Enhancing Sustainable Development in Sub-Saharan Africa:

New Integrated Sustainability Mechanisms
for Securing Substantial Benefits of Renewable
Energy Projects

Eugene Chidiebere Xavier Ikejamba

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**ENHANCING SUSTAINABLE DEVELOPMENT IN
SUB-SAHARAN AFRICA: NEW INTEGRATED
SUSTAINABILITY MECHANISMS FOR SECURING
SUBSTANTIAL BENEFITS OF RENEWABLE
ENERGY PROJECTS**

DISSERTATION

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DEDICATED TO MY PARENTS AND SIBLINGS,
TO THE MANY AFRICANS WHO STRIVE EACH DAY TO SURVIVE,
MAY YOUR SPIRITS NEVER BE BROKEN

Prologue (A Realist Perspective)

Sub-Saharan Africa (SSA), if viewed appropriately, represents a region vast in resources, both human and natural. However, from many discussions it emerges as a region marred in corruption, diseases, failures and all possible negative attrition.

“Does the region possess the potential to develop and thrive?” – Absolutely!

Is the region developing and thriving? There is no single answer to this question. Predominantly, I cannot and choose not to base the answer of the preceding question on publications of large financial institutions who publish on the development and growth impacts of developing countries and the surrounding regions. It is known for a fact that the “unofficial economy” is the backbone of the Sub-Saharan region. It is estimated to command 72% of all employment within the region. Nevertheless, it is not considered in the calculation of a country’s GDP. It is astonishing to notice that the development of the corresponding countries within the region is based only on the “official economy”, which is utilized to represent the whole country. Whilst in some countries, approximately 70% or more people live on less than a dollar a day. Could this be considered development? Being a development optimist or pessimist is inconsequential in this situation. Being a realist is paramount. The region cannot boast that it is developing when experiencing diminutive power generated, more job losses, higher cost of living, less educative impact and less awareness creation.

OK! Let’s assume that GDP is not utilized to determine the development of a country but infrastructural development and investments. For a fact it is known that major infrastructural developments are occurring across the Sub-Sahara, but how does this benefit the low-socioeconomic groups? Take for example, the implementation of renewable energy (RE) development projects. When these projects are being planned and gaining media attention, Africans tend to get overly excited and lose sight of what these “development projects” really represent. Energy projects, waste management, agricultural and food security projects and even education cease to exist after some years of implementation because when these projects are planned, the excitement clouds the judgment of looking into the future (the concept of sustainability). So, back to the question –

“Is the region of Sub-Saharan Africa developing?” – Personally speaking, both Yes (because I am an African) & No (because I am a realist)!

My personal opinion may not matter that much, but ask the same question to the low and middle class families across the region and approximately 99% of this class will provide you the “No” answer as I have provided. Of course, time and development goes concurrently. However, the region of SSA has come so far to continually remain stagnant in its physical development of the low-socioeconomic groups. Prior to civilization, our ancestors survived, created energy, recycled their waste, transported themselves in the best possible ways and traded unused goods for useful goods. Now, with the birth of modern technology we have ways to efficiently carry out our day to day activities but still lack the drive to develop our region. The ignorance we are so proud of plays a huge role in the shortcomings of living sustainably in a positive way. Africa cannot continue to depend on the west for “free” handouts. A fraction of all supposed funding, if implemented accordingly can change the lives of thousands of people through education of the mind and the creation of awareness to live sustainably. Yet, billions of the “so-called” development investments have been poured into the region and there seem to be no change.

You may consider the above statements, a *rant* – asking, what it has to do with this thesis? – Everything. It has everything to do with this thesis. The renewable energy sector in SSA is currently growing and numerous projects are being implemented across the region. However, if the true concept of sustainability is not considered prior to the implementation of these projects, they are bound to fail and will definitely fail because the issues of nepotism, corruption and ill-management impairs these projects after a while. The current energy infrastructure is illustrative. In this thesis, as the topic suggests, my goal is to enhance sustainable development and maximize the corresponding benefits with a focus on renewable energy development projects in Sub-Saharan Africa. However, to successfully carry this out, it is paramount to not just understand the RE sector but to understand the way of life, the concept of sustainability (the African perspective) and also the so-called “African ignorance”. The latter is crucial. As identifying the problems and expressing the situation as is, is the first step to determining an applicable solution.

In this thesis, sustainability characteristics are identified that must be considered by stakeholders, especially government officials to support the implementation of sustainable RE development projects. Based on these characteristics, five aspects to study and develop on were selected: location analysis, sustainable management, protection of infrastructure, societal benefits and framework for implementation (not included in this thesis). This selection is based on the fact that although a vast number of studies on policies have been carried out, very few to none are ever implemented within the region. As such the implementation of projects without clear policies presents a sense of urgency to develop both implementation and management methods

and solutions. Such that these so-called development projects will avoid replicating the deteriorating state of the current energy infrastructure found in most SSA countries.

Researching these five aspects supports and contributes to the sustainability of RE development projects in the region of Sub-Saharan Africa. In the *location analysis* section, we develop a multi-step approach that combines multiple characteristics towards determining the optimal locations for these projects within the region. We take into account the current state of existing infrastructure (losses in transmission, existing energy plants etc.), geographic and demographic characteristics (population cluster, movement of the habitants, wind density information, transmission length possibilities etc.). In the *sustainable management* section, we present the empirical reality and failures of RE development projects in SSA and also provide recommendations for the sustainable management of these projects. We utilized a bottom-up approach where we engaged with mainly project beneficiaries to understand the reality surrounding the implementation of these projects. Furthermore, we engaged in a dialogue with the project developers and the financing government as the case presented itself. Combining the findings from all stakeholders, we deduced the main reasons as to why these projects fail and may continue to fail if the right methods towards making these projects sustainable are not considered and implemented. Throughout the study, we utilized the ethnographic approach that allows us to go into analysis of the specific area, identify contextual factors and examine the cultural and institutional dimensions of this topic. During the whole of the study, we present the situation as is. This is the first step to being able to provide the necessary and applicable solution towards the failures.

In the *protection of infrastructure* section we carry out an analysis to deduce the impact that disturbances such as theft and vandalism may have on RE development projects. Although these aspects are never considered in projects implemented within the region, it is important that project developers and financers practically take this into account. SSA is a tortuous region. Comparing the current energy infrastructure to the future expectations of RE infrastructure realistically does not indicate any improvement. This is because most projects that have been implemented have failed to take any sort of sustainability characteristics into account. However, how long these projects will last is something that is known: it will be short. Realistically!

We must consider the aspect of vandalism and theft in all corresponding projects for them to be sustainable. They should have all appropriate management methods and systems in place for the societal benefits of these projects to be achieved as we have shown in the last section of this thesis. In the *societal benefits* section, we provide the benefits of these so-called development projects

based on the implementation methods utilized and the current state of the projects using the bottom-up approach and presenting the views of the project beneficiaries. In essence, if the aspects and characteristics of sustainability presented in this thesis and modeled around the way of life of the region are not considered prior to the implementation of RE development projects in SSA, these projects, to cut a long story short will not survive and only become waste taking up space in potential land space. This is the inconvenient truth. Solving Africa's problems does not require the development of sophisticated technology, models or solutions. As such, my aim isn't to satisfy the urge of the norm but rather to contribute to the "missing" developmental knowledge, while realistically taking into account the way of life and working (*Human Touch*) of the corresponding countries within the region.

Finally, throughout this study we take into account the problem as is, whilst considering the way of life of the region thus leading to the development of a ***New Integrated Sustainability Mechanisms for Securing Substantial Benefits of Renewable Energy Projects.***

Many people, especially ignorant people, want to punish you for speaking the truth, for being correct, for being you. Never apologize for being correct, or for being years ahead of your time. If you're right and you know it, speak your mind. Speak your mind. Even if you are a minority of one, the truth is still the truth. - Unknown

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Abbreviations

SSA	Sub-Saharan Africa
RE	Renewable Energy
REP	Renewable Energy Projects
PPP	Public-Private Partnership
SP	Solar Parks
WP	Wind Parks
EROI	Energy Return on Investment
SWAPs	Solar and Wind-Assisted Parks
POM	Problem Owner Method
GM	Grid Method
MCLP	Maximal Covering Location Problem
FFM	Fewest Facilities Model
MTDM	Minimum Transmission Distance Model
KWh	Kilowatt hour
MW	Megawatt
GWh	Gigawatt hour
RETs	Renewable Energy Technologies

Chapter 1

Introduction

Parts of this Chapter is Published in the Journal of Renewable Energy as Ikejemba, E. C. X., Schuur, P. C., Van Hillegersberg, J., & Mpuan, P. (2017). Failures & Generic Recommendations Towards the Sustainable Management of Renewable Energy Projects in Sub-Saharan Africa (Part 2 of 2).

“As Africans, our pragmatic nature to problem solving isn’t unacceptable. However, it is difficult to accurately define and solve the problem when we are within the problem itself.” –

The Author

The basic livelihood of millions of Africans is being threatened due to lack of reliable and stable energy supply. This issue has eluded both the ordinary people and technocrats for decades now. Stakeholders in the energy sector have failed at overcoming obstacles and harnessing the full potential of energy resources for use. Mismanagement of the current methods and systems of generating power culminates in depriving millions of households and businesses of electricity for lengthy periods of time. Considering that electricity plays a vital role in different aspects of modern society, ranging from businesses, hospitals to schools, the electrical power outage has become a major impediment to Africa's development.

Enhancing sustainable development in the renewable energy (RE) sector entails utilizing appropriate technology for power generation and effective management in such a way that a balance in the economic, social and environmental development objectives of the current and future generation can be reached. The discussion of enhancing RE development in both developing and underdeveloped countries can be viewed from different perspectives. It may be accomplished in ways including but not limited to:

I. Policy Development	II. System Maintenance
III. Applicable Technological Design	IV. Economic Viability
V. Sustainable Management (especially in developing countries)	VI. Societal Benefits
VII. RE Applications	VIII. Sustainable Production
IX. Location Analysis	X. Logistics and Supply Chain
XI. Quality Assurance	XII. Appropriate Framework Implementation
XIII. Protection of Infrastructure/
Vandalism and Crime Cessation	XIV. Project Control
XV. Aspects of Corruption in
Implementation	XVI. Knowledge Transfer

The different focuses listed above are all issues that are important to enhancing sustainable development of RE development projects in Sub-Saharan Africa (SSA). This is because a heightened number of projects executed in Africa have failed or are bound to fail, due to either one or more of the perspectives indicated not being taken into consideration when projects are planned or implemented. It is without doubt that most of these projects in Africa are being implemented by western investors or contractors. Whilst these projects are considered to be of high quality, some of the project implementers lose sight of the fact that the method of application in a developed country is notably different when it comes to its acceptance and post-management in developing countries in SSA. Several projects of this nature that have failed (AssociatedPress, 2007) and why they fail (Ika & Saint-Macary, 2014)

have been published with some referring to these projects as “Colonialism in the form of investment” (Carrington, 2011). This is notable as three out of every four development projects implemented in Africa fails and it is blamed on the fact that development projects cannot be governed from “outside” (Tost, 2013).

Although literature does exist about the different areas of focus listed above, only a miniscule part of the literature is focused on the perspective of Africa, specifically Nigeria, Ghana and other Sub-Saharan African (SSA) countries. In this research, we have selected four different issues to focus on: (i) Location Analysis; (ii) Sustainable Management; (iii) Protection of infrastructure; and finally, (iv) Societal Benefits. Although the framework for implementation will be studied and developed, it will however not be included in this thesis for reasons of commercialization.

The remainder of this chapter is structured as follows: Section 1.1 explains the research motivation from a personal and generic perspective. Section 1.2 discusses the scope of the research based on the four selected points. Afterwards, in Section 1.3, we present the problem formulation for each of the four selected foci. Section 1.4 addresses theory by conducting literature review and Section 1.5 addresses the research methodology utilized for each of the research focuses. Section 1.6 aims to connect the findings to practical application in an African perspective. Section 1.7 presents additional remarks on the study and in conclusion, Section 1.8 presents the composition of the remainder of this thesis.

1.1. Research Motivation

Issues surrounding development usually create feelings of absurdity when discussed by individuals within most African countries. This stems from the reality that so many projects have been hyped up and discussed in the media only for these projects never to come to fruition. Some of these projects that have been installed fully or partially have also failed or stopped due to inaccurate planning during project installation or more importantly scheduled maintenance and management not being carried out. This is a discussion that spreads through every single sector of the Sub-Saharan African economy. This thesis focuses on issues surrounding: (i) establishing renewable energy in SSA and (ii) enhancing it in such a way that it can be utilized sustainably for the future generations. Thus our focus is on the following different aspects:

- ❖ Location Analysis and Selection
- ❖ Sustainable Management Method
- ❖ Protection of Infrastructure/Vandalism and Crime Cessation
- ❖ Societal Benefits

Newly designed and implemented RE plants or micro-grids need to be robust, maintained and most importantly, sustainable to serve their purpose. Nigeria, for example, the supposed “giant of Africa” is a country that is continually suffering economically due to power outages. Just as in many other SSA countries. Sub-Saharan African countries are without doubt blessed with abundant natural resources such as the energy from the sun. However, harnessing this energy is one attribute and then transmitting this power is another attribute. We believe that the current advancement in technology does enough to harness the minimum required energy for use. Therefore, we emphasize that our focus is not on the further development of this technology as can be seen from the selected focus. Many SSA countries are still in the process of development and with this, many inhabitants reside in places referred to as a "slum" or "ghetto". In places of this nature, the possibilities of power transmission are limited and difficult as houses are even located in places with no clear walking path and most of these residences are left with no choice than to sprout the transmission lines. It has become a huge problem for the power companies to accurately calculate the charges per households in these communities. Based on a sample exercise, randomly carried out with approximately 200 persons in different areas of Lagos, it is widely believed that no calculations (based on tariffs per household) are actually executed but rather a bogus monetary number is generated per street and divided by the number of houses on that specific street (when the author attempted to reach the DISCOs [Power Distribution Company] no responses were provided). This has caused so many households to opt for the so-called prepaid metre. In addition to the issues that plague the transmission of power, Nigeria loses a vast amount of electricity during its transmission along very long distances and the lack of the necessary infrastructure and capable management makes it even more difficult to control.

The management incapacity of projects of this nature is one of the issues amongst many that plague its sustainable management. Nepotism plays a huge role in this tomfoolery. This is widely seen across all sectors in most SSA countries where one with or without an education or an experience in a different field is provided a top position in a sector that has no connection to his/her experience. In addition, one other attribute that leads to the failure of these projects is corruption. This increases the frustration of the people that benefit or should be benefitting from the project and thus leads to vandalism of the corresponding infrastructure. This is one of the subjects that hinder a country from moving towards actual development. In this research we infer that the issues of nepotism and corruption are some of the main causes of failure towards the sustainable development of RE projects in SSA. Vandalism and theft of RE infrastructure is one area that hasn't had a great deal of focus in science. It is known that currently the renewable energy market is increasing exponentially in Africa and with this increment it is expected that theft and vandalism of the infrastructure will

inevitably occur. This however, is tightly connected to the management system of the project. In view of the fact that an incapable management will not be able to effectively manage the system, vandalism and theft could effectively render the project useless or ineffectual.

It is speculated that a vast number of RE projects are being implemented in countries like Nigeria, Ghana and a few SSA countries. In actual fact, the percentage of projects actually being implemented is far less than what is being promulgated. Amongst the various reasons already listed in previous texts, one other reason is the financial viability of these projects. Many Africans after having gone through the unequal distribution of wealth are left without any choice, other than to exclude themselves from the aspect of country development to rather focus on the aspects of individual so-called “hustle”. Individuals and institutions display the dangers of ignorance with respect to the issues of sustainable development and the utilization of clean energy. Therefore, proving that the usage of RE-related technologies yields financial and environmental rewards in the long or short term is salient.

In this context, we accentuate that the focus of our research is to develop a sustainable modus operandi for RE development projects by evaluating and determining the appropriate locations for solar farms and solar and wind assisted parks (SWAPs) taking into account several characteristics such as geographical and meteorological data. In addition, this research develops solutions and recommendations that assist in sustainable management and mitigating vandalism of renewable energy related resources and finally, evaluates and presents the actual societal benefits for utilizing renewable energy resources.

1.2. Research Scope

In this section, we describe the scope of the research, and explain the focus of the research based on the four different aspects indicated earlier.

1.2.1. Scope Levels

- Community Level (CL): Also considered as a sub-state level or a small project (SP). This scope encompasses all projects implemented within the context of communities.
- Nationwide Level (NL): Implementations that are focused on a national perspective or a large project (LP).

The scope has been broken down into levels so as to assist in the design of the research. Given that this research is intended to be multidisciplinary, the scope levels assist in assigning the five different focus points of the research to the corresponding scope level as shown in Table 1.1 below:

Table 1.1: Research focus and the corresponding scope levels

<i>Research Focus</i>	<i>Corresponding Scope Levels</i>
Location Analysis	<ul style="list-style-type: none"> • Community Level – (Chapter 2) • Nationwide Level – (Chapter 3)
Sustainable Management	<ul style="list-style-type: none"> • Community Level – (Chapter 4 & 5) • Nationwide Level – (Chapter 4 & 5)
Protection of RE Infrastructure	<ul style="list-style-type: none"> • Community Level (Chapter 6)
Societal Benefits	<ul style="list-style-type: none"> • Community Level (Chapter 7)
<i>Framework for Implementation</i>	<ul style="list-style-type: none"> • <i>All Levels = Community +Nationwide Levels</i>

With respect to the sections on protection of RE infrastructure (Chapter 6) and societal benefits (Chapter 7), all scope levels are incorporated into one generalization but with a main focus on the sub-state level. We place emphasis on the level of planning, the financing government and the project developers that implement the projects. We further analyze the precautions they implement towards development projects to generally manage the projects, to curb disturbances such as theft and vandalism and finally, maximizing the benefits of these development projects.

1.3. Problem Formulation

This section describes the background of our research demarcated according to the main research focus. We elaborate on location analysis, sustainable management, the protection of the corresponding infrastructure and the societal benefits.

