as part of the means and opportunity for growth and development of those communities.

7.2 Recommendations for Further Studies

The findings from this study reveal factors that both aid and impede mass deployment and sustained performance of solar PV installations to rural locations. Some of these findings reinforce what is already well known; some are new and others may not conform to what is generally accepted. Additionally, while some of the findings in the study could be easily extrapolated to other countries, others are peculiar to the Nigerian situation. It is however fundamental that a shift from an ‘all government’ approach to a tripartite arrangement involving government, the private sector and national/international donor organisations could lead to improved and desired outcomes such as substantial increase in the rate of rural electrification and the number of rural people benefitting from it. The findings could therefore be considered as central to enhanced performance of such installations and, as such, provide a platform for further studies involving greater number of study cases. For example, the recommendation **“***Appropriate policies to elicit active private sector participation must be inculcated in the country’s Energy Policy…*” (Section 6.5) may require further research to develop indigenous business and market models that could stimulate active private sector participation in the RE sector in Nigeria. In the same vein, through analysis and appraisal of designs, and further evaluations of the reasons for failure, models that could reduce the effect of technical factors in the underperformance of deployed solar PV installations may be generated. On a larger scale, studies may be carried out across two or more developing countries to investigate and compare the factors that influence the deployment and performance of solar PV installations in each country.

As earlier mentioned in section 6.5, a comprehensive analysis and review of Nigeria’s National Energy Policy, as it contributes to the poor state of RE take-up and performance, may support improved outcomes. Hence, an in-depth study on the implementation, effects, and defects of the various policies and reforms that have been introduced in the energy sector since the early 2000s could also be a valuable contribution to the body of knowledge.

Finally, due to the prevailing unrest and insurgences in some parts of Nigeria, this study has been restricted to the southwest and south-south regions of the country; similar studies may be carried out on a wider geographical spread when such constraints are no more in existence. Such studies could involve wind systems which, though not common in the southern part of the country, are more prevalent in the northern part where wind speeds are sufficient for electricity generation in rural locations.

7.3 Reflections and Closing Remarks

This study has taken the researcher through the different phases of decisions and experiences a typical PhD researcher encounters. Technical factors were initially thought to be the sole reason for the underperforming/failed solar installation in rural communities in the country and the aim of the study originally was to design and build a solar PV installation with improved technical features. This, presumably, would have enhanced performance characteristics and could therefore be used as a model in subsequent deployments to rural locations. The course of the study was changed however to one that could provide a more realistic and holistic approach to the myriad of factors that were revealed at an early stage. Looking back, this had proved decisive as it has enabled a more in-depth study into the subject matter and the revelation of diverse factors, issues and policies that both support and impede mass deployment and sustained performance of solar PV installations to rural locations which the original aim focus on technical features alone may not have achieved.

Unlike a predominantly experimental study carried out within the comfort and controlled environment of a laboratory, the seven locations used for the study are isolated rural communities that were not easily accessible. Hence, the visits made to these locations for physical evaluation and assessment of solar PV installations and data collection through interaction with rural dwellers were demanding but revealing experiences. In addition, the process of obtaining the necessary information from different stakeholders proved both challenging and enlightening. Difficulties in getting government officials to grant interviews, their unwillingness to release information and the dearth of such information on government agencies' websites reduce the richness and the depth that may have otherwise been attained in the study, and equally highlighted the need for flexibility in data collection methods based on the various barriers encountered that may not be present in other settings. Nevertheless, these combined to enrich the researcher's knowledge in the subject matter, and enhanced his capacity to obtain the required information from people with diverse backgrounds.

In addition, the findings during the course of the study formed the basis of presentations at the International Conference of Science Research and Applications and the International Conference on Environmental Issues (ICEI2) held in Lagos, Nigeria in September 2011 (Onasanya et al., 2011) and April 2012 (Onasanya et al., 2012) respectively. They highlighted the inadequacies of the prevailing centralised electricity infrastructures in Nigeria, especially in reaching isolated communities in the country, and therefore advocated an optimised utilisation of RE resources in the provision of energy services in such places. Similarly, the researcher participated in the United Kingdom Energy Research Centre (UKERC)'s Poster Presentations held at the University of Warwick, Coventry, during the Summer School of July 2013 (Onasanya, 2013), while, based on the findings from this study, a paper was presented at the 3rd International Conference "Micro Perspectives for Decentralized Energy Supply" in Bangalore, India in April, 2015 (Onasanya and Wright, 2015). The author also participated in the inaugural Smart Villages regional Workshop in West Africa held in Accra, Ghana in May 2016, and a number of workshops and seminars on improving the take-up of renewable energy technologies were also attended during the course of the study.

In conclusion, as noted by Alazraque-Cherni (2008, pp. 112), "the difficulties encountered on the way of implementing RET in remote rural areas of developing countries do not change the fundamental fact that RETs represent an appropriate way to provide energy to these areas. RETs offer the possibility of improving sustainability at local levels and enhancing the conditions of groups of users". Indeed, in Nigeria, the use of solar PV remains a viable means to reach many isolated "un-electrified" rural communities with low probabilities of grid extension in the immediate future. However, for such measures to be effective, the prevailing inhibiting factors against effective deployment and enhanced performance of such installations, as identified in this study, must be mitigated or eliminated.