1.3.1. Location Analysis

One of the most important characteristics of any sustainable energy project that is usually overlooked or not taken into consideration within the African context is the selection of optimal locations. More often than not, solar energy projects in Africa fail because they lack proper planning and long-term government support, according to a study on solar power in Nigeria (VanguardNews, 2016). However, it is known that most of these projects are profit driven, especially the private projects, and as such project developers opt to develop in locations where the returns are considered more lucrative. In doing this, they are sometimes blinded or bedazzled within the process by not taking into account the further possibility of cost reduction, profit accession, movement of the population, transportation of electricity and

the state of existing infrastructure. It is important to select the appropriate locations for SWAPs to better provide more efficient service to target nodes and reduce the reliance on a central generating station that is not sustainable. A vast majority of decision makers in African countries, however, do not take this into account. In several Sub-Saharan African countries, for example in Nigeria, it is a known fact that up to 40% of energy is lost during transmission (Ikeme & Ebohon, 2005). Some energy developers claim that it is actually not a problem of theirs as long as a power purchase agreement (PPA) is signed. This has caused some dispute between energy generating companies and power distributing companies in Nigeria (Yusuf, 2017). In spite of the facts above, what is failed to be understood or taken into consideration is that designing parks with an optimal location can amongst other advantages assist in mitigating issues such as power loss during transmission and easily tracking felonious users sprouting the transmission lines over long distances.

In some regions of SSA, there are multiple power plants that are in close proximity to one another that should be able to provide sufficient electricity to surrounding households. However, due to the deteriorating nature of the transmission lines substantial energy losses occur. Adding to the debacle is the frequent shortage of water to the dams and the shortage of gas to the gas power plants. It is important to develop and implement RE powered solutions for the communities. To implement this, *selecting the appropriate locations* is important as we take into account several problems plaguing the development of African countries, such as population to cover, energy transmission losses, felonious users etc. Nevertheless, it seems plausible that the lack of investment in technology is the main problem. The absence of modern equipment, qualified maintenance and management staff pose numerous problems for adequate power production and distribution.

1.3.2. Sustainable Management

The sustainable management of an RE project after its commissioning in SSA is the most important aspect of the project. Numerous approved and implemented projects in several countries within the Sub-Saharan region have failed to live up to their promises. These results from the fact that after projects have been implemented neither an effective management method nor maintenance plan is ever designed. This raises the question about the adequacy of plans designed prior to the implementation of the project, therefore engendering to the negative premonition and acceptance of clean energy within the mass population. In a study done on RE in Nigeria and Ghana, it was found that “So many projects fail because, when we talk about solar parks in Africa, most of the time people think this is just about finding an empty plot of land and implementing a project,” little thought is given to how projects will be managed once built (VanguardNews, 2016).

```
graph TD; GG[Government Gazette] -- "Project Publication" --> OP[Organizations Submit Proposals]; OP -- "Proposals Examined Appropriately" --> PAO["Project Awarded to Organization 'D'"]; GG -- "Direct Nepotism" --> PDA["Project Directly Awarded to Organization 'A'"]; PDA -.-> PIA["Project Indirectly Awarded to Organization 'B'"]; PIA -.-> PII["Project Implementation impossible by Organization 'A'"]; GG -.->|Indirect Nepotism| PAOC["Project Awarded to Organization 'C'"]; OP -->|Indirect Nepotism| PAOC;
```

The flowchart illustrates the process of project awarding, distinguishing between Direct Nepotism and Indirect Nepotism.

Direct Nepotism Path:

- Government Gazette** (Start) leads to **Organizations Submit Proposals** via **Project Publication**.
- Organizations Submit Proposals** leads to **Project Awarded to Organization "D"** via **Proposals Examined Appropriately**.
- Government Gazette** leads to **Project Directly Awarded to Organization "A"** via **Direct Nepotism**.
- Project Directly Awarded to Organization "A"** leads to **Project Indirectly Awarded to Organization "B"** via a dashed line.
- Project Indirectly Awarded to Organization "B"** leads to **Project Implementation impossible by Organization "A"** via a dashed line.

Indirect Nepotism Path:

- Government Gazette** leads to **Project Awarded to Organization "C"** via a dashed line labeled **Indirect Nepotism**.
- Organizations Submit Proposals** leads to **Project Awarded to Organization "C"** via a solid line labeled **Indirect Nepotism**.

- Project directly awarded to organization A: This case involves *direct nepotism* whereby projects are awarded directly to organizations that have personal relationships to the government or the awarding personnel.
- Project indirectly awarded to organization B: This involves cases whereby projects awarded to organization “A” are not implementable by the organization. Therefore

leading to the awarded organization outsourcing the whole project to organization “B”.

- Project awarded to organization C: This involves the application of *indirect nepotism* whereby the organization to be awarded the project is already known from the onset and as such the “genuine” procedure implemented to award the project is executed to divert any unwanted attention of corrupt practices.
- Project awarded to organization D: This case is whereby the project proposals undergo genuine scrutiny and the organization with exceptional experience is fairly awarded the project.

The rationale for the above explanation is to understand from a general perspective how projects are awarded and more importantly to be able to retrace and distinguish the responsibility of each player within the projects. In this study, our focus is strictly on RE-related projects and we exclude the aspect of corruption as that could outright become a whole other study on its own.

The management of projects should be the responsibility of an entity, either the awarding government or the implementing organization. In Nigeria for example, so many small RE projects have been implemented around the country, ranging from solar boreholes to thousands of street lights and hospitals. However, despite the potential of these projects, most of them have been left to deteriorate with no maintenance, no cleaning, no repairs and more importantly no sustainable management that encompasses them all. Indication from an impromptu conversation with project developers and financing government officials indicated that the state of the projects is not even known or recorded. This situation has created a negative attitude towards the acceptance of sustainable and clean energy usage within the minds of the masses making it even more difficult for developing governments to adopt the technology.

We believe that renewable energies are the way of the future given the amount of human CO₂ upsetting the natural balance of the carbon cycle. Nonetheless, for RE related projects to surge positively, ***a sustainable management method for publicly implemented projects is needed to control*** the deteriorating nature of the already implemented projects and future planned projects in Sub-Saharan Africa.

1.3.3. Protection of Infrastructure

The renewable energy market, specifically solar energy, has grown substantially over the past few years. However, the growth of this market has also provided opportunities for high level of theft and vandalism to those knowledgeable of the technology. There is an indication that

as the price of stolen spare parts (e.g. scrap metal, copper etc.) from the current energy infrastructure diminishes, offenders examine other methods to earn amoral living. As such the theft of infrastructures from RE development projects (e.g. solar panels) also increases. Regrettably, the correlation doesn't work in the opposite, as even with a price increase of scrap metal and copper, the theft of solar panels is expected to grow. Based on a statistical study provided by SolarInsure, vandalism and theft that occurred in the solar energy sector grew by more than 15% between 2008 and 2009, and is expected to surge even if the market becomes saturated (Ireland, 2010). Theft and vandalism of energy related resources plagues countries within Sub-Saharan Africa. In addition, given the global energy crisis within developing countries on the increase, vandalism and theft of power related resources are not excluded from the problems faced by countries in SSA.

Theft and vandalism of RE-related infrastructure within SSA are currently modest. They are however expected to surge within the next decade as RE projects increase across SSA. One can only opine that it is only a matter of time before the whole situation of theft and vandalism to current energy infrastructures replicates within the RE development sector. For example, in Nigeria, a country that relies heavily on the oil sector for approximately 80% of its revenue (Odularu, 2007), continued vandalism and theft to infrastructures is an immense obstacle. From a short interview with residents in one of the affected areas where solar panels have been stolen in Northern Nigeria and a village in Kenya, it was relatively comprehensible that this state of affairs stems from the inequitable distribution of wealth by the government and the non-cooperation of operating organizations.

Many of the delinquents, who manage to purloin solar panels, do this within areas that are both on and off the grid where RE is the main source of energy and the ground mounted systems are utilized. With minimum security in areas such as these, they become susceptible to being carted away. It is known that systems built on elevated structures are considered safe, they are however not immune from criminals as has also been reported in countries like Nigeria, Kenya, Ghana, South Africa and Gabon (Lamiley, 2013; Masinga, 2015; AllAfrica, 2013) where solar panels have been taken off the roof of individual homeowners and also from the street solar lightings. Mastery is required to un-mount RE infrastructures without vandalizing them, nonetheless criminals are learning fast within the industry. The use of technological advancement such as online 3D maps has been advantageous for criminals in pinpointing installed RE infrastructures (SustainableBusiness, 2013), particularly in remote areas where their misdeeds are plausible to go unnoticed as earlier indicated.

This situation creates innumerable problems and also contributes to the slow acceptance of clean energy in developing countries coupled with its management. Therefore, in cessation,

for an expected positive surge in the usage of RE in the future, *applicable solutions and recommendations against the expected growth in RE infrastructure theft and vandalism should be developed* and implemented simultaneously in SSA. In this way the sustainability repute of these development projects is reified.

1.3.4. Societal Benefits

There is a global perspective on the societal benefits of utilizing renewable energy resources. More often than not, it revolves within the characteristics of being good for the environment, low energy prices, better health benefit and needless to say the aspects of job creation and economic interests.

Very few to no disadvantages exist towards the societal benefits of utilizing renewable energy in Sub-Saharan Africa. The general disadvantages that exist are more on the possibility to generate a large quantity of energy and the unpredictability of the resources to be available when required (Solar School, 2015). For example, the rain required to fill dams, the sun required by the solar panels and the wind required for the turbines. However, this study our focus isn't on the already known positive or negative benefits of utilizing renewable energy, but rather to present the dwindling reality of utilizing renewable energy technologies in SSA when all aspects of sustainability are not considered prior to the implementation of projects. Whilst most of these benefits are easily recognizable within western and developed countries, in Sub-Saharan Africa a completely divergent scenario is envisaged but not taken into account. This includes, the way of life and understanding, aspects of knowledge transfer, technological design and acceptance etc.

Our goal with this section is to *study and present what the realistic societal benefits are within the perspective of RE development projects in Sub-Saharan Africa* via the investigation of past implemented projects and planned projects and if necessary, provide compelling recommendations to support the sustainability of these projects.

1.4. Literature Review

In this section, we explore literature and we outline studies that are relevant to the location analysis for RE projects in Africa, sustainable management methods, protection of infrastructure and societal benefits within the scope of RE in SSA. With the further development of RE technologies and their implementation in Sub-Saharan Africa, within the recent decade, only limited studies have been executed within the perspective of SSA. Given that the study is multi-disciplinary, we classify the literature reviewed based on the research focus as also seen in Table 1.1.

1.4.1. Location Analysis

Hakimi (1964) presents models (the p -median) and methods to determine the optimum locations of public facilities. The study has been successfully utilized in controlling the outbreak of diseases in countries, strategically locating facilities such as police stations and communication networks. We study the elements of these models further in the subsequent chapters and also utilize them where applicable in Chapter 2 and 3.

Batta et al. (2013) study the locating of facilities using dispersion, population and equity criteria. The authors prove that a suitable utilization of the above listed criteria (dispersion, population and equity) can lead to fairly feasible solutions with respect to the p -median objective. More importantly, the problem owners or decision makers should validate through the constraints that the chosen potential locations are selected based on the above criteria. Further analysis to their study indicates that when potential locations are restricted to nodes and parameters based on the listed criteria, this seems to result in effectively eliminating unwanted locations.

Agbetuyi et al. (2012) present a study on wind energy in Nigeria. The study describes the wind energy potential in Nigeria and specifies the conditions to be met before wind energy generators can be connected to the existing grid and how they can be connected. The effect the new generation source might have on the existing power network is also analyzed. In addition, the authors discuss the ability of a site to sufficiently accommodate wind energy generation not only dependent on wind speeds but also on its ability to interconnect to the existing grid. They take into account the wind mean speed over multiple years to map out various potential locations. These elements are further studied and utilized appropriately in Chapter 2 and 3.

Gervet and Atef (2013) present a two-stage optimization model to locate RE parks in Egypt. They present methods that take into account both past and future data, namely dynamic programming, constrained local search and integer linear programming. Within the study their main goal is to design a decision support tool that seeks the best trade-off cost/return on investment by taking into account physical installation constraints as well as energy requirements and costs. Within the study, Egypt was the main focus. The authors state that the methodology utilized can be implemented in other countries. However, this is failed to be elaborated on. Given that the energy network in Egypt is predominantly adequate, when considering the African perspective we fail to see the study's applicability to other developing African countries mainly in the Sub-Sahara where infrastructures are below par and population distribution is erratic. Furthermore, given that maximizing the population to be covered should be of importance, it is however not considered within their study.

Alfaro and Miller (2013) present a study on satisfying the rural residential demand in Liberia with decentralized renewable energy schemes. The authors analyze the potential of decentralized generation to provide electricity to the rural Liberian population. Two methods are presented that could be utilized to reach rural electrification, namely grid expansion (GE) and decentralized generation (DG). GE extends the centralized generation capacity by creating transmission and distribution networks to rural populations. DG uses smaller generation units (such as micro-grids) located close to the rural load centres, avoiding large distribution networks. We look into the practical application of these methods in Chapter 2 and 3. Furthermore, due to the deteriorated state of the infrastructure caused by civil war, the authors utilize different methods such as population growth and yearly increase in connections to forecast the electricity demand.

Ye et al. (2011) present a location set covering approach for waste recycling centres in Taiwan. The method utilized is also applicable to locating RE parks. However, the study suggests the implementation of a new location model to reduce the number of existing centres in such a way that the usage of land resources is reduced. The total transportation distance would reduce and therefore lead to increased efficiency. The idea of utilizing location models to increase efficiency and reduce transportation cost is correlated to this study and as such we study these elements in the subsequent chapters with a focus on implementing renewable energy development projects.

Note that the first study on location theory started in the early 1900's when Alfred Weber examined how to locate a single warehouse such that the total of all distances between the warehouse and customers is minimal (Weber, 1929). Since then, research around location theory has expanded to cover numerous sectors. However, only limited research has focused on RE development in SSA. To the best of our knowledge no paper has focused on the location of RE parks with the aim to maximize the coverage of the people. Most of the research conducted on RE in SSA is focused on the design (Fadare, 2009), strategic development (Uduma & Arciszewski, 2010), energy development (Ajayi, 2013) and energy generation (Wen-Shan, Mohammad, Md, & Hasimah, 2012). It is important to note that all these studies do provide solutions to SSA's energy quandary but none focus on determining the locations for RE parks whilst taking into account the potential for maximum coverage of the population, countering the sprouting of transmission lines, and the reduction of investment cost towards new projects.

1.4.2. Sustainable Management

Few to none paper(s) exist on the management of RE projects in Africa. Primarily, the papers currently available focus on the technical optimization. It is imperative to note that this

section of our research focuses on the aspect of governance of these projects and not on the technical optimization. As in any RE project there are factors that contribute to its success immensely. This includes planning, implementation, maintenance, as well as technological impact and its acceptance. This is all encompassed by the sustainable management of the project after its implementation. Community engagement is one aspect that is closely linked to the overall sustainable management and is essential for the overall success of a project.

Alvial-Palavicino et al. (2011) present a methodology for community engagement in the introduction of renewable based micro-grids. The methodology presented by the authors is based on the notion of a community moving towards the phase of utilizing resources in a more sustainable way and how technological intervention affects them from the perspective of a socio-ecological system. The presented methods are divided into three different stages, with each concentrated on magnifying elements of the socio-ecological structure and amalgamation among stakeholders: building trust, co-construction and ensuring sustainability. Furthermore, this encompasses: i) opening up to the plurality of stakeholders' visions, ii) promoting transparency and trust among stakeholders, iii) engaging and integrating the community with the project, becoming owners, managers and responsible for the energy production and consumption system iv) building capacities that enhance their ability to cope autonomously with changes, and v) promoting sustainable use of resources, i.e., energy efficiency. Although the study does provide feasible methodologies that are applicable to developing economies, it does however neglect to elaborate on the aspect of managing the projects after implementation. We investigate the aspect of community involvement towards project sustainability in Chapter 4 and 5 of this thesis via an ethnographic perspective.

Kossova and Sheluntcova (2016) carried out a study on evaluating the performance of public sector projects in Russia. According to the authors, public sector projects in Russia are inefficiently executed. The main reason presented is an absence of generally accepted procedures to evaluate the projects being implemented. The authors indicate the application of two different approaches: the social rate of time preferences and the social opportunity cost of capital. They propose a methodology for projects related to any industry. The authors claim that it is imperative to note that the findings of the study are applicable to countries with unequal development of economic activities. However, its application to countries in Africa may differ due to the steps taken for projects to be awarded. Nevertheless, we explore and further investigate its application to SSA in Chapter 5.

Bendoly et al. (2006) indicate that in management of operations even when procedures are known and do appertain, they may also be difficult to execute considering lack of information, trust, or proper incentives. A common factor in this disintegration is people. When it comes

to execution, the success of managing operations and the accuracy of theories, it is found that these rely heavily on our understanding of human behavior. The absence of trust within the supply chain, misalignment of incentives, and the aversion of natural risk are but three behavioral issues that can cynically impact the successful management of operations. This is more often than not the case with project implementation in most SSA countries. Nonetheless, we further analyze this case to deduce the reasons for project failure and understand the interconnectedness of these issues in Chapter 4 and 5.

Cooke-Davies (2002) discusses the factors that are critical to project success. This is done by elaborating on and answering three separate questions: “What factors lead to project management success?”, “What factors lead to a successful project?” and “What factors lead to consistently successful projects?” The author delineates the difference between project success (measured against the overall objectives of the project) and project management success (measured against the widespread and traditional measures of performance against cost, time and quality). The study was empirically conducted with participation from organizations within Europe. It presents some hard facts towards designing a successful project. Its applicability to renewable energy projects in the SSA context is analyzed further in Chapter 4 and 5.

Munns and Bjeirmi (1996) focus on identifying the intersection between project and project management. They also elaborate on how the confusion between them affects their correlation. Their study pinpoints the different individuals involved within a project and project management, in partnership with their objectives, expectations and impact. The study demonstrates how a better acknowledgement of the difference between both will bring an elevated possibility of project success. The study provides multiple insights and factors that affect the sustainable management of projects. It does, however, fail to elaborate on the management after its implementation. However, the authors do discuss the lifecycle of the projects itself.

1.4.3. Protection of RE Infrastructure

There currently exists no literature on the aspects of protecting RE infrastructure within SSA. As such we analyze the impact that disturbances such as theft and vandalism would have on RE development projects in the region whilst taking into account realistically defined characteristics of the region in SSA. In addition, but not included in this thesis, we also study why these disturbances are not considered prior to the implementation of these development projects from the actors perspective and how to further impede these disturbances drawing from initial analysis.

Although limited literature exists for both parts, nonetheless, in the analysis part (quantitative) we utilize a Markov chain approach as presented by Stander et al. (1989) to model the focus of specific offenders. Markov theory has been designed to be memoryless. In our analysis in Chapter 6 we add memory to our model by duplicating states and adding memory to the duplications. This way we stay within the Markov framework, but still incorporate how the past does influence the future. Although these theories usually require historical data to predict future occurrences, in our study we utilize the approach by Hauser et al. (1990) that uses a consumer clinic to obtain data to calibrate the sales trajectory of a new car. In our study we utilize a comparable approach to generate the data required in Chapter 6.

1.4.4. Societal Benefits

Since the dawn of renewable energy in Sub-Saharan Africa, so many projects and plans have been made towards the implementation of RE development projects. This includes the implementation on PV projects, solar and sustainable cookers in rural areas etc. Multiple papers have been published with respect to these circumstances. However, no single paper has actually focused on the “true” societal benefits of utilizing RE related infrastructures in Sub-Saharan Africa.

Terrapon-Pfaff et al. (2014) present a review on the impact and sustainability of small scale RE projects in developing countries. In their study, they investigate 23 projects after their implementation to deduce factors that lead to the success and failures of the projects. We consider the design proposed by the authors in Chapter 7 of this thesis. Although an important study towards the sustainability of projects in developing countries, it does not however cover the aspect of societal benefits given the circumstances in Sub-Saharan Africa that may differ from those in other developing countries outside Africa.

Multiple papers have been published with respect to sustainable development. Nonetheless, what most authors omit or do not consider is the true situation surrounding the aspects of RE development projects in SSA. For example, in the paper by Oyedepo (2012), on energy for sustainable development in Nigeria, the author presents the potential of renewable energy in Nigeria and presents the factors that need to be considered towards an energy sustainable country. However, the author relinquishes the true state of infrastructures and the reality surrounding the implementation of RE projects in the country. Notwithstanding, we consider aspects of this study in our Chapter 7.

In the next section we present our research methodology utilized for each focus in this thesis. We further elaborate on the selection of each methodology and provide in-depth explanation as to why we deem it the best fit for studies focused on Sub-Saharan Africa.

1.5. Research Methodology

In this section, we present the research methodology utilized in this thesis. Given that this study covers multiple research foci within the realm of sustainable development, a mixed method approach is utilized. The mixed method approach is most suitable as this study spans across various mechanisms for sustainable development. A benefit of this approach (mixed method) is presented in the book, “designing and conducting mixed methods research” (Creswell & Clark, 2007).

- Chapter 2 – Integer Linear Programming (ILP)
- Chapter 3 – Integer Linear Programming (ILP)
- Chapter 4 – Ethnography
- Chapter 5 – Ethnography
- Chapter 6 – Markov Theory, Numerical and Statistical Analysis, Clinical data generation
- Chapter 7 - Ethnography

The research methodologies are explained locally within the chapters. However, given the pervasiveness of the *ethnographic* approach we further elaborate on that now. We believe it is the most congruous approach to finding an equilibrium point between traditional scientific methods and an appreciation for the complex and multi-faceted context and way of life of the Sub-Sahara. Given that one of the secondary aims of this research is to present the situation as is whilst maintaining acceptable scientific integrity, ethnography presents that opportunity.

The etymology of the term “ethnography” combines two words: ἔθνος (*ethnos*) "people" and γράφω (*grapho*) "I write". Specifically, *ethnos* refers to ethnicities whilst *grapho* means describing phenomena (Neuman, 2014). Hence, ethnography is the art of writing or describing people, cultures or ethnicities. Some authors present ethnography as a complete methodological approach to research, whilst others present it as a technique for data collection in field research (Bikner-Ahsbabs, Knipping, & Presmeg, 2015; Marvasti, 2004; Gupta & Awasthy, 2015). Consequently, it is possible to employ ethnography as a methodological framework which encompasses different research techniques and methods on the one hand, and using ethnography as a method for gathering data for analysis in a suitable research design on the other hand. Here, we address ethnography as a research approach in entirety and not merely as a data collection technique.

Ethnography has a unique disciplinary character in that it is normally associated with humanities and social sciences disciplines. In these disciplines, large volumes of research involve field work, interaction with people, observations of the physical world and

environment, societies and cultures. For many social sciences and humanities researchers, the ‘world out there’ is their laboratory. This comes in contrast to what physical scientists - such as physicists, chemists and biologists - encounter in their research. For these categories of researchers, it is possible for the entirety of their research to be conducted in enclosed systems such as laboratories, or even solely conducted on computer systems as portrayed in the cases of computational simulations. Ethnography is said to have originated from cultural anthropology and always focuses on studying unique people, their culture and ways of life, history, environment, belief systems and perceptions in detail (Thomas, 1993; Neuman, 2014). Nevertheless, the research method has evolved over the years into a concrete and widely used method across different disciplines (Bikner-Ahsbahr, Knipping, & Presmeg, 2015; Given, 2008). Ethnography has gained traction from researchers and is now employed in research across multiple disciplines.

The adoption of the ethnographic method in research does not only depend on the characteristics of the method itself, it is also contingent on the type of research being conducted. In the case of the studies on RE and sustainability in SSA, the primary reason which justifies ethnography as the most suitable method is that the type of research being undertaken is an action research involving field work. The study focuses on current challenges facing a definite set of countries in SSA and their journey towards sustainable development. This requires direct interaction with, and observation of the people, their institutions, infrastructure and systems. The ethnographic method makes this possible in ways elaborated below.

Core of ethnography is direct field work: Ethnography basically refers to field research and includes participant observation in most cases. In ethnography, researchers have the opportunity to immerse themselves in the context of the research with the goal to gain direct insight and experience of the subject matter (Given, 2008). As a result, researchers who are interested in understanding the nuances of an issue or getting a good grasp of the big picture adopt the ethnographic method and step out into the field. This means that, by virtue of its field orientation, ethnographic research greatly differs from what many call armchair research or speculation (Neuman, 2014).

Data collection technique is qualitative: Ethnography does not solely lead to qualitative data mainly because researchers may also collect quantitative data in the course of an ethnographical study. Ethnography is known to use more “soft data” than “hard data” (Neuman, 2014). Nevertheless, most ethnographers seek qualitative data more than quantitative data. To a very large extent, most ethnographical studies are unique in their focus on *issues* rather than *statistics* in data collection and analysis. With the ethnographic method,

researchers are more interested in understanding causes and effects, describing relationships, and theorizing observations and making categorical assumptions or conclusions about factors that underlie a particular phenomenon. They are less interested in quantifying observations. In studies mainly involving observation, interviews about issues, quantitative data may be of little or no relevance (Thomas, 1993).

Data collected is primary: Primary and secondary data are the two basic types of data used in most studies. Primary data is known to possess originality mainly because it is first-hand data collected by the researcher (Marvasti, 2004; Gupta & Awasthy, 2015). Conversely, secondary data is already processed and interpreted and may not offer a true reflection of the current issue being investigated, as is the situation in SSA's development. This is why ethnography is popular among many researchers. The direct observation does not only give the researcher a true experience of the situation being investigated, it also enhances the quality and representativeness of the data being collected. This quality gives ethnographical research the edge in identifying and communicating unambiguous and factual information.

Offers opportunities for validation: The validity of data collected in a study is paramount to providing corresponding recommendations. Collecting primary data alone may not satisfy the desire of many researchers to obtain valid information. One of the pronounced methods used to attain validity in research is triangulation (Neuman, 2014; Bernard, 2006). Ethnography offers the opportunity to triangulate information obtained, thereby offering researchers a platform to verify and confirm information whilst on the field. Researchers are also able to cross-examine their observations with the findings of other researchers in ethnographic studies.

In addition to the points stated above, which already offer an idea about the strengths of the ethnographic method, we further identify some specific factors we considered in applying this method to our study.

Context of study: The context of our study had a huge impact on the choice of research design. Our study covered the region of the Sub-Sahara, which included countries like Ghana, Nigeria, Gabon, South Africa, Tanzania, etc. Although great differences exist in the cultures of the people of these countries, there is a high level of homogeneity in their renewable energy records (which was the subject of our study). Thus, context here refers to the conditions of the renewable projects in Sub-Saharan African countries. The ethnographical method allowed an in-depth, descriptive and explanatory approach to be applied for empirical assessments of the factors causing the failures and sustainable management challenges of renewable energy projects.

Objectives of study: The aim of the research was to solicit the expert views of project managers and other stakeholders in the renewable energy sectors in SSA. This required direct engagement with them without electronic or print media. As a result, most of the respondents had the confidence to voice out their opinions on the reality of the situation and open up about issues which would have been ignored if other methods such as self-administered questionnaires were used to collect data. Our study also aimed to figure out the solutions to the problems with RE development projects and a direct engagement with stakeholders was the most appropriate way to arrive at realistic and applicable solutions.

Cases of RE projects: Also, the researchers needed to confirm in person the state of the renewable energy projects under study. Hence, direct observation was indispensable in ascertaining the true state of the projects within the corresponding countries in SSA.

Underpinning concepts with empirical observations: It is a tradition among most research to precede empirical research with reviews of existing literature. This was not different in our study. We encountered different scenarios and concepts in the course of our literature studies which needed to be underpinned by empirical findings. Adopting the ethnographic method was essential because it enabled the researchers to get a first-hand grasp of the issues and relate the concepts and ideas outlined in literature with actual observations in the field. Ethnography was the right conduit to give meaning to concepts.

A typical ethnographic study requires that the researcher becomes part of, or in one way or the other attains proximity to the society or group being studied (Gupta & Awasthy, 2015). This was the main strategy adopted in carrying out this study. Field work and direct contact with the subjects of the study was carried out. This was not done haphazardly because a carefully crafted but flexible plan was pre-designed to ensure that the encounters were tactical. Planned site visits were carried out to all corresponding RE projects for observation, and the conduction of ethnographic interviews was executed as indicated within the corresponding chapters.

In applying the ethnographic method, the core principles of the scientific method were observed mainly because we anticipated challenges from the scientific community regarding the validity of the results. Until recently, a stark distinction between social science and humanities research methods such as ethnography and physical science methods was maintained. This was so because many researchers expressed doubt over the scientific value of methods such as ethnography. The criticisms from the scientific community placed ethnography and related methods under constant skepticism for being pseudoscientific (Neuman, 2014). Any researcher adopting such a method was laden with the burden to prove its appropriateness and scientific value. The contribution developed by ethnography is the fact

that it investigates the procedures by which the unknown becomes known and therefore comprehends knowledge not as a substance, but as comparative and situational (Caduff, 1999). These developments have made establishing the validity of the ethnographic method possible, in principle and practice.

Advancement in ethnographic methods has resulted in established guidelines for achieving validity in ethnographic studies. Our steps towards attaining validity began with the commitment of the researcher to obtaining credible data. We ensured that data was original and recounted to reflect respondents' own expressions rather than a translation in the researcher's own words. In order to avoid lacing observations with the researcher's own biases, due diligence was followed and the observer's notes were reviewed by colleagues involved in the study to certify the integrity of observations. But validity goes beyond the researcher to include the quality of the data gathered.

Furthermore, we did triangulate the data obtained in the study. This was done by repeating questions and observations over the multiple cases of RE projects involved in the study. We posed identical questions to participants from different countries in the Sub-Saharan region. The recurrence of issues raised cross-border instilled confidence that the findings are not merely aggregates of opinions but real issues confronting SSA.

According to some experts, implementing the ethnographic method can be enhanced when the researcher is already familiar with the research setting (Given, 2008). The researcher's familiarity with the certain ensured that the right questions were asked and respondents did not mislead the researcher with erroneous information. It also guided the researcher to go to the right places and in some cases helped to keep the researcher out of tense zones. Finally, the findings were also validated by cross-checking the data gathered with relevant existing literature in some cases. Our research relied on the few sources available on SSA. However, more cross-examinations were made with the findings of researchers in areas outside of the SSA region.

1.6. Practical Application

1.6.1. Pitting Literature with Practical Application in SSA

The appropriate location and management of RE development projects coupled with the protection of the corresponding infrastructure are important aspects towards the "real" actualization of enhancing sustainable development in developing countries within Sub-Saharan Africa. The practical applications of already existing theories are quite complicated since most theories and developments within the field have been more technological and not

developed within the perspective of SSA. In addition, numerous studies claim to present solutions that assist in mitigating the energy problems in Africa. However, we find them insufficient as a consequence of one or more of the following justifications:

- *Applicable mainly to first world countries:* with most solutions developed for first world countries and developed countries, it is difficult to apply the same solutions to countries in SSA as they are doomed to fail if the conditions of the locals are not taken into account.
- *Insufficient in practical application with respect to SSA:* there is limited framework that provides the application of developed solution to the context of SSA. They mostly provide recommendations for solving the energy crisis. Nevertheless, these studies fail to take into account the realistic way of life of the region and the characteristics such as population movement and immense losses in transmission lines and incapable infrastructure.
- *Mainly focused on policies:* Most of the studies published are mainly focused on the development of policies as a starting point to solving the energy problems. An important issue is that although policies are still currently being adopted, it is also imperative to develop applicable solutions towards RE implementation because, despite the absence of clear policy adoptions, projects are still being planned and implemented.

The idea of this study is to utilize a bottom-up approach that includes the decentralization of energy generation plants to solve the energy crisis within SSA.

1.6.2. Research Plan

In this research study, our aim is to develop and present solutions towards enhancing sustainable development in the field of renewable energy in Sub-Saharan Africa. The research focus has been selected based on the urgency to further develop and provide solutions that are undergirded in a sustainable way. Given the approach utilized in our study, we deduced that major contributions are needed for literature to provide solutions to inquiries from practice in SSA. Several studies have been executed but most of these studies miss out on the main issue of how to solve the energy crisis in SSA. This study aims to bridge the gap between literature and applicable solutions for SSA. The following elements are the main focus of this study:

- *Proposing location models and methods of application:* Optimizing the availability of arable lands for the usage of solar and wind assisted parks to tackle the cases of power outages, taking into account current power plant locations, geographical,

demographical and other important characteristics such as transmission, wind viability, aerial plan of households in villages and communities etc.

- *Presentation of sustainable management methods*: Ascertaining factors that lead to the deteriorating nature of the RE infrastructure and developing applicable solutions to lead to the sustainable management of these resources taking into account all participating stakeholders.
- *Developing future solutions to the expected rise in RE-infrastructure theft*: Evaluating the impact that vandalism and theft of RE related infrastructure inflicts on countries in SSA and consequently develop solutions and recommendations that will assist in mitigating vandalism and theft of energy related resources.
- *Analyzing the societal benefits of RE projects in SSA*: This requires investigating already implemented projects within the SSA region and weighing the “factual” benefits over expected/theoretical benefits. Using the findings further developments could be implemented.

1.7. Additional Remarks

The absence of sustainable management as earlier noted is a major setback for RE development projects in SSA and thus it negatively affects the general perception and adoption of the technology by the people. Solutions developed for first world counterparts will in no way be implementable in SSA developing countries because such solutions do not take into account the culture, tradition and way of life of the African people. Such models and solutions also require competent and scientifically proven management methods to oversee and control the project. It is only feasible to develop solutions that are easily implementable and manageable within the African context.

This is not to say that management in SSA is horrendous, but that given the history and issues affecting not just RE-related projects but development projects in general, it is more appropriate to develop solutions that fit perfectly within a developing country's context. In contrast, a step- wise bottom-up approach will provide the best potential solution to solve the energy crisis in Sub-Saharan Africa. Given that as Africans our approach to problem solving is rather pragmatic, this research aims to find an equilibrium point between applicable science and pragmatic decision making whilst still focusing on the research plan.

Section 1.8 outlines the remainder of this research study, where it references to the focus of the research earlier indicated in the research plan. It further elucidates how each of the focus points of the research study fits within the context of the following chapters.

1.8. Summary and Thesis Outline

This chapter presents the introduction to the research study on enhancing sustainable development and maximizing the corresponding benefits in Sub-Saharan Africa with a focus on renewable energy.

Chapter 2 is attributed to the first focus of the research plan, i.e., location analysis and selection (see Section 1.5.2). It follows our approach of a bottom-up solution approach and also the decentralization of energy generating plants. We develop a multi-step approach - including mathematical programming - to design a capacitated network of SPs and SWAPs. We take into account geographical and demographical characteristics. Meteorological data is also taken into consideration for preferred wind power generation. To test and validate our approach, we select as case study the state of Anambra, since this is the first state in Nigeria to embrace structural planning for its cities. More importantly, Anambra state is currently depending on neighboring states for its electricity supply. We present different solution approaches to reducing transmission cost and the losses incurred during transmission using mathematical models. In the end we design a capacitated energy network which is powerful enough to cover almost the entire energy requirement of Anambra. The density of the network is such that the majority of households are within reasonable distance from the nearest energy park. This way the state will be self-supporting energy-wise in a sustainable way. In Chapter 3, the developed models are further extended to cover Nigeria and Ghana.

In addition to Chapter 2, Chapter 3 also deals with the first point on the research plan. However, Chapter 3 deals with a much larger perspective (country-wide) and a further development on models and its applications. In particular, the chapter focuses on Nigeria and Ghana. The power supply infrastructure of both countries, as well as the policies surrounding the provision of off-grid energy is analyzed in depth. We present the advantages and disadvantages of two different methods (the grid approach and the problem owner method [POM]). We choose a hybrid approach by combining the grid (distance concept) and the problem owner method (topological vicinity concept). We apply the grid method to regions with high population density and utilize the POM for less populated areas. Furthermore, we take into account power plants that are operational or will be so in the near future. In the above fashion we design two separate, capacitated networks of SPs and SWAPs, one for Ghana and one for Nigeria. Each of these is robust enough to cover - in a sustainable way - the energy requirement of the majority of households by a facility within reasonable distance.

Chapter 4 deals with the second point on the research plan; we investigate 29 projects across 10 Sub-Saharan African countries. In this chapter we present the empirical reality and failures

of publicly implemented projects across these countries. This study engages directly (ethnographically) with the local communities benefitting or expected to benefit from the projects, the implementing organizations and government. We carried out an extensive dialogue with all participating stakeholders and were able to amalgamate the true reasons for RE development project failures in SSA based on the responses provided and from physical examination of the implemented projects. Despite the differences in culture and understanding, the reasons for failure of the projects are found to be similar across the different countries: (i) political agenda, (ii) process of awarding projects, (iii) stakeholder co-operation, (iv) planning & implementation, (v) maintenance and (vi) public acceptance & inclusion.

Chapter 5, as Chapter 4, also deals with the second point of the research plan focusing on the sustainable management of RE development projects in Sub-Saharan Africa. However, in Chapter 4, the focus was directed at the empirical reality and failures of projects. In Chapter 5, the focus is placed on the failures and generic recommendations towards the sustainable management of these projects. We create the interconnection between stakeholders (financing government, implementing organization, public beneficiaries) and the corresponding reasons for failure attributed to each of them are meticulously deduced. We further explain in-depth about the failures, whilst engaging the perspective of all participating stakeholders. Based on the findings, corresponding recommendations that are adoptable by the stakeholders themselves towards the sustainable management of these projects are developed. Combining findings from past literature on the failures of RE projects in SSA with an ethnographic approach and practical experience in the implementation of renewable energy projects in Sub-Saharan Africa, we propose the following solutions: (i) transparency, (ii) ownership, (iii) shared responsibility and (iv) community involvement. We present applicable recommendations that should be taken into account by stakeholders towards implementation of any sustainable renewable energy project.