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Appendices

Appendix 1: Notification of Field Study and Data Collection

Onasanya, M.A
9, Badejoko Street,
Ikosi, Ketu,
Lagos, Nigeria.
16[th] February, 2012

The Chairman,
Ibeju Lekki Local Government,
Ibeju, Lekki,
Lagos State

OFFICE OF THE EX. CHAIRMAN
RECEIVED
Sign
Date 16-02-12
IBEJU-LEKKI LOCAL GOVT.

Dear Sir,

NOTIFICATION OF FIELD STUDY AND DATA COLLECTION

My name is Onasanya, Mobolaji A., a lecturer in the department of Electrical Engineering Yaba College of Technology and also a PhD student in De Montfort University, Leicester, UK. My PhD research topic **A Systems Analysis and Development of the Potentials of Local Renewable Energy Systems for Rural Services in Nigeria** involves data collection from communities that are not presently connected to the National Electricity Supply System. Towards this, I've chosen. Ide village, via Eleko, Ibeju Lekki Local Government, Lagos State along with three other settlements in Plateau,, Enugu and Kogi States for my study and data collection. The data collection will take the form of face – to – face interview and answering a set of questions set out in a questionnaire.

Kindly note that personal data are not required for the study. Also, while the co-operation of residents is being sought, their participation in the study is entirely voluntary. I also wish to highlight that the study solely aims to improve the on the general welfare of residents of remote locations and is devoid of any tribal , religious or political undertone.

I hope to receive your best assurances towards achieving a seamless research exercise.

Thank You

Onasanya, M.A

Appendix 2: Question Guides for Stakeholders' Interviews and Discussions Sessions

De Montfort University, Leicester, UK

Institute of Energy and Sustainable Development

Question Guides for Stakeholders' Interviews and Discussions Sessions

The aim of this Questions Guide is to gather primary information through Interview and Discussions Sessions from stakeholders active in the deployment, maintenance and usage of solar PV installations in rural locations in Nigeria, as part of a study on the *Evaluation and Development of the Potentials of Photovoltaic Systems for Water Pumping and Electricity Services in Rural Areas of Nigeria.* The primary purpose of the study is to improve the general welfare of rural residents in the country, and is therefore devoid of any form of tribal, religious or political undertone.

While participation in the interview is entirely voluntary, your impartial contributions to the course of the study is valued as these will form an integral part of the study.

General

Name of Community: ………………………………………………………

Approx. Population (or number of households)………………………………..

Type of solar PV Installation in the community: (a) For Water Services Only

(b) For Electricity Services only (c) For both Water and electricity services

Capacity of the solar PV installation

Date the installation was deployed:………………………………….

Functionality status of the Installation:………………………………

Consumers (Rural Dwellers)

- Number of hours per day of access to electricity (or water) services provided by the installation
- Performance of installation
- Level of satisfaction of performance of installation
- The type fuel/energy source used by the community before deployment of the installation to the community (e.g. other sources of water)
- Other sources of energy used for daily activities
- Monthly expenditures on fuels and energy by source.
- Affordability of the tariff (if any) compared to amount spent on other sources of energy

- Existence or otherwise of Community Development Association; their functions and effectiveness
- Does the project enjoy the support of the benefitting community?
- Is the project cost effective?
- Frequency and nature of system/equipment breakdowns.
- Types of training (if any) provided for community members
- Post installation maintenance arrangements and mechanism available
- Pre and post installation challenges encountered with respect to the installation
- Communication Channel to installers
- Effectiveness of response time by installers

Contractors/ Energy providers

- Experience in deployment of PV Installations
- Mode of deployment
- Process of obtaining contracts
- Means of financing the deployment
- Terms of contractual agreement: Any post-installation arrangements? If yes, what sort?
- Business Model implemented for the deployment
- Particular challenges encountered in executing the projects
- How often do faults/ complaints occur?
- How are the faults repaired? Any training provided for local community members?
- Any community involvement?
- Payment arrangement for by the community/ community organisation?
- Ease of access to community
- Peculiar challenges encountered pre and post installation
- Consumers' attitudes that may have enhanced or mitigated the performance of the installation
- Degree of Consumers' satisfaction (or otherwise) with the installation and reason for this
- What do you consider/ encounter as peculiar challenges in the country's rural electricity sector
- Suggestions on how electricity/water access to rural communities can be economically and sustainably improved.

Officials of Government Agencies

- How are communities to have installation deployed chosen or decided
- How to decide the size of installation and the deployment model to adopt (directly by the agency or by contractors)
- What is the driving principle behind the projects?
- In the case of deployment to be made by contractors, the process of award of contracts
- The requirements or preconditions (if any) for communities to have the installation deployed
- Post-Installations procedures in place to ensure enhanced performance of the installations
- To share their experiences on the success and failures of deployed Installations
- Highlight prevailing challenges and suggest ways of mitigating them