Chapter 6 deals with the third point on the research plan. We present an analysis on the impact of theft and vandalism in relation to the sustainability of renewable energy development projects in Sub-Saharan Africa utilizing a mathematical analysis approach. In this chapter, we analyze the impact of these disturbances on implemented projects. We utilize a consumer clinic approach to generate data that realistically represents the situation. We define our instigators practically (Government Inequality, Crime to Survive, Sabotage) and demarcate the actions of the offenders into 4 types: (1) vandalization of small RE projects (SPv), (2) theft of RE infrastructures from small RE projects (SPt), (3) vandalization of large RE projects (LPv) and (4) theft of RE infrastructures from large RE projects (LPt). To counteract these actions we define three types of security interference: human, societal and

technical. We model the career of an RE criminal as a multi-stage Markov model. In every stage the offender can commit any of the offences SPv, SPt, LPv, LPt, or go to rest. Transition probabilities reflect offender maturity. Moreover they are affected by the level of interference installed at the project site. Calibrated on a dialogue with 144 respondents, our Markov model directs us to adequate interferences per project. Specifically, for large projects technical and human security are the most effective, whereas, for small projects we recommend societal security.

Chapter 7 deals with the fourth point of the research plan. In this chapter, we investigate the actual societal benefits of RE development projects in SSA by exhaustively taking into account the conditions of the locals and participating stakeholders of the projects. Utilizing the same ethnographic approach as in Chapter 4 and 5, we are able to deduce the actual benefits when projects are implemented, giving the realistic situation. Based on the implementation approach and practical experiences, we provide corresponding recommendations that should be adopted by all participating stakeholders within SSA.

Chapter 8 presents the conclusions of the thesis and other recommendations that should be considered by stakeholders towards the implementation and sustainability of RE development projects in the region of Sub-Saharan Africa. We present a recap on the research methodology utilized and further provide the possibilities for future research.

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Chapter 2

Locating Solar and Wind Parks in South Eastern Nigeria for Maximum Population Coverage: A Multi-Step Approach

“Africa cannot continue to be fully dependent on the rest of the world. After all our ways of life are completely different, we must learn to develop ourselves just as our ancestors did prior to colonization” – The Author

1. Introduction

The Federal Republic of Nigeria devised a year 2020 goal to produce, transmit and disperse 35,000MW of electricity. In 2009, Nigeria's total production capacity was 8,876MW, but only 3,653MW was available, which is less than 41% of the total installed capacity. The strategic goal for the power sector is to establish that the sector is able to efficiently provide sustainable, reliable and reasonably priced power in a deregulated market, while optimizing the on and off-grid energy mix. To successfully attain this goal, there is a need to aggressively pursue the harnessing of renewable energy resources. Nigeria proclaimed that a target of 7% of the total energy by 2025 should be generated from renewable sources (Okanlawon, 2012).

Renewable Energy (RE) encompasses resources that rely on fuel sources that reinstate themselves over a brief period of time and do not subside. These resources are repeatedly recharged on a human timescale such as the wind, sun, organic plant, moving water, waste materials and the heat released from the earth also known as geothermal heat. Since they are of particular interest because of their state of application and proven technology, our focus is on *Solar Parks* (SPs) and *Wind Parks* (WPs). Here, WPs are restricted to areas that are suitable from a meteorological point of view. Frequently, SPs and WPs are combined into so-called *Solar and Wind-Assisted Parks* (SWAPs). These combine the steady solar output with the more volatile wind output. Wind energy is superior to solar energy for multiple reasons (Tumbale & Jagadeesan, 2009). Wind energy also has a higher Energy Return on Investment (EROI) (2009). The latter is used to compare the quantity of energy supplied to the quantity of energy used in a supply process. The higher the ratio, the less energy is consumed in producing the energy. A wind turbine EROI is approximately 36.5:1, while a solar panel has an EROI of 5:1. So, next to releasing less CO₂, wind turbines also outperform solar panels in returning more energy for a certain amount of energy invested (Blakers, Andrew, & Weber, 2009).

An important benefit of RE is that it creates little or no waste compared to the traditional electricity generation methods. RE projects also provide high economic benefits to the rural areas and to the low-socioeconomic groups, as most developments and projects are executed away from large urban cities and suburbs. These benefits may range from the increased use of local services to the use of arable lands. Using various forms of RE means that there is no single source of failure anymore, which will help to create a more stable electricity network and thus reduce power outage. Research shows (Trieb, 2005) that the distribution of solar resources across Africa is uniformly distributed, with more than 80 percent of the African landscape receiving almost 2,000 kWh per square meter per year. A recent study shows that a solar park covering just 0.3% of the total area of North Africa can supply all of the energy required by the European Union. The demand for energy in Nigeria is escalating due to the increase in

population. Currently, the inadequate energy provided does not cover the demand of the ever rising population of the country (Ajayi & Ajanaku, 2009). Presently, around the world we are experiencing shortages in energy resources and there is an urgent need to develop a more sustainable energy structure to cater for improvement and growth. One of the feasible options to utilize is Renewable Energy sources. Nigeria is truly blessed with numerous natural and renewable energy resources that are not detrimental to nature, but the resources available are heavily unexploited, ranging from wind and solar energy to biomass (Oyedepo, 2012). Habitants of villages and rural areas confide in burning of wood to satisfy their energy needs, causing enormous danger to forestry, exhaling greenhouse gases, and contaminating the environment, thus, contributing to global warming (Ajayi & Ajanaku, 2009).

According to a report published in 2007 (ECNUNDP, 2007), only 20% of Nigeria's hydro-power potential is utilized, and the quantity of solar emission in the country is about $5.5\text{kW}\cdot\text{hr}/\text{m}^2\cdot\text{day}$, yielding a huge prospect for energy production if the total amount can be developed and utilized appropriately. Nigeria has been evaluated as having the capacity and potential for the application of wind energy (Ajayi & Ajanaku, 2009). In spite of this, the foundation and infrastructure for supplying energy to the vast population has remained heavily inadequate. Electrical power outage has become no less than a norm in Nigeria. No set of individuals, not even ministers, are spared. Some individuals (i.e., elites) who possess the connections and wealth to implement solar panels do so, while the rest of the population (middle and low income families) are left with no choice than to purchase imported cheap electrical generators that release toxic fumes detrimental to human health.

Considering that electricity plays a vital role in modern society, the electrical power outage has become a major impediment for Nigeria's development. Another weakness of the Nigerian power supply is that there is considerable loss during transmission. One approximates that between 30% and 35% of power produced in Nigerian power stations is lost in this process (Ikeme & Ebohon, 2005). Compared to power losses across transmission lines in the United States, this is usually less than one percent even across significant distances. It is nonviable to determine how exactly and how much of this incompetency is due to felonious users spouting the transmission lines, but it seems plausible that the lack of investment in technology is the main problem. The absence of modern equipment and qualified maintenance staff pose numerous problems for adequate power production and distribution. Several sources stipulate that Nigeria's power production capacity is between 5,000 and 6,000 MW (Sambo, 2005; FRN, 2008). Nevertheless, by government's own acknowledgement, actual output has never exceeded 4,000 MW. In real life, the actual production is usually far beneath this, whereas actual electricity demand including off-grid generators is believed to be approximately 10,000 MW (FRN, 2008).

The goal of this research is to develop a multi-step approach - including mathematical programming - to design a capacitated network of SPs and REPs in South-Eastern Nigeria, taking into account geographical and demographical characteristics. Meteorological data will also be taken into consideration for preferred wind power generation. To test and validate our approach, we select as case study the state of Anambra, since this is the first state in Nigeria to embrace structural planning for its cities. Anambra is developing into a major economic centre in Nigeria and West Africa (AnambraLGA, 2013). Moreover, Anambra is currently depending on neighboring states for its electricity supply. We design a capacitated energy network powerful enough to cover almost the entire energy requirement of Anambra. The density of the network is such that the majority of households are within reasonable distance (at most 30 km) from the nearest energy park. In this way Anambra will be self-supporting energy-wise in a sustainable way.

The remainder of the chapter is structured as follows. In Section 2 we describe related work and we state our contribution. In Section 3 we analyze the current situation and introduce our case study. Section 4 outlines our multi-step approach. In Section 5 we put the approach to work and obtain a blueprint of a capacitated energy network. Section 6 discusses our results. Finally, in Section 7 we draw our conclusions and give recommendations for future research.

2. Related Work

Several papers aim to address the problem of locating Solar and Wind-Assisted Parks in specific countries with diverse objective functions. For example, Nakataa, Kuboa, & Lamontb (2005) discuss the design of renewable energy systems with application in rural areas in Japan, whilst Arnette (2010) focuses on decision tools to increase Solar and Wind-Assisted Parks in the United States. With respect to Nigeria, multiple papers (e.g. Kennedy-Darling, Hoyt, Murao & Ross (2008)) have reported about the long history regarding windmills. These were utilized in Nigeria as early as the mid-1960s. In the northern territories of Garo and Sokoto, over 20 schools and homes utilized windmills to pump and provide water to their surroundings. The following decade witnessed a decline in the prices of fossil fuels and the disappearance of all other alternatives of energy. Investment in sustainable energy discontinued and the infrastructure deteriorated. The actual foundation of sustainable energy is currently obsolete, but research into the practicability of sustainable energy (wind energy) in certain regions shows that the physical possibility for this type of power production is high in some regions of Nigeria (Anyawu & Iwuagwu, 1995). Presently in Nigeria, only 10% of rural areas and 40% of the total population have access to electricity (Mohamed & Petinrin, 2013). The Solar Energy Society of

Nigeria and the Nigerian Energy Commission have been assigned with developing a standalone solar-powered solution for the rural households.

A survey of different models presented by Pohekar & Ramachandran (2004) on energy planning using multi-criteria decision making shows that while such approaches discuss the best compromise between objectives, they do not take into consideration the physical location of the parks nor the population to be covered. Wen-Shan, Mohammad & Hasimah (2012) review different approaches to optimally distribute renewable energy. It is stated that optimally distributed generation is beneficial because of its ability to reduce power loss, lower investment cost and most importantly, exploit renewable energy resources, which is good for the environment. Although considerable research has been conducted, the systematic principle for this subject remains as yet untouched.

A drawback of the various approaches is that they focus on the current demand, cost and source of renewable energy. Moreover, they ignore the location of the parks. The latter is vital to reduce the cost of transporting electricity and to attain maximum coverage of the needs of the population. To the best of our knowledge, present-day models do not take into account population or households for maximum coverage. It is therefore necessary to develop a multi-step approach or an optimization technique to design a capacitated network that takes into account demographical, geographical and meteorological characteristics and also provides economic and environmental advantages. We incorporate the latter in our model.

3. Analysis of the Current State

In this section, the present situation is described. In Section 3.1 we present energy statistics. Next, Section 3.2 introduces our case study region: Anambra.

3.1. Nigerian Energy Division: Past and Present

In 1972 the Nigerian Electric Power Authority was established by the merger - sponsored by the government - between the Niger Dams Authority and the Electric Corporation of Nigeria. The electric power sector was dominated by a government owned company, called the Power Holding Company of Nigeria (PHCN). It solely owned all power stations, distribution systems and the transmission networks. However, currently the power industry has been privatized in a deal that saw PHCN unbundled into six generating companies (Gencos)—(four for thermal power and two for hydro)—and 11 distribution companies (Discos), and sold to new private owners (Oni, 2015). Nigeria's Energy Production from 1972 to 2012 can be seen in Fig. 2.1.

Fig. 2.1: Nigeria's Energy Production measured in Million Tonnes of Oil Equivalent (IEA, 2015)

As earlier stated, before and until the mid-1960s, in the northern territories of Nigeria windmills were utilized to pump and provide water to schools and homes. Following the decline in the prices of fossil fuels and other alternatives of energy, investment in sustainable energy discontinued and the infrastructure deteriorated as can be seen from Fig. 2.1. In addition, from the period of 1972 till 2006, no sources of renewables such as wind and solar were statistically recorded. In addition, the average annual growth rate for natural gases plummeted from the year 2000 to 2006 both for energy consumption and production (ECN, 2008). This fuels the fact that for Nigeria to meet the energy demand of a vast growing population, harnessing of renewable energy resources needs to be aggressively pursued. This shows a huge improvement potential for renewable energy. In the subsequent sections we aim to design a blueprint for an RE network covering almost the entire energy requirement of the state of Anambra. However, before doing so, we present in Section 3.2 some basic demographic facts of the state of Anambra that are used in the sequel.

3.2. Anambra State

Anambra State is a state in South-Eastern Nigeria with a population of 4,612,868 in 2009 (Okunna, 2009). It has a total area of 4,844 square kilometers and a population density of 840/km² (See Fig. 2.2, Fig. 2.3 and Table 2.1). Anambra is rich in natural gas, crude oil, bauxite, and ceramic. It has an almost 100 percent arable soil. With an annual population growth rate of 2.21 percent, over the last two decades the rural/urban exodus has caused a shift making

Anambra a highly urbanized state with 62% of its population living in urban areas (UN-Habitat, 2013).

Fig. 2.2: Map of Nigeria displaying the 36 States of the Federation (NatGeo, 2010)

Fig. 2.3: Map of Anambra State displaying the Local Government Areas (AnambraLGA, 2013)

Table 2.1: Population of the study region according to Local Government Area. (NPC, 2014)

Local Government Area	Pop	Local Government Area	Pop	Local Government Area	Pop	Local Government Area	Pop
Aguata	474114	Awka South	215930	Idemili South	205119	Ogbaru	316896
Anambra East	95730	Ayamelum	141821	Ihiala	296781	Onitsha North	200219
Anambra West	180253	Dunukofia	113156	Njikoka	120551	Onitsha South	223574
Anaocha	331515	Ekwusigo	147360	Nnewi North	200064	Orumba North	210661
Awka North	100348	Idemili North	460272	Nnewi South	243634	Orumba South	153219
						Oyi	181651

4. Outline of our Multi-Step Approach

In this section we outline a multi-step approach - including mathematical programming - to design a capacitated network of SPs and SWAPs in the state of Anambra, taking into account geographical, demographical and meteorological characteristics. Details per step are given in Section 5. Our approach comprises the following six steps:

Step 1: *Construct a longlist of potential locations for SPs and SWAPs.* To this end we place a suitable grid over the state of Anambra. With each grid point we identify the number of households around it. For potential SP locations we take grid points that are compatible with current land use. For potential SWAP locations we take grid points that - on top of that - have enough wind potential.

Step 2: *Construct a shortlist of potential locations for SPs and SWAPs. Stipulate that any of the parks on this shortlist may only serve households within a certain distance D .* In this step the longlist from Step 1 is reduced by taking into account the major and minor urban areas and the cost of transporting energy.

Step 3: *Solve an integer linear programming problem yielding a smallest subset of the shortlist (SPs and SWAPs together) such that almost all (say 95%) of the overall energy requirement is covered.*

In this step we do not differentiate between SPs and SWAPs, but take each energy park on the short list from Step 2 as potential power supplier.

Step 4: *Solve an integer linear programming problem yielding a smallest subset of the SWAPs appearing on the shortlist from Step 2 such that a substantial part of the overall energy*

requirement is covered. In this step we concentrate on SWAPs, since these parks are preferable to SPs.

Step 5: *Combine the subsets found in Step 3 and Step 4 and let the parks that are close coincide.* In this way we compensate for the fact that our (preferred) SWAPs are confined to specific windy areas by augmenting them with SPs such that we cover almost the entire energy requirement.

Step 6: *Allocate the demand of each grid point to the nearest park (provided the distance is smaller than D) and thus obtain for each SP and each SWAP the required capacity.* We determine the average electricity demand per household and from that the demand for each grid point within a distance D of one of the chosen parks. Each grid point demand is allocated to the nearest park. We end up with an efficient capacitated network of SPs and SWAPs capable of covering almost the entire energy requirement of Anambra in a sustainable way.

Now that we introduced our multi-step approach to design a capacitated network of SPs and SWAPs, we detail our approach and demonstrate its applicability in the next section.

5. Detailing our Multi-Step Approach and Putting it to Work

In this section, we describe in detail how the solution approach that we have introduced in the previous section, works per step and put it to practice.

5.1. Step 1: constructing a longlist of potential energy park locations

In areas with an acceptable presence of wind, the quantity of potential production of power is prescribed by the size of the installed windmills. Windmills exist in different sizes ranging from small windmills utilized in pumping up water to large windmills capable of supplying power to an entire province. Usually the larger windmills are affixed to a mini-grid to reduce the dependence on fossil fuels.

Several studies have been conducted in Nigeria for the potential of wind energy (Anyawu & Iwuagwu, 1995; Okoro, Chikuni, & Govender, 2007; Ngala, Alkali, & Aji, 2007). The speed of wind in Nigeria generally ranges from 1.4 - 3.0m/s in the southern areas and 4.0 - 5.12m/s in the northern provinces of the country (see Fig. 2.4). It is noted that the speed of wind is in most cases weak in the southern part of the country except for the coastal and offshore regions (Idris, Lamin, Ladan, & Yusuf, 2012). Most of the northern states in Nigeria are considered feasible for wind energy (Ngala, Alkali, & Aji, 2007), whereas Anambra's neighbor state Enugu is the only south-eastern state eligible for wind energy (Agbetuyi, Akinbulire, Abdulkareem, & Awosope,

2012) with wind energy density estimate at 25m height given by Table 2.2. Comparing Anambra and Enugu, it is found that Enugu is better in mean wind speed, but they both can be suitable for standalone and medium scale wind power generation. The land usage of Anambra can be seen in Fig 2.5.

In addition, there is a high potential of solar energy in Nigeria and Sub-Saharan Africa in general. Nigeria's geographical location is an advantage that facilitates large scale solar energy generation. It is important to note that if solar panels or modules are utilized to cover one percent of Nigeria's land area, then it is feasible to generate 1850×10^3 GWh of solar electricity per year. This is one hundred times more than the current grid electricity consumption level in the country (Sambo & Bala, 2000).

Table 2.2: Wind Energy Density Estimate for Enugu State at 25m Height (Agbetuyi et al., 2012)

Station	Mean Wind Speed at 25m level	Monthly Mean Wind Energy	Annual Wind Energy	Annual Wind Energy from a Wind Turbine (KWh)	
				10m Blade Diameter	25m Blade Diameter
Enugu	3.37	7.83	93.91	7,375.75	46,097.96

Fig. 2.4: Isovents in m/s determined from 40 year's measurements at 10 m height, obtained from Nigeria meteorological department, Oshodi, Lagos State, Nigeria (NIMET, 2009)

To discretize our problem, we place a suitable square grid over the state of Anambra. Given that (i) Nigeria loses at least 35% of electricity during transmission as indicated in Section 1 (ii) renewable energy is the source of energy in this instance (iii) the high cost of RE investment (iv) the total land area and population density of the state, it is evident that losing a high percentage of the transmitted power should be eliminated. Therefore, we opt for a square grid of 3.3 kilometres by 3.3 kilometres which also conforms to the distance limit to be introduced. We take into account the data for wind energy potential in Nigeria (Ajayi O. O., 2010) as well as solar energy potential. However, based upon data for current land usage, we exclude the agricultural and green areas important to the state of Anambra. Ultimately, we obtain 262 locations for SPs and 25 for SWAPs, as displayed in Fig. 2.6.

Fig. 2.6: Potential Locations for SWAPs and Standalone Solar Energy Parks

As can be seen, the north and north-eastern areas are selected as potential locations for both windmills and solar panels. This is due to the feasibility of wind potential in Enugu just north-east of Anambra. Across the image it can be seen that only selected locations are appropriate for solar panels as the disruption of natural reserve, plantation and forest is fully taken into consideration. In Section 5.2, we reduce the number of potential locations by taking into account the major and minor urban areas and the cost of transporting. With each grid point we identify the number of households nearest to it. Thus we obtain the number H_i of households to be served in grid point i . This is used in our model in Step 3 (see Section 5.3).

5.2. Step 2: constructing a shortlist of potential energy park locations

To reduce the number of potential energy park locations, we identify the major and minor urban areas since these accommodate most of the population of the state. In addition, we assume that villages are dispersed uniformly over the other areas of the map. Clearly, the farther electricity is transported the higher the overall costs. We take this into consideration as we reduce the number of potential sites for SWAPs and SPs. We analyze two different options for selecting from the already existing potential locations determined in Fig 2.6.

- I. Choose from the already selected potential locations those locations that are within one square grid bordering the minor and major urban areas. Thus, it is possible to transport most of the electricity that the state requires at a lower initial overall cost.

Fig. 2.7: Example of transmission from urban areas to villages

Fig 2.7 illustrates that the parks are located closer to the major and minor urban areas. Since these areas are more populated, overall transmission costs are lower.

- II. We select locations closer to the villages dispersed away from the major and minor urban areas. Since the village areas are more rural, this option has the potential to develop and create jobs for residents in the areas. Also, this option will not lead to NIMBY (not in my

backyard) behaviour. In particular, no massive complaints on horizon pollution are to be expected.

Fig. 2.8: Example of transmission from villages to urban areas

In Fig 2.8, the parks are located closer to villages rather than to the major and minor urban areas. Although we can distribute electricity to villages at a cheaper rate, a disadvantage of this set-up is that the transmission costs to an urban area are high, since the dense population in such an area requires many transmission lines over a large distance. Therefore, this option leads to higher overall costs.

Analyzing both options, we decide to utilize the first option as this is a more suitable option in terms of maximum population coverage and minimum overall transmission costs. Utilizing the above information and analysis we obtain a shortlist with 71 potential locations for SPs and 22 for SWAPs (see Fig 2.9).

Fig. 2.9: New Potential Locations for SWAPs and Standalone Solar Energy Parks

In the Nigerian power supply network there is considerable loss during transmission (approximately between 30% and 35%, see Section 1). To help avoid this, we choose - in the sequel - the energy parks such that the vast majority of the households is within a pre-defined distance D from the nearest park. In our case study we take D to be 30 km. This number is based on expert opinion on the loss in Nigeria of electricity during transmission. From the shortlist displayed in Fig. 2.9 we choose in Section 5.3 optimal locations for both the SPs and the SWAPs.

5.3. Step 3: using integer linear programming to obtain a smallest subset of the shortlist that covers the total energy requirement up to a given degree

In this section we do not differentiate between SPs and SWAPs, but take each energy park on the shortlist from Step 2 as potential power supplier. Recall that there are 71 potential locations for SPs and 22 for SWAPs on the shortlist, so we consider $71+22 = 93$ potential locations.

Our aim is to find a smallest subset of the shortlist that covers a pre-defined fraction α of the total energy need in the state of Anambra. The reach of each park is such that only households within a distance of D (of 30 km) from the park are supplied. As for data, we estimate the population of Anambra using a uniform distribution within each municipality. The transmission distances are computed as straight line distances (between settlements and potential parks as shown in the grid network).

We propose the following integer linear programming problem (ILP):

Indices:

i = index of household location, $i = 1, 2, \dots, I$

j = index of potential park location, $j = 1, 2, \dots, J$

Parameters:

d_{ij} = distance between household location i and potential park location j

D = maximum allowed distance for serving a household from a park

$V_i = \{j \mid d_{ij} \leq D\}$ =
set of potential park locations within distance D from household location i

H_i = number of households attributed to household location i

α = fraction of all households that is served by the parks

Decision variables:

$X_j = \begin{cases} 1 & \text{if a park is allocated to potential park location } j, \\ 0 & \text{otherwise.} \end{cases}$

$Y_{ij} = \begin{cases} 1 & \text{if household location } i \text{ is served by a park at potential park location } j \in V_i, \\ 0 & \text{otherwise.} \end{cases}$

Problem formulation:

$$\text{Minimize } \sum_{j=1}^J X_j \quad (1)$$

subject to:

$$\sum_{i=1}^I \sum_{j \in V_i} H_i Y_{ij} \geq \alpha \sum_{i=1}^I H_i \quad (2)$$

$$\sum_{j \in V_i} Y_{ij} \leq 1 \quad \forall i \quad (3)$$

$$Y_{ij} \leq X_j \quad \forall i \forall j \in V_i \quad (4)$$

$$X_j \in \{0,1\} \quad \forall j \quad (5)$$

$$Y_{ij} \in \{0,1\} \quad \forall i \forall j \in V_i \quad (6)$$

Objective (1) minimizes the number of parks needed. Constraint (2) ensures that a fraction α of the total demand of the state is satisfied by parks serving only households within a distance D . Constraint (3) stipulates that every household is at most assigned to one park within the specified distance limit D . Constraint (4) authorizes power distribution only from locations - within a distance D - at which parks have been located. Constraints (5) & (6) are binary requirements for the model variables.

Let Y_{ij}^* and X_j^* be optimal values of the decision variables. Then they cover two essential issues:

- (i) the number of parks needed: $\sum_{j=1}^J X_j^*$
- (ii) the required fraction F_j per park j of the total energy capacity needed:

$$F_j = \sum_{i \in W_j} H_i Y_{ij}^* / \sum_{i=1}^I H_i \text{ where } W_j = \{i \mid d_{ij} \leq D\} \quad (7)$$

We solve the above ILP for various values of α around 0.95 using advanced integrated multidimensional modelling software. The solution is rather insensitive to α and is given by the following set of parks: the SPs; $S_1, S_2, \dots, S_6$ and the SWAPs R_1, R_2 , all displayed in Fig. 2.10.

Fig. 2.10: Optimal Locations for SWAPs and Standalone Solar Energy Parks

5.4. Step 4: using ILP to obtain a smallest subset of the SWAPs on the shortlist of Step 2 covering a substantial part of the total energy requirement

In this section we concentrate on SWAPs, since these parks are preferable to SPs. Thus, we take each Solar and Wind-Assisted Park on the shortlist from Step 2 as potential power supplier. Recall that there are 22 potential locations. Our aim is to find a smallest subset of SWAPs on the shortlist that covers a pre-defined fraction α of the total energy need in the state of Anambra. As before, the reach of each SWAP is such that only households within a distance of D (of 30 km) from the park are supplied.

We solve the ILP given in Step 3, but now we take the potential locations of the SWAPs as only potential park locations. The best coverage obtained (in view of the D -boundary) is given by α around 0.60186 by the following set of SWAPs: R_1, R_2, R_3 all displayed in Fig. 2.11.

Fig. 2.11: Optimal Locations for SWAPs only

As can be seen by comparing Fig. 2.10 and Fig. 2.11, the locations for R_1 and R_2 contained in the subset of Step 4 are identical to the locations of R_1 and R_2 determined in the subset of Step 3. In the following section, we combine the subsets found in Step 3 and Step 4. This is because the locations are close to each other and either of the parks could be developed to satisfy the energy needs of the corresponding households allocated to it.

5.5. Step 5: combine the subsets found in Step 3 and Step 4 and let the parks that are close coincide

From Fig. 2.12, we see that the SWAP R_3 and the SP S_4 are quite close. It is possible to replace S_4 by R_3 or R_3 by S_4 .

Thus we end up at the following RE network:

- (1) Establish Solar Parks at the locations S_1 , S_2 , S_3 , S_5 , and S_6 .
- (2) Establish Solar and Wind-Assisted Parks at the locations R_1 and R_2 .
- (3) Establish Solar Parks and/or Solar and Wind-Assisted Parks at the locations S_4 and/or R_3 .

Fig. 2.12: Proposed Locations for SWAPs and Standalone Solar Energy Parks

5.6. Step 6: allocate the demand of each grid point to the nearest park (provided the distance is smaller than D) and thus obtain for each SP and each SWAP the required capacity

Utilizing the energy data in Section 1 and 2 and population characteristics in Section 3, we are able to estimate the required electricity production capacity for Anambra in 2020:

	Available Energy Capacity (2013)	Required Energy Capacity (2020)	Population (2013)	Forecasted Population (2020)
Nigeria	3,653 MW	35,000 MW	159,708,000	210,158,000
Anambra State	106 MW	1,157 MW	4,612,868	6,945,045

Based on the values for *Required Energy Capacity (2020)* and *Available Energy Capacity (2013)*, to accomplish the 2020 vision, a minimum growth of 150 MW each year is needed for Anambra state, since

$$\therefore (Req (2020) - Av (2013)) / (2020 - 2013) = 150MW$$

To make Anambra independent of fossil fuels, we may start with building our network of SPs and SWAPs such that the initial total capacity is 150MW which surpasses the current availability of 106MW generated by fossil fuels. Next, we augment the total capacity every year with a minimum of 150MW. For each of the park locations, we use the grid points presented by the output of the models to calculate the total population to be covered by the park. Using the total population within coverage of each park, the following method is used to calculate the amount of extra energy capacity needed yearly to meet the 2020 goals.

$$\frac{\text{Population under coverage of each park}}{\text{Total Population}} \times 150MW$$

For a particular park j the latter value is derived from the model output by expressing it as $F_j \times 150MW$ with F_j given by (7) in Section 5.3.

Applying the above method we are able to determine the amount of extra energy to be produced yearly by each of the parks to meet the needs of the population and the 2020 goals as can be seen in Fig. 2.13. Here, we combined the total amount of energy to be produced by parks that share the same neighboring facilities and are situated within the same local government areas. Given that the locations selected are all feasible with approximately 5.5kW-hr/m²-day, the sites selected to meet the forecasted demand will require a minimum of approximately 80,000 photovoltaic panels. To maximize the potential of the SWAPs selected areas, wind turbines at a height of 25m should be utilized with a 25m blade diameter as has been indicated in Table 2.2 of this study.

Fig. 2.13: Total required yearly growth of energy capacity to be produced by SWAPs and Standalone Solar Energy Parks

6. Discussions

To the best of our knowledge, this chapter depicts the first research ever taken into constructing a concrete blue print of a renewable energy network in (one of the states of) Nigeria. Our multi-step approach is intuitive by nature: an obvious longlist of locations is reduced to a shortlist which is then further refined through integer linear programming (ILP). Throughout, we incorporate geographical, demographical and meteorological characteristics. By running the program twice (first for SPs and SWAPs, then for SWAPs only), we get to see the location problem from two different angles. This view is then combined in a way that gives due attention to the preferable SWAPs. A practical point is that the ILP is solved in reasonable computation time, allowing us to test multiple parameter values. A final benefit of our approach is the detailed calculation of energy capacity needed to be extra built every year. In this way the SPs and SWAPs can be gradually installed using a fixed growth scenario. The multi-step approach introduced in this chapter can be implemented in various geographic settings and for various meteorological conditions. The selection of the grid and the distance

limit should be carefully adapted to the specific setting. In particular, general losses experienced by the state in power transmission should be taken into account.

7. Conclusions and Future Research

In this chapter, we developed a multi-step approach - including mathematical programming - to design a capacitated network of SPs and SWAPs in South-Eastern Nigeria, taking into account geographical and demographical characteristics. Meteorological data are also being taken into consideration for preferred wind power generation.

To test and validate our approach, we selected as case study the state of Anambra, since this is the first state in Nigeria to embrace structural planning for its cities. Anambra is currently depending on neighboring states for its electricity supply. We designed a capacitated energy network consisting of five Solar Parks and three Solar and Wind-Assisted Parks which is powerful enough to cover almost the entire energy requirement of Anambra. For each of these parks we calculated the required capacity, both for now as well as in the near future. The density of the network is such that the majority of households are within reasonable distance (at most 30 km) from the nearest energy park. In this way Anambra will be self-supporting energy-wise in a sustainable way. One may ask: why parks? Why not putting solar panels on rooftops and small wind turbines feeding some house districts? The reason that these options are less appropriate is that for individuals there is no easy option to transfer excess energy to the on-grid network due to the non-existence of adequate infrastructure and policies.

As in any model approach we made several assumptions which need a critical review. First of all we chose to discretize the location problem by using a square grid of 3.3 by 3.3 kilometres. In a subsequent study, it may be worthwhile to examine the sensitivity of our results by changing the grid dimensions. Next, we assumed that the population is uniformly distributed around a grid point. It is interesting to use the actual demographic data instead. Then, for suitable wind park locations, we confined ourselves to the border of the state, whereas one might also consider inland locations. Another point of interest is the choice of the distance D indicating the reach of each park. It was chosen as 30 km on the basis of expert interviews. Of course, in future, as technology proceeds, D can be chosen larger enabling us to build fewer parks. As for the parameter α indicating the fraction of households covered, we might have differentiated by taking higher values in industrial areas. Finally, there is the cost factor which was left out. It may be interesting, e.g., to take into account higher costs for wind parks. As for the present study, we are convinced that by using it as a blueprint, detailed steps can be set

towards a design and realization of SWAPs and Solar Parks in the state of Anambra, with all the benefits involved for the economy as well as employment.

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Chapter 3

Designing a Nation-wide Network of Solar and Wind-Assisted Parks for Nigeria and for Ghana

“Africans must change their mind and actions. The key to building your continent depends on your will-power, persistent effort and action towards self liberation.” –

Lailah Gifty Akita

1. Introduction

In Chapter 2, a multi-step approach - including mathematical programming was developed - to design a capacitated network of Solar Parks (SPs) as well as Solar and Wind-Assisted Parks (SWAPs) (i.e., parks that generate both solar and wind energy) in South-Eastern Nigeria, taking into account geographical and demographical characteristics. This chapter extends the application of the SWAP model to a country's perspective. Here, we focus on Nigeria and Ghana. Let us start by defining some key notions. Next, in Section 1.1 we introduce generic concepts that are used throughout the chapter. We present the advantages and disadvantages of the grid method (used in Chapter 2) and the so-called problem owner method (POM, see below) and their consequences on the energy status in Africa.

Definitions:

Grid Method (GM): The GM in this context is a method whereby potential locations are selected from points on a 2-dimensional $m \times n$ grid graph $G_{m,n}$. In addition, it may be described as a green field method, whereby the options of selecting potential locations are not constrained by a public office or a problem owner.

Problem Owner Method (POM): The POM in this context is a condition or a state, whereby the potential locations considered are provided by a public office, a third party or an individual. It may be considered as a brown field method such that the potential locations are selected from any existing locations.

Micro-Grid: A micro-grid is a miniature power generation grid that can operate independently (off-grid) or in concomitance with the area's main electrical grid (on-grid).

Off-Grid Energy: Off-grid energy is energy that is provided by micro-grids to villages and communities that are - generally - not connected to the main electrical or national grid.

On-Grid Energy: On-grid energy is energy that is provided by national or main electrical grid.

Smart Grid: Special case of a micro-grid where communication technology and digital information are utilized to control and optimize the grid in real time.

1.1. Generic Concepts for Selecting Potential Locations

The importance of selecting appropriate locations when designing SWAPs is high. This indicates the line that defines either the success or failure of the project. It better provides more efficient service and reduces the cost of power transportation and complications. At an

interview carried out with several decision makers in the field of renewable energy (RE) in Sub-Saharan Africa (private communication (2015)), a vast majority did not consider the issue of determining optimal locations when installing Solar PV smart or micro-grids.

However, in the aspect of wind energy, determining the appropriate locations is important as the direction of the wind is essential. Nevertheless, more than 80% of the interviewees claim the only data they utilize in determining the appropriate locations is retrieved from the meteorological department. The interview response shows that the population, household distribution, community usage data and several relevant characteristics are not taken into consideration. It is known that many solar and wind energy projects in Africa fail due to miscalculations, inappropriate location selection, investor scare, vandalism, theft and mismanagement of the resources. The number of failed renewable energy projects in Africa over the last 20 years is unacceptable, and verging on the irresponsible. These failed projects have set back development by raising aspirations and then failing to deliver. Particularly in Sub-Saharan Africa, the electric utility infrastructure necessary for large-scale renewable energy power plants is lacking, which leads to underdevelopment and poverty.

There are, however, multiple methods for selecting potential location(s) for SWAPs, micro-grids or energy generation systems, such as the *grid method* (as utilized in Chapter 2) and the *problem owner method*, whereby the problem owner presents own potential location(s). Both methods have advantages as well as disadvantages.

Advantages of the grid method:

- Takes into account all possible potential locations, albeit within a grid structure.
- Directly takes into account geographical and demographical characteristics.
- With the GM, performing sensitivity analysis is straightforward; so as to assess the impact that changes in a certain parameter (grid dimensions) will have on the conclusions of the experiment.
- Utilizing the GM and our mathematical model, we are able to minimize the number of facilities required, based on the demographical and geographical characteristics of the target area.
- Requires less study towards application.

Disadvantages of the grid method:

- Requires a considerable amount of time to design and determine the appropriate dimensions of the grid. Sensitivity analysis can, however, be executed to assess the impact that changes in grid dimensions will have on the findings of the model.
- Variability in dimensioning grid.

Advantages of the problem owner method:

- Direct availability of potential locations.
- Computation times are short.
- Maximum control.
- Multiple changes can be implemented and experiments can be carried out in shorter periods of time.

Disadvantages of the problem owner method:

- Does not take into account all possible/potential locations.
- Probability of omitting better potential locations. However, this can be curbed by executing an extensive initial study.
- The number of facilities is dictated and does not necessarily represent the required number when we impose the constraint that every demand location is within a pre-specified distance from a facility.
- The POM mainly focuses on the size of facilities and may not necessarily consider the requirement of the communities surrounding the facilities.

Given the absence of modern structural and urban planning in most African cities, villages and communities, it is important to select the appropriate locations for facilities so as to promote the conservation of natural reserve. However, in such situations of underdevelopment the difficulty in selecting appropriate locations intensifies.

In the present chapter we design two separate, capacitated networks of SPs and SWAPs, one for Ghana, one for Nigeria. Each of these is powerful enough to cover - in a sustainable way - the energy requirement of the majority of households by a facility within reasonable distance.

The remainder of the chapter is structured as follows: Section 2 presents an overview of relevant literature. In Section 3, we discuss variants of the SWAP model. In particular, we describe the fewest facilities model, yielding the smallest number of facilities enabling near-coverage of total demand. Starting from that smallest number we introduce models for further optimization. We do so both for the grid method as well as for POM. In Section 4 we analyze the current energy situation in Nigeria and Ghana, respectively. In addition, the policies surrounding the provision of off-grid energy (micro-grids) are discussed. In Section 5, we present our solution approach where we also develop new methods, variants and extensions of our model and discuss their application to Nigeria and Ghana. We take into account additional characteristics such as existing and future/planned power plants and population characteristics per local government area. In Section 6, we implement our solution approach

to determine the appropriate locations for Solar Parks (SPs) and Solar and Wind-Assisted Parks (SWAPs). In Section 7 we present a discussion of the findings of our solution approach and experiments and finally, in Section 8 we present the recommendations and conclusions to the chapter.

2. Related Work

Research on location theory started in the early 1900's when Alfred Weber examined how to locate a single warehouse such that the total of all distances between the warehouse and customers is minimal (Weber, 1929). Following this embryonic study, location theory was driven by some applications which inspired researchers from different fields of study. The development and investment in a new facility such as a micro-grid or an off-grid energy system, is typically expensive and a time-delicate project. Before a facility can be established, candidate sites must be identified, suitable capacity specifications must be determined for the facility, and large amounts of capital must be assigned. While the main aim driving the location of such a system is dependent on the individual firm or government, the soaring costs associated with this action make almost any location-allocation project a long-term investment. Thus, SWAPs which are positioned today are anticipated to be running for a long period of time. Natural changes during the life-span of the facility can drastically affect the interest of a particular location, twirling today's optimal location into an investment disaster. Therefore, establishing the best sites for new SWAPs is an important strategic challenge (Ye & Chuang, 2011).

In the field of Operations Research, researchers have created a vast number of mathematical models to solve a wide range of location-allocation problems. A number of different objective functions have been devised to make such models applicable to different situations. Regrettably, the produced models can be difficult to solve to optimality (Meng, Ma, Han, & Wu, 2013). The computational difficulty presented by intricate location models has, until lately, limited most study in this realm to fixed and deterministic problems. In the latter, all inputs such as time, distances and demands are known quantities and outputs are cited as zero-one decision values (Berman, Hajizadeh, & Krass, 2013). While such problems can provide users with awareness about generic location selection, modeling the uncertainties that are important in making real-world decisions is impossible for these models. In locating micro-grids and off-grid energy (SWAPs) - providing either private or public utility services - it is critical to assure that the selected location sites serve the cause of minimizing community cost or maximizing the benefits for the habitants. Likewise, the capacity allocation to these SWAPs possesses a direct impact on the system's efficiency as a whole.

The formulation of the location-allocation model represents an important role in energy utility planning, as it yields a framework for exploring problems with regards to accessibility, differentiating the caliber of previous location decisions, and providing several solutions that change and improve the existing system (Rahman & Smith, Deployment of rural health facilities in a developing country, 1999). A crucial issue highlighted during the course of this study is the selection of a suitable objective function or measure. Formulating the objective function highly depends on the ownership of the SWAPs, both whether private or public and the condition of the SWAPs, as has been earlier mentioned (Rushton, 1987).

In addition, if we compare private to public, private SWAPs are often cited to achieve stated organizational objectives, such as maximize profit or minimize cost. Contrary to private SWAPs, the goals and objectives of public SWAPs are more strenuous to realize. However, various possible criteria (objective functions) exist when viewed from the perspective of location theory. The problem owner is left to make the decision that aligns with the proposed goal of optimizing profit, cost or public service as the case may be. Furthermore, note that a vast amount of recent literature exists for locating wind park facilities, but, to the best of our knowledge no paper currently exists that discusses selecting the appropriate locations for SWAPs or Solar Parks in Sub-Saharan Africa as this is important from the perspective of designing a sustainable energy future for developing countries. Ikejemba & Schuur (2016) take into account a sense of security based on distance by introducing a parameter D (maximum allowed distance for serving a household from a park), as well as transportation costs, demographical and geographical characteristics.

In the next section we showcase the various types of location models and their applicability in locating SWAPs. Throughout the chapter the following indices, parameters and decision variables are used:

General list of parameters and decision variables:

Indices:

i = index of demand location, $i \in I$;

j = index of potential facility location, $j \in J$;

Parameters:

d_{ij} = the distance between demand location i and potential facility location j ;

D = maximum allowed distance for serving a demand location from a facility;

$$V_i = \{j \mid d_{ij} \leq D\} =$$

set of potential facility locations within distance D from demand location i ;

p = the number of facilities to be located;

h_i = demand at demand location i

Decision variables:

$$X_j = \begin{cases} 1 & \text{if a facility is allocated to a potential facility location } j, \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_i = \begin{cases} 1 & \text{if demand location } i \text{ is (fully) served,} \\ 0 & \text{otherwise.} \end{cases}$$

$$Y_{ij} = \begin{cases} 1 & \text{if demand location } i \text{ is being served by a facility at } j, \\ 0 & \text{otherwise.} \end{cases}$$

2.1. Location Models

In this section, we present and review different models with respect to location-allocation problems. In particular, we analyze the *Maximal Covering Location Problem (MCLP)* and the *Basic p -Median Model*.

Maximal Covering Location Problem (MCLP)

The Maximal Covering Location Problem (MCLP) was first proposed by Church and ReVelle (1974) and is one of the most familiar models utilized in the planning of public healthcare that seeks to maximize the population to be covered given a restrained number of clinics. An ample amount of research has been executed using MCLP to model facility locations and several techniques - from heuristics to exact methods - have been suggested to solve the problem. Several researchers such as Oppong (1996), Batta et al. (2014) and Li et al. (2011) provide detailed descriptions of these models. Lately, the MCLP has been utilized to successfully solve larger problems with higher complexity and problems with more than one objective (Doerner, Focke, & Gutjahr, 2007).

The MCLP aims to obtain the solution to the problem of locating facilities such that the coverage of demand for services within a given acceptable service distance is maximized. Since the MCLP has been shown to be combinatorially complex, a number of heuristics have been developed (AdensoDiaz & Rodriguez, 1997; Galvao, Espejo, & Boffey, 2000). Furthermore, the MCLP can be visualized as an alternative formulation of other well-known location models such as the Location Set Covering model and the p -Median model (Church & ReVelle, 1976).

This problem can be formulated in the following way:

$$\text{Maximize } z = \sum_{i \in I} h_i Y_i \quad (1)$$

$$\text{subject to: } \sum_{j \in J} X_j = p \quad (2)$$

$$\sum_{j \in V_i} X_j \geq Y_i \quad \forall i \in I \quad (3)$$

$$X_j \in \{0,1\} \quad \forall j \in J \quad (4)$$

$$Y_i \in \{0,1\} \quad \forall i \in I \quad (5)$$

The objective (1) is to maximize the number of people served or "covered" within the desired service distance. The number of facilities allocated is restricted to equal p in constraint (2). Constraints of type (3) allow Y_i equaling 1 only when one or more facilities are established at sites in the set V_i . Constraints (4) & (5) are binary requirements for the model variables.

The Basic p -Median Model

The basic p -Median model established by Hakimi (1964) is one of the most favored models for locating public facilities (Dantrakul, Likasiri, & Pongvuthithum, 2014). According to Sleep & McLaerty (1992), it has successfully been utilized in controlling the outbreak of diseases. The model minimizes the distance between customers and facilities and can be formulated as follows:

$$\text{Minimize } \sum_i \sum_j d_{ij} Y_{ij} \quad (6)$$

$$\text{subject to: } \sum_j X_j = p \quad (7)$$

$$\sum_j Y_{ij} = 1 \quad \forall i \quad (8)$$

$$Y_{ij} \leq X_j, \quad \forall i, j \quad (9)$$

$$X_j \in \{0,1\} \quad \forall j \quad (10)$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j \quad (11)$$

The objective function (6) minimizes the total distance between demand locations and facilities. Constraint (7) ensures that exactly p facilities are opened. Constraint (8) stipulates

that every demand location is assigned to precisely one facility. Constraint (9) authorizes assigning only to places at which facilities have been located. Constraint (10) & (11) are binary requirements for the model variables. A variation of the p -Median model is described as finding the location of p facilities such that the total demand-weighted distance between demand locations and facilities is minimized (Owen & Daskin, 1998). Constraints are as above, but the objective is in this case:

$$\text{Minimize } \sum_i \sum_j d_{ij} Y_{ij} h_i \quad (12)$$

This p -Median model is captivating since it captures the fact that as the combined weighted distance of travel is getting smaller, the more favorable it is for demand locations to be connected to the nearest facility. It has often become a norm that the use of facilities decreases expeditiously when the time for customers to reach these facilities exceeds a specific time. According to Rahman (1991), this is the norm with the use of certain facilities in rural areas in developing states.

3. Model Variations

Policy makers or public officials (e.g., using the POM) may have different objectives than those that can be obtained with the SWAP model (Ikejemba & Schuur, 2016). These objectives may lead to variants of the SWAP model, with different constraints and/or objective functions. We therefore examine model variations to provide solutions to problems with different objective functions that may exist in locating SPs and/or SWAPs. The following two questions are crucial:

Q1: What is the smallest number of facilities for which almost all the demand locations have a connection to the selected facilities within a distance limit D ?

Q2: Given a fixed number of facilities, how do we allocate the facilities optimally? Here, the word “optimal” may refer to different objectives, such as minimal total (weighted) distance, etc.

3.1. The Fewest Facilities Model (FFM)

In this section we consider the question

Q1: What is the smallest number of facilities for which almost all the demand locations have a connection to the grid within a distance limit D ?

Section 3.1.1 focuses on the grid context. Next, Section 3.1.2 discusses the POM setting.

3.1.1. Grid Variant

When working with a grid (as in Ikejemba & Schuur (2016)), distances between potential facility locations and demand locations are easily generated. Thus, we may use the following model (which we refer to as **FFM-grid**):

$$\text{Minimize } \sum_{j \in J} X_j \quad (i)$$

subject to:

$$\sum_{i \in I} \sum_{j \in V_i} h_i Y_{ij} \geq \alpha \sum_{i \in I} h_i \quad (ii)$$

$$\sum_{j \in V_i} Y_{ij} \leq 1 \quad \forall i \quad (iii)$$

$$Y_{ij} \leq X_j \quad \forall i \forall j \in V_i \quad (iv)$$

$$X_j \in \{0,1\} \quad \forall j \quad (v)$$

$$Y_{ij} \in \{0,1\} \quad \forall i \forall j \in V_i \quad (vi)$$

Objective (i) minimizes the number of facilities needed. Constraint (ii) ensures that a fraction α of the total demand is satisfied by facilities serving only demand points within a distance D . Constraint (iii) stipulates that every demand point is at most assigned to one facility within the specified distance limit D . Constraint (iv) authorizes power distribution only from locations - within a distance D - at which facilities have been located. Constraints (v) & (vi) are binary requirements for the model variables.

3.1.2. POM Variant

In the context of the Problem Owner Method (POM), the concept of distances is no longer that useful anymore. Let us explain why. In the POM approach, the potential facility locations are provided by experts from the Ministry of Power. Actually, each of these POM locations is given by the Ministry as a *sub-state* of one of the states. Since every potential facility location j is a sub-state, it makes sense to represent the demand locations as sub-states as well. In the same spirit, let us introduce for every demand location i the set:

$$\tilde{V}_i = \{j \mid j \text{ is adjacent to } i\}$$

which can be conceived as a topological equivalent of the set V_i introduced before. Here, “adjacent to” may mean “coinciding with” as well.

Now, to find the smallest number of facilities such that a fraction α of the total demand is satisfied by facilities serving only adjacent demand points, solve the integer linear programming problem FFM-grid from the previous section with V_i replaced by $\tilde{V}_i$. Let us denote the resulting integer linear program problem by FFM-POM.

3.2. Optimal Allocation of a Fixed Number of Facilities

Once we have found the preferred number of facilities from question Q1, it is crucial to allocate the facilities adequately. Hence the question:

Q2: Given a fixed number of p facilities, how do we allocate the facilities optimally? Here, the word “optimal” may refer to different objectives. Focusing on the grid variant, let us discuss three ideas:

- Idea 1: Maximizing the demand served with p facilities and distance limit D .
- Idea 2: Minimizing the total weighted transmission distance given a total of p facilities.
- Idea 3: Combining Idea 1 and Idea 2 as follows: (i) as first-priority goal maximize the demand served with p facilities and distance limit D (ii) as second-priority goal minimize the total weighted transmission distance given a total of p facilities and given as constraint the maximal demand served that was obtained as first-priority goal.

3.2.1. Max h_i Model

Idea 1: Maximizing the demand served with p facilities and distance limit D .

The model below is a proposed extension of the p -Median model. It deals with maximizing the service level in the case of a distance limit. In Owen & Daskin's (1998) paper, models exist for which the maximum distance between demand locations and facilities is minimized. In this section, we incorporate a distance limit for transmission from a facility to a demand location. The objective function below maximizes the demand served with p facilities and D distance limit.

$$\text{Maximize } \sum_{i \in I} \sum_{j \in V_i} h_i Y_{ij}$$

The constraint below ensures that exactly p facilities are installed.

$$\text{subject to: } \sum_{j \in J} X_j = p$$

The constraint below stipulates that every demand location is at most assigned to a facility within the specified distance limit D .

$$\sum_{j \in V_i} Y_{ij} \leq 1 \quad \forall i$$

The constraint below authorizes assigning only to places at which facilities have been located within the distance limit D .

$$Y_{ij} \leq X_j \quad \forall i, \forall j \in V_i$$

The constraints below are binary requirements for the model variables.

$$X_j \in \{0,1\} \quad \forall j$$

$$Y_{ij} \in \{0,1\} \quad \forall i, \forall j \in V_i$$

The **Max h_i** model above always provides a feasible solution since it does not stipulate that all demands have to be met. Moreover, we know from **FFM-grid**, constraint (ii), that the objective has a lower bound given by $\alpha \sum_{i \in I} h_i$.

Clearly, in a POM setting, to maximize the demand served with p facilities serving only adjacent demand points, one solves the above **Max h_i** problem with V_i replaced by $\tilde{V}_i$. Let us denote the resulting integer linear program problem by **Max h_i -POM**.

3.2.2. The Minimum Transmission Distance Model (MTDM)

Idea 2: Minimizing the total weighted transmission distance given a total number of p facilities. This is the variation of the p -Median model discussed in Section 2.1 (Owen & Daskin, 1998):

$$\text{Minimize } \sum_i \sum_j d_{ij} Y_{ij} h_i$$

$$\text{subject to: } \sum_j X_j = p$$

$$\sum_j Y_{ij} = 1 \quad \forall i$$

$$Y_{ij} \leq X_j \quad \forall i, j$$

$$X_j \in \{0,1\} \quad \forall j$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j$$

3.2.3. Combining the Max Model with the MTDM Model

Idea 3: Combine the **Max** model with the **MTDM** model as follows:

$$\text{Minimize } \sum \sum h$$

$$\text{subject to: } \sum_{j \in V_i} Y_{ij} h_i = \text{optimal value of } \mathbf{Max} \ h_i$$

$$\sum_j X_j = p$$

$$\sum_j Y_{ij} \leq 1 \quad \forall i$$

$$Y_{ij} \leq X_j \quad \forall i, j$$

$$X_j \in \{0,1\} \quad \forall j$$

$$Y_{ij} \in \{0,1\} \quad \forall i, j$$

Of course, one should be careful when executing the **Max** h_i or the combined approach, because it could potentially exclude coverage areas when dealing with a given p number of facilities. In situations where all possible households are to be covered, it is advisable to run the models with variations of p until the constraint $\sum_j Y_{ij} = 1$ holds.

4. Power Supply Infrastructure and SWAP Options in Nigeria and Ghana

In Chapter 2, a multi-step approach - including mathematical programming – was developed to design a capacitated network of SPs and SWAPs in South-Eastern Nigeria, taking into account geographical and demographical characteristics. In this section we examine SWAP options for Nigeria and Ghana. We introduce constraints that take into account power stations, future plans/ expansion of power stations, current solar facilities (if existing) and current wind statistics. Our research focuses on the design of SWAPs to support existing power infrastructure and to power off-grid communities. In addition, when designing SWAPs for off-grid communities and villages, the specific energy requirements are taken into consideration from surveys and interviews.

Section 4.1 outlines the existing and future power supply infrastructure in Nigeria, as well as the options for renewable energy. The same is done in Section 4.2 for Ghana. Section 4.3 compares the power supply infrastructure of both countries, as well as the consequences thereof for our approach.

4.1. Power Supply in Nigeria

The Federal Ministry of Power in Nigeria indicated that the country's peak power generation as of late 2014 was approximately 3,513.5MW, against a peak demand of 12,800MW. So, only 27% of the peak demand was satisfied (Punch Newspaper, 2014). Nigeria is currently ranked as the third largest country without access to electricity by the International Energy Agency (IEA), whereas recent specialized research indicates that a 100% steady power supply from renewable energy is conceivable in Nigeria (Charles, 2014). The Nigerian Government is prone to produce, transmit, and disperse 35,000MW to 40,000MW of electricity according to the devised year 2020 goal which would entail a yearly investment of approximately \$4 billion over a period of (presumably) seven years (Roadmap For Power Sector Reform, August 2013). However, the proposed paramount mover of this vault in generation is natural gas, ready to be saddled from Nigeria's tremendous reserves. As per the August 2013 Roadmap, the Federal Government of Nigeria aspires to expand energy production from fossil fuel sources to more than 20,000MW by 2020. It is without doubt that Nigeria is blessed with adequate RE assets to meet its present and future development prerequisites. Be that as it may, the hydropower plants are the main sustainable resources currently being utilized. However, the inability of the hydro power plants to work at installed capacity is usually credited to subsequent causes such as: (i) seasonal variation in flow to the reservoir, (ii) inter-annual variation in flow to the reservoir, (iii) conflict among competitive uses, (iv) sediment trapped in the reservoir, (v) upkeep and extra part issues, (vi) insufficient fund, (vii) human resources, and (viii) strategy/policy issues (Jimoh, 2007).

Fig. 3.1 shows where the main power plants (production) in Nigeria are currently located and also showcases the sizes of power generating plants per city in the country. This data is important in determining the appropriate location for SWAPs in Nigeria as illustrated on a smaller independent scale in Anambra State located in the South Eastern part of the country. As of December 2014, the total installed capacity of the power plants was 7,445 MW. Available capacity was 4,949 MW (2014 Year in Review, Presidential Task Force on Power, Pg. 53). Actual average generation was significantly less than 3,900 MW. Almost all the gas powered plants have considerable gas shortages due to constraints in supply, thereby adding to the impediment of power generation. There currently are 81 registered licensed power generating companies in Nigeria according to the Nigerian Electricity Regulatory Commission with power generation ranging from just 1MW to approximately 3000MW. However, it is difficult to track down on actual generation as over 50% of the registered licensed organizations are off-grid and there is no federal or state infrastructure or system in place to determine which organizations actually generate power or how much power is actually being generated.

Fig. 3.1: Power Plants in Nigeria Differentiated by Plant Capacity (ArcGIS)

Fig. 3.2 depicts the Nigerian power grid source indicating both the current principal power plants and the future planned installations. The figure also shows the transmission grids for both present and future. However, when we analyze the current status and future outlook of the transmission, we find that the current transmission capability is substantially less than 6000MW for the whole country. More importantly, the current infrastructure has a significantly high technical loss, which in power transmission includes theft of electricity by felonious users spouting the transmission lines (as explained in Chapter 1), but is also attributed to poor equipment maintenance, planning and calculation mistakes, mismanagement of processes and accounting errors. In addition, the current transmission infrastructure has low infrastructure coverage of less than 40% of the population and a low per capita generation of less than 25W (Labo, 2010). Ikejemba & Schuur (2016) indicate the high potential of solar energy in Nigeria and Sub-Saharan Africa in general. Nigeria's geographical location is an advantage that facilitates energy generation from the sun in a large quantity. It is also important to note that if solar panels or modules were utilized to cover 0.01 of Nigeria's land area, the possibility to generate 1850×10^3 GWh of solar electricity per year is attainable; this is one hundred times more than the current grid electricity consumption level in the country (Sambo & Bala, 2000).

Fig. 3.2: Nigeria's Power Grid Source [Present and Future] - (Global Energy Network Institute, 2014)

Currently, wind energy is not utilized as part of the energy generation in Nigeria. What are accessible are artifacts indicating its past use. Be that as it may, the determination to implement a sustainable resolution to the energy crisis in Nigeria has provoked the legislature and additionally autonomous analysts to survey the country's possibilities for wind power generation (Oluseyi, 2010). Individual researchers on their part have made various assessments of potentials and availability to determine the magnitude of wind resources as shown in Chapter 2. Research activities on wind energy prospect in Nigeria, whatever the boundary of their uncertainties, have identified that extraordinary potential exists in wind energy for power generation in Nigeria. However, it is established that the wind speeds are frail in the southern part, except for the waterfront, coastal and seaward locations which are blustery. Offshore territories from Lagos through Ondo, Delta, Rivers, Bayelsa to Akwa Ibom States were accounted for to have possibilities for reaping solid wind energy throughout the year. Within the country, the wind speed in the northern region was reported as the strongest. Moreover, the mountainous landscape of the middle belt and northern border exhibit a high potential for substantial wind energy. It was however detected that, attributable to difference

in topography and irregularity in landscape, sizeable differences may be present within the same area (Ajayi, 2009).

Most results (NIMET, 2009) in the light of utilizing 40 years (1968-2007) accessible average wind information from the entire forty-four wind stations covering the states of the country indicate that, the nation's wind jurisdiction is found to lie between inferior and average. The southern states have their average wind profile at 10m height in the range between 3.0 – 3.5 m/s, contingent upon the states, and northern states fit with mean wind paces of between 4.0 – 7.5 m/s. This implies that Nigeria has great wind resources in almost all locations within the country. In spite of the fact that wind speeds in the southern states are low, they can be utilized for standalone SWAPs to generate power utilizing small scale wind turbines (Oluseyi, 2010). This if utilized, will be a noteworthy leap forward for the country and sub-provincial territories not connected to the national power grid. However, given the technological advances between 2007 and 2015, it is possible to implement wind technology virtually in any location with minimal wind speed as current technology (*Due to a confidentiality clause the names of the wind technology have been omitted*) utilizes minimum wind speed to generate adequate power to small villages and communities across Sub-Sahara African countries.

4.2. Power Supply in Ghana

Energy supply in Ghana has worsened over the years, impacting businesses, manufacturers, organizations and households vigorously, with regulators blaming the crisis on declined water levels in the dams coupled with gas shortage to power Ghana's thermal plants. In view of the strew of information, it is relatively arduous to acknowledge the actual installed capacity of power in Ghana. Nevertheless, a selection of facts and information indicates that it ranges between 2000MW and 2800MW with actual power availability falling between 1200MW (Laary, 2015) and 2000MW (USAid, 2015). This serves a population of 25 million that is growing at 2.1% per year. With a client base of roughly 1.4 million, it has been evaluated that 45%-47% of Ghana households, including 15%-17% of the rural communities, have access to grid power (Asante & Clotey, 2007). All the regional capitals have been anchored to the national grid (See Fig. 3.3). This figure also shows the small and medium hydro resources in Ghana. Power utilization in the rural regions is assessed to be higher in the waterfront region (27%) and forest (19%) biological zones than in the savannah (4.3%) regions of the nation. Urbanization in Ghana was anticipated to increase from around 40% in 2000 to around 55% in 2012 and in the long run to 60% by 2020. Somewhat more than 33% of the urban populace lives in Greater Accra and is relied upon to stretch around 40% by 2020 (RCEEG, 2005). An impressive amount of family spending goes into energy usage. Power sources in urban zones are more enhanced than in the rural regions, since access to different types of commercial

fuels and machines is higher in the urban zones than in the country regions. Frequently the costs of power alternatives are higher in the provincial regions than in the urban areas where salaries are lower.

The government of Ghana has been seeking after a national energy policy. However, a large portion of the population stays without connection to the national power grid. It is exceptionally expensive to construct long-interval transmission lines to serve little groups, particularly when these groups are generally poor and can't sustain to pay rates sufficiently high to take care of the expense of these power services. In addition, there is little to no verification of increased economic activities in areas or communities that benefited from the national electrification scheme (Asante & Clotney, 2007). Micro-grids (smaller scale power generation) and provincially installed generation systems such as solar panels, wind turbines, batteries and so forth can be more reasonable. In any case, it is expected that rural electrification will continue to be a challenge for the nation. The Minister for Power of the Republic of Ghana has however guaranteed the country that the power catastrophe would be over before the end of 2015 after various measures he said government was executing (Laary, 2015). Then again, numerous individuals question the promise as this is not the first time government authorities have given such affirmations of ending the sporadic power supply going for a long time now. With the heightened power problems in the nation, government has opened up the area to permit private segment interest in power generation. In Ghana the total installed generation capacity as of December 2010 was 2,186 MW (GEC, 2011). However, currently the estimated installed capacity is somewhat between 2000MW and 2800MW. This includes:

- The Akosombo Hydroelectric Power Plant with an installed capacity of 1,020 MW. The Akosombo plant has been retrofitted with the replacement of the old turbine runners with new ones as well as electromechanical works aimed at restoring the plant to its original condition. The retrofit was completed in March 2005.
- 160-MW Kpong Hydroelectric Power Plant.
- 550-MW installed thermal capacity at the Takoradi Thermal Power Station.
- 126-MW Diesel Power Plant at Tema 1 and 50MW at Tema 2.
- 200-MW Sunon-Asogli (SAPP) thermal plant and 80-MW Mines reserve plant (MRP)

A 125-MW Power Barge “the Osagyefo Power Barge” is also available and is currently berthed at Effasu Mangyea in the Western Region with arrangements ongoing to establish viable fuel sources for it. The Osagyefo barge was developed by the Ghana National Petroleum Corporation in order to utilize the natural gas available in the Tano oil and gas fields for power generation. The barge has been completed and is yet to go into commercial operation

(Asante & Clotney, 2007). It is difficult to ascertain the clear number of power plants currently in Ghana because a substantial number of power plants are known to exist or forecasted but the actual installed capacity and/or actual generation is unknown. Adding to the difficulty, as is the case in Nigeria, there are no mechanisms or infrastructure in place to account for updated data on the issues surrounding the power plants. However, a number of future thermal power stations and hydro-electric power stations have been planned for the country. This can be seen in Fig. 3.3. Until a couple of years back, there was minimal financial enthusiasm for creating power from scaled down hydro plants in Ghana, as an overabundance of inexpensive power from the hydro power facilities at Akosombo and Kpong was accessible. Therefore, a considerable number of the smaller hydro locales that were discovered suitable for advancement for the rural communities were not developed; and, starting now, some of these rural communities have either been connected with the main national grid or are within a couple of kilometres from the national grid (Dernedde & Ofosu-Ahenkorak, 2002). Subsequently, the improvement of these communities for electrification has been debilitated impressively.

Just like Nigeria, Ghana is abundantly blessed with a lot of renewable energy forms. It is among the nations in the Economic Community of West African States (ECOWAS) with tremendous renewable energy potential. All the major Renewable Energy resources like the sun, wind, biomass and hydro can possibly enhance the power generation for the nation. The average daily sun light level of the nation ranges from 4 to 6 kWh/m², with the most astounding potential happening in the northern part of the nation where the electrification rate is extremely low (DLR, 2004). Wind speed over 6m/s at a height of 50m has been determined for some locations, indicating the feasibility for grid and off-grid power as well as for pumping water (GEC, 2011). The largest photovoltaic (PV) project in Africa, the Nzema project, that is being designed to be situated in Ghana, is expected to provide electricity to more than 100,000 households (Vaughan, 2012). The expected 155MW plant will increase Ghana's electricity generating capacity by 6%. Installation of more than 630,000 solar PV modules was expected to begin by the end of 2013 with electricity being generated early in 2014 and due to reach full capacity at the end of 2015 (Vaughan, 2012).

Nevertheless, this has not been the case as the US \$350 million scheme has been delayed for unknown reasons usually faulted on the issues of funding and in turn delaying the project till 2017. This raises the hopes of businesses and individuals who hope to gain from the electrification and only to be let down by the delay caused. Based on a short interview and survey carried out in Accra (private communication (2015)), a regular statement perceived from households in villages and communities is:

"So many foreign companies and organizations visit us and carry out surveys on renewable energy and provide us with hopes of electrification. However, for so many years we have never heard from them and as such we are tired of hearing about development projects. We want the project to present itself".

Fig. 3.3: Ghana Grid Power Source (Global Energy Network Institute, 2014)

Nonetheless, this does not affect the solar energy potential that Ghana possesses as is the case in Nigeria. It is the main goal of the Ghana power industry to have approximately 10% of its energies generated from RE sources excluding large-scale hydropower by 2020 (EFG, 2013). It is also without doubt that Ghana has great wind resources and locations of the high wind areas – such as the Accra Plains, Nkwanta, Gambaga mountains and Kwahu. These locations are similar to the locations in Nigeria with feasible wind potentials based on the technology utilized. The topmost energy that could be exploited from Ghana's available wind resource for power is estimated to be about 500 – 600GWh/year according to the Arakis Energy Group (2013). To give an example – According to the Energy Commission of Ghana in 2011, the largest Akosombo hydroelectric power station in Ghana produced 6,495GWhrs of electricity and, including all Ghana's geothermal power stations in addition, total energy generated was 11,200GWhrs in the same year (AEG, 2013). However, these analyses do not take into account further constraint factors. Wind power in Ghana can possibly contribute altogether to the nation's energy industry giving the present advances in wind energy innovation. It is doable and conceivable to execute small scale wind power generators to villages and communities with negligible wind possibilities. Constructive disposition of technologies for distributed energy generation in rural areas where the renewable energy resources are available can help quell the present energy crisis in Ghana as is the case with our research. Expansion of energy resources to incorporate renewable resources remains a key scheme of the government (Gyamfi, Modjinou, & Djordjevic, 2015). This presents high potential for grid and off-grid joint RE applications.

4.3. Comparing the Power Supply Infrastructure of Nigeria and Ghana

The power supply infrastructure of Nigeria is quite similar to that of Ghana, albeit that Ghana has more hydro power in place. However, Ghana has a smaller population than Nigeria that is primarily concentrated in the highly populated areas. Consequently, we apply a simpler approach to Ghana than to Nigeria. In fact, we use only the grid method. In the sequel, we confine our methodological discussion to Nigeria. However, in the end, we present our final findings for both countries.

5. Solution Approach

In this section we present diverging potential solution approaches to be utilized in locating SWAPs so as to meet the energy demand of each of the two countries. We take into account geographical, demographical and meteorological characteristics.

5.1. Assumptions

In implementing our solution approaches we make the following assumptions:

1. The population within a specific state with power plants has priority to be served before power is exported out of the state (i.e., households with the closest proximity to the power plants are served first until the capacity of the plant is fully utilized).
2. Energy requirement per state is approximated based on the population and present and future energy plants of the country.
3. For states with power plant(s) meeting the energy requirement of the population no additional SWAPs are considered.
4. The population per sub-state is uniformly distributed.

5.2. Solution Approach 1 – Grid Approach Applied Cluster-Wise

This solution approach is utilized for states with considerably high population density and no set of power plants meeting the energy requirement of the population within the state. The approach is similar to that utilized by Ikejemba & Schuur (2016). However, for this approach to work in the present context, it is important to demarcate the locations within the countries into *clusters* representing the states. For a specific cluster we proceed as follows:

Step 1: *Construct a longlist of potential locations for SPs and SWAPs.* To this end we place a suitable grid over the cluster. Each grid point is turned into a demand location by identifying the number of households around it. For potential SP locations we take grid points that are compatible with current land use. For potential SWAP locations we take grid points that - on top of that - have enough wind potential.

Step 2: *Construct a shortlist of potential locations for SPs and SWAPs. Stipulate that any of the facilities on this shortlist may only serve demand locations within a certain distance D .* In this step the longlist from Step 1 is reduced by taking into account the major and minor urban areas and the cost of transporting energy.

Step 3: *Solve an integer linear programming problem yielding a smallest subset of the shortlist (SPs and SWAPs together) such that almost all (say 95%) of the overall energy requirement is covered.*

Step 4: *Solve an integer linear programming problem yielding a smallest subset of the SWAPs appearing on the shortlist from Step 2 such that a substantial part of the overall energy requirement is covered.* In this step we concentrate on SWAPs, since these parks are preferable to SPs.

Step 5: *Combine the subsets found in Step 3 and Step 4 and let the facilities that are close coincide.*

As in Chapter 2, the model utilized in Step 3 as well as in Step 4 to execute the grid approach is given by FFM-grid (see Section 3.1.1).

5.3. Solution Approach 2 – POM Approach

This solution approach is utilized for the collection S of states with low population density and no set of power plants meeting the energy requirement of the population within the state. We start off from a list of potential locations for SWAPs. Since the POM approach is used, these potential facility locations are provided by experts from the Ministry of Power. From this list consider the set $\tilde{J}$ of all those locations that are situated within one of the states of the collection S .

Recall from Section 3.1.2 that each of these POM locations is given by the Ministry as a *sub-state* of one of the states of S . Since every potential facility location j from $\tilde{J}$ is a sub-state, it makes sense to represent the demand locations as sub-states as well.

Now, to ensure that a fraction α of the total demand of all sub-states adjacent to a sub-state from $\tilde{J}$ is satisfied, solve the integer linear programming problem FFM-POM from Section 3.1.2.

6. Bringing our Solution Method to Practice

Focusing on Nigeria, we begin by analyzing the population of the states and extracting the top 10 states with the largest population. This is followed by further analysis on the states with a large population density. Amongst the 36 states in Nigeria only three states appear on both lists of most populated and with a high density. However, to reduce the number of demand locations and variables for our POM method (see Section 5.3) we opt to merge the list of most populated areas with the highest density, thus obtaining a total list of 16 states.

Next, for each of these 16 states, we verify whether a power plant is within the state and, if so, calculate the *energy support coefficient* (ESC), which is the ratio of the total energy provided by the plant to the total energy required by the state. However, it should be noted that as of May 2015, the Nigerian Electricity Regulatory Commission (NERC) reported that only five of the total power plants in Nigeria were functional. This has been attributed to the shortage of gas to the plants and water management problems at the hydro plants (Udo, 2015). This fuels the need for the country to develop and implement renewable resources in a decentralized manner. From Table 3.1 it is clear that each of these 16 states requires a SWAP to help satisfy the energy requirement of the population.

Table 3.1: Power plant availability versus energy requirement for the highly populated 16 states

State	Power Plant Available? (Yes/No)	Operational, Partially Operational, Not Operational	Peak Plant Size (MW)	Minimum Energy Requirement (MW)	Energy Support Coefficient	New SWAP Required? (Yes/No)
Lagos	Yes	Partially Operational	1080	2344	0.46	Yes
Kano	No		N/A	2430	ESC < 1	Yes
Anambra	No		N/A	1053	ESC < 1	Yes
Rivers	Yes	Partially Operational	624	1350	0.46	Yes
Kaduna	No		N/A	1557	ESC < 1	Yes
Imo	Yes	Non Operational		1010	ESC < 1	Yes
Katsina	No		N/A	1477	ESC < 1	Yes
Akwa Ibom	Yes	Non Operational		1014	ESC < 1	Yes
Oyo	No		N/A	1450	ESC < 1	Yes
Bauchi	No		N/A	1209	ESC < 1	Yes
Abia	Yes	Partially Operational	118	714	0.17	Yes
Jigawa	No		N/A	1105	ESC < 1	Yes
Ebonyi	No		N/A	549	ESC < 1	Yes
Benue	No		N/A	1083	ESC < 1	Yes
Ekiti	No		N/A	614	ESC < 1	Yes
Osun	No		N/A	879	ESC < 1	Yes

6.1. Grid Approach Applied Cluster-Wise

In this section we utilize the **FFM-grid** model for each of the 16 states considered highly populated and with a high population density. We solve the associated ILP (see Section 3.1.1) for various values of α around 0.7 using advanced integrated multidimensional modelling software. This is because given that the highly populated states have their inhabitants mostly clustered within an area it is easy to cover a higher number of the population with a low α value. The solution is rather insensitive to α and is given by the following set of parks as seen in sample Figs. 3.4 and 3.5 for Bauchi and Akwa Ibom state, respectively. Furthermore, Table 3.2 presents a compiled solution for each of the 16 states.

In Fig. 3.4 below, it can be seen that only SWAPs have been allocated to the state. This represents a feasible solution because Bauchi state is one of the states with an excellent wind potential in the northern part of the country. However, in Akwa Ibom state (see Fig. 3.5) a different scenario is obtained for both SPs and SWAPs. SPs have been indicated to perform better inland of the state. Although there is potential for SWAPs given the mean wind speed of the state, offshore SWAPs locations south of the state will be preferable.

The computational results for the rest of the high density states can be seen in Table 3.2. The corresponding plant sizes are attributed to the population of the sub-state together with that

- (i) the number of parks needed: $\sum_{j \in J} \mathbf{X}_j^*$
- (ii) the required capacity $\mathbf{F}_j$ per facility j
 $\mathbf{F}_j = \sum_{i \in W_j} \mathbf{h}_i \mathbf{Y}_{ij}^*$ where $W_j = \{i \mid d_{ij} \leq D\}$

State	No of Selected Locations	Energy Requirement (MW)	Sub-State Locations	Type	Size (MW)
Lagos	3	1264	Epe	SP	42
			Kosofe	SP	157
			Badagry	SWAPs	55
Kano	4	2430	Kibiya	SWAPs	102
			Dawakin Tofa	SWAPs	181
			Warawa	SWAPs	97
			Karaye	SWAPs	106

Anambra	6	1157	Nnewi South	SP	49
			Ihiala	SP	63
			Orumba North	SWAPs	36
			Onitsha North	SP	26
			Awka North	SWAPs	23
			Anyamelum	SWAPs	33
Rivers	1	726	Degema	SWAPs	146
Kaduna	3	1557	Kaura	SPs	82
			Ikara	SWAPs	92
			Giwa	SWAPs	138
Imo	2	1010	Ideato North	SPs	93
			Ohaji	SPs	109
Katsina	3	1477	Batagarawa	SWAPs	101
			Faskari	SWAPs	104
			Musawa	SPs	91
Akwa Ibom	6	1014	Etim Ekpo	SPs	30
			Ibeno	SWAPs	21
			Eastern Obolo	SWAPs	17
			Uruan	SPs	33
			Ibiono Ibom	SPs	54
			Etinan	SPs	48
Oyo	2	1450	Oluyole	SPs	207
			Olorunsogo	SPs	83
Bauchi	3	1209	Gamawa	SWAPs	72
			Toro	SWAPs	87
			Alkaleri	SWAPs	83
Abia	2	596	Arochukwu	SPs	79
			Ukwa West	SPs	41
Jigawa	3	1105	Biriniwa	SWAPs	65
			Ringim	SWAPs	88
			Garki	SPs	69
Ebonyi	2	549	Ishielu	SWAPs	54
			Afikpo South	SPs	56
Benue	3	1083	Oju	SWAPs	84
			Logo	SWAPs	85
			Apa	SPs	48
Ekiti	2	614	Ikole	SPs	62
			Ekiti South West	SPs	61
Osun	2	879	Odo-Otin	SPs	99
			Isokan	SPs	77

So, when we aim for an energy coverage of 70% in the highly populated states, then we need 47 facilities to accomplish this, of which 24 are SPs (so there is not enough wind), and 23 are SWAPs (enough wind). A mixture of SPs and SWAPs is not occurring, primarily because of lack of space. Fig. 3.6 shows the locations of these 15 facilities.

Fig. 3.6: Proposed locations for SPs and SWAPs for highly populated areas in Nigeria generating coverage of 70%

6.2. POM Approach Applied on the Set of Less Densely Populated States

In this section we utilize the FFM-POM model for the rest of the 20 states not included in the previous experiment (i.e., the less densely populated states). However, in this case we carry out a 2 step-approach. Hereby, we initially utilize the FFM-POM model (see Section 3.1.2). Having obtained the minimal number (say p) of facilities needed, we use this number in the **Max h_i -POM** model to find the set of p facility locations that maximizes the demand covered.

We solve the FFM-POM problem with various values of α using the advanced integrated multidimensional modeling software. The output (i.e., the number of SPs and SWAPs to locate) based on the values of α can be seen in Table 3.3. Next, we execute the **Max h_i -POM** problem, the output of which is represented by whether a location is selected or not based on the result value of α .

Table 3.3: SPs and SWAPs to be located for the 20 lowly populated states for various values of α

State	POM Locations	Location Selected (Yes/No)				Type	Size (MW)
		$\alpha = 0.6$ p=12	$\alpha = 0.7$ p=15	$\alpha = 0.8$ p=19	$\alpha = 0.9$ p=21		
F.C.T	Abuja	Yes	Yes	Yes	Yes	SWAPs	103
Kogi	Adavi	Yes	Yes	Yes	Yes	SPs/SWAPs	52
Ondo	Akure North	Yes	Yes	Yes	Yes	SPs	50
	Okitipupa	No	Yes	Yes	Yes	SPs	44
Taraba	Bali	Yes	Yes	Yes	Yes	SPs/SWAPs	51
Cross River	Biase	Yes	Yes	Yes	Yes	SPs	61
	Obudu	No	Yes	Yes	Yes	SPs/SWAPs	47
Nasarawa	Doma	Yes	Yes	Yes	Yes	SWAPs	55
Enugu	Enugu East	Yes	Yes	Yes	Yes	SPs/SWAPs	49
Edo	Etsako West	No	No	No	Yes	SPs	36
	Ovia North East	No	No	Yes	Yes	SPs	40
Ogun	Ewekoro	Yes	Yes	Yes	Yes	SPs	64
Yobe	Fune	No	No	Yes	Yes	SWAPs	41
Adamawa	Hong	No	No	No	No	-	-
	Jada	No	No	No	No	-	-
Kwara	Ilorin West	No	No	No	No	-	-
	Pategi	No	No	Yes	Yes	SPs	38
Plateau	Jos South	Yes	Yes	Yes	Yes	SPs	51
	Langtang South	No	No	No	No	SPs/SWAPs	27
Bayelsa	Kolokuma	No	No	No	Yes	SPs/SWAPs	36
Gombe	Kwami	Yes	Yes	Yes	Yes	SWAPs	59
Kebbi	Maiyama	No	No	No	No	-	-
Zamfara	Maru	Yes	Yes	Yes	Yes	SWAPs	52
Delta	Okpe	Yes	Yes	Yes	Yes	SPs	67
Sokoto	Sokoto North	No	No	Yes	Yes	SWAPs	36
Sokoto	Tambuwal	No	Yes	Yes	Yes	SWAPs	44

Let us illustrate the interpretation of the table above. Suppose, we aim for an energy coverage of 70% in the lowly populated states then we need 15 facilities to accomplish this, of which six are SPs (so there is not enough wind), four are a mixture of SWAPs and SPs (so wind is moderate), and five are SWAPs (enough wind). Fig. 3.7 shows the locations of these 15 facilities.

Fig. 3.7: Proposed locations for SPs and SWAPs for lowly populated areas in Nigeria generating coverage of 70%

6.3. Main results for Ghana

For brevity of exposition, let us only briefly indicate our results for Ghana. For Ghana we used only the grid approach since Ghana has a smaller population that is primarily concentrated in the highly populated areas. Given that Ghana has numerous hydro power plants running short of water, it is important that a backup system be introduced for those plants. However, small sized SPs and SWAPs could be implemented in areas where power is unreachable to people off-grid. Taking all the above into account in our experiment we found five locations for SWAPs and nine for SPs. They are situated as indicated by Fig. 3.8.

Fig. 3.8: Proposed locations for SPs and SWAPs in Ghana generating coverage of 70%

7. Conclusions and Further Research

In this chapter we develop a hybrid approach to design a nation-wide capacitated network of Solar Parks (SPs) as well as Solar and Wind-Assisted Parks (SWAPs) (i.e., parks that generate both solar and wind energy) for two separate countries: Nigeria and Ghana. We take into account geographical, demographical and meteorological characteristics.

The power supply infrastructures of both countries, as well as the policies surrounding the provision of off-grid energy are analyzed in depth. In tackling the location problems occurring, we present the advantages and disadvantages of the grid method - utilized in the previous chapter - and the so-called problem owner method (POM). In the POM, each potential facility location is provided by experts from the Ministry of Power, rather amply as a *sub-state* of one of the states. Therefore, in the POM approach we are forced to shift from the distance concept – used in the grid method – to a more topological vicinity concept. We choose for a hybrid approach by combining the grid and the problem owner method. We apply the grid method to regions with high population density and utilize the POM for less populated areas. Furthermore, we take into account power plants that are operational or will be so in the near future.

In the above fashion we design two separate, capacitated networks of SPs and SWAPs, one for Ghana, one for Nigeria. For Nigeria, coverage of the lowly populated areas varies from 60% (if we place 12 facilities) to 90% (if we place 21 facilities). To accomplish 70% coverage for the whole of Nigeria we need: (i) 15 facilities for the lowly populated areas, of which six are SPs (so there is not enough wind), four are a mixture of SWAPs and SPs (so wind is moderate), and five are SWAPs (enough wind) (ii) 47 facilities for the highly populated areas, of which 24 are SPs, and 23 are SWAPs. A mixture of SWAPs and SPs is not feasible in the latter areas. As for Ghana, we found five locations for SWAPs and nine for SPs

Thus we obtain a blueprint of a capacitated network of SPs and SWAPs that satisfies – in a sustainable way - the energy requirement of the majority of households by a facility within reasonable distance. In our research we make a number of assumptions. For instance, we assume that the population within a specific state with power plants has priority to be served before power is exported out of the state. Currently, this is generally not the case, leading to power loss due to long transmission lines. Moreover, we assume that the population per sub-state is uniformly distributed.

Future research may take into account a detailed analysis of the widely branching and intricate electricity distribution system including the inherent power loss. Also, actual demographic data may be used. Another interesting issue is the cost factor, which was left out. One may think of a break even analysis taking into account the higher costs for wind parks. All in all, we are convinced that the present study is both an enabler as well as a blueprint towards a sustainable energy future for Nigeria as well as Ghana.

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Chapter 4

The Sustainable Management of Renewable Energy Projects in Sub-Saharan Africa: Empirical Reality & Failures

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*“You either get the point of Africa or you don't.
What draws me back year after year is that it's like
seeing the world with the lid off.” – A.A. Gill*

1. Introduction

One of the reasons for the deteriorating nature of publicly funded renewable energy projects in Sub-Saharan Africa (SSA) is the absence of a sustainable management method and more specifically, the inability to appropriately trace the designation of responsibilities. It is without doubt that publicly funded projects require dedication, planning and a transparent partnership with the implementing organization. Nonetheless, the sustainable management of these projects is commonly exasperating for the stakeholders involved in the project because the aim of implementation and responsibilities are not distinctly clarified. Consequently, it makes the projects multitudinously uncertain to manage effectively within Sub-Saharan Africa.

Generally, publicly funded projects possess characteristics such as prolonged durations, substantial budgets, multiple stakeholders and apprehension which are difficult to model, implement and manage effectively (Chih & Zwikael, 2015). It is important to indicate the differences in objectives of privately-funded projects and publicly-funded projects. Oftentimes, privately funded projects are mainly focused on the objective of maximizing profits, return on investments and minimizing losses. Publicly funded projects are “thought” to have multiple objectives within the development of social values and provision of basic necessities within the concept of fundamental human rights¹. It is expected that private organizations that invest in renewable energy projects in SSA, will execute a suitable management method in order to maximize their corresponding profit and return on investment. Hence, it is important to note that this study focuses mainly on publicly funded and, to partial extent, on projects founded on public-private partnership within the renewable energy field. Although a public-private partnership is considered beneficial to the provision of better public services via innovation and technology, this is not usually the case in “actual” renewable energy projects in SSA. The reason for a partial focus on public-private partnership (PPP) is that a clear path to the agreement within the PPP is not usually provided and as such, private organizations that participate in PPPs focus on acquiring a return on their investment even prior to the commencement of the project by bloating the total cost of the project.

In a study done on RE in Nigeria and Ghana, it was found that “So many projects fail because, when we talk about solar parks in Africa, most of the time people think this is just about finding an empty plot of land and implementing a project” (VanguardNews, 2016). Clearly, little thought

¹ This is the expected situation but in most cases differs from expectation.

is given to how projects will be managed once they are established, which largely contributes to their failure. In many countries within West Africa for example, many small and medium-sized PV projects have been implemented, ranging from solar boreholes to lighting thousands of street lights and powering the emergency department of hospitals. However, despite the potential of these projects, most of them have been left to deteriorate with no maintenance, no cleaning, no repairs and more importantly no sustainable management method that encompasses them all. Some of these projects are precipitously discontinued during planning and sometimes during implementation leading to the dissipation of limited resources such as funding and time. This situation has created a negative attitude towards the acceptance of sustainable and clean energy usage within the minds of the masses making it difficult for governments of these developing countries to adopt RE technology. Because most public projects are funded from taxpayers' money, these projects are frequently reviewed (Patanakul, Kwak, Ofer, & Liu, 2016). However, within developing countries in Africa, more often than not, these scrutinies do not provide solutions to the existing problem of sustainably managing RE projects.

Multiple studies have been conducted on the different aspects of managing public projects within different sectors of the economies in Sub-Saharan Africa. However, some of these studies (Ofori D. F., 2006; Shiferaw, Klakegg, & Haavaldsen, 2012; Ofori D. , 2014) are more in a generic form covering the entire aspect of project management within specific countries in SSA. This research differentiates itself from other studies carried out on the management of projects by pitting a direct focus on renewable energy in Sub-Saharan Africa. Our study investigates the failures of past projects in SSA by analyzing the linkages within the overall system encompassing the implementing government, the organization implementing the projects and more importantly, the public expected to benefit from the implementation of the project. By investigating the connections and the responsibilities of each stakeholder defined within the system, this research presents several points that require concentration to effectively manage publicly implemented RE projects. Understanding the principal concept provided in this chapter of the overall system from project awarding to its implementation and finally to its sustainable management will enhance the sustainability of future projects and will provide the governments awarding the projects with methods on managing such projects. In addition, this study focuses mainly on publicly funded projects whilst partially focusing on public-private partnership as earlier indicated. Generically, this research aims to provide applicable solutions to the management of RE projects in Sub-Saharan Africa so as to enhance its sustainable development and technological acceptance.

The rest of this chapter is outlined as follows. In Section 2 we describe related work from literature. In Section 3 we analyze the current state affairs. In Section 4 we present our findings and conclusion.

2. Related Work & Literature Review

This section presents an overview of the literature related to the management of RE projects in SSA. In Section 2.1 we describe the characteristics of public, private and public-private RE projects. In the remainder of this section (as well as the chapter) we focus on public projects. Section 2.2 illustrates failures of these as reported in literature. In Section 2.3 we outline the challenges involved with public RE projects in SSA. In line with that, Section 2.4 describes the intricate problem of designating responsibilities within RE projects. Finally, Section 2.5 outlines our focus on ‘Sustainable Management’ as a way to secure RE projects in SSA.

2.1. The Public-Private Mix of Renewable Energy Projects in SSA

Renewable energy development is a crucial part of the way forward in sustainable development. For reasons transcending economic benefits, both the public and private sectors are assiduously engaged in developing the technological systems, governance frameworks, project management, monitoring and evaluation methods that are necessary for developing the renewable energy sector. For example, the *public sector* – which comprises government institutions, agencies and professionals – is known to invest largely in research and development of renewable energy systems, offering incentives and favorable policies such as tax exemptions for the development of the renewable energy sector (Haas, et al., 2004; Verbong & Geels, 2007). As a result, governments, international organizations, universities and other research institutions are actively involved in and, in most cases, at the forefront of renewable energy innovation and development (Foxon, et al., 2005; Menanteau, Finon, & Lamy, 2003). The leadership role assumed by public organizations in stimulating the development of renewable energy also reinforces the ethical underpinnings of renewable energy development. Hence, in the public sector, social and environmental benefits are elevated above economic reasons within the framework of the three core aspects of sustainability (Elkington, 1997; Ajayi & Ajayi, 2013).

Notably, the adoption and use of renewable energy technologies is more widespread among *private* organizations and individuals in SSA countries. Solar power generation units, smart grid systems, among others are mainly used in homes and private establishments (Martinot, Chaurey, Lew, Moreira, & Wamukonya, 2002; Amankwah-Amoah & Sarpong, 2016). Also, although the

initial investment in renewable energy technology is high, their long time benefits are known to outweigh high initial costs (Menanteau, Finon, & Lamy, 2003). Furthermore, the future of energy consumption is forecast to be mostly renewable and many governments, private organizations and companies are strategically transitioning their policies, and business models along this new paradigm. Consequently, more private organizations and investors continue to join the bandwagon for sustainable development by committing their resources to developing renewable energy technologies for commercialization. Therefore, the broader picture of renewable energy development depicts a mix of both public and private initiatives.

The *mix of public and private initiatives* is even more profound in developed countries where public-private partnerships have emerged as a model for designing, implementing and monitoring renewable energy projects (Chaurey, Krithika, Palit, Rakesh, & Sovacool, 2012). Interestingly, these developed countries are mainly capitalist and liberal economies. As such, the hand of the government is hardly directly involved in the actual management of renewable energy projects. Largely, the public sector's role rests on provision of funding, regulatory mechanisms, demanding accountability, promoting fair competition and transparency (Meyer, 2007). These practices in developed countries are often put forward as exemplary models for developing nations to emulate. Sadly, the application and performance of such 'developed country models' are no less than fatal in developing countries.

Here, we attempt to decouple public RE projects from private RE projects mainly because of the unfortunate reputation that public RE projects have earned over their failure largely due to inefficiency and ineffectiveness in management. In addition, we consider the difference in the management of RE projects and the public and private sectors in SSA countries where public RE projects have a higher rate of failure. Hence, the remainder of this section focuses only on public RE projects in SSA.

2.2. Failure of Public RE Projects in SSA

Public projects in SSA countries generally come with high expectations and a lot of hype (Borup, Brown, Konrad, & Van Lente, 2006). With regards to expectations, public RE projects are often designed to provide solutions to problems that confronts the general public. Thus, the initiation of numerous RE projects come with expectations to provide people with access to electricity to power their homes, hospitals, streetlights and other energy-dependent facilities. In most cases, these expectations are shared by both the implementing agencies (government) and beneficiaries

(people). On the other hand, hype often follows these expectations. In SSA, the media is very quick to disseminate information on public RE projects. Also, politicians, administrators and other bureaucrats involved in public RE projects are interested in claiming credit for initiating the projects. These levels of hype and expectation are not peculiar to SSA countries but common to countries around the world (Borup, Brown, Konrad, & Van Lente, 2006; Ruef & Markard, 2010; Verbong, Geels, & Raven, 2008). However, the experiences and performance of RE projects after the hype and expectation differ from country to country.

Within SSA countries, we identify five basic kinds of RE project failures: (i) shelved RE projects; (ii) stalled RE projects; (iii) appropriated RE projects; (iv) malfunctioning RE projects; and (v) nonfunctioning RE projects.

Shelved RE projects, as the name suggests, are those projects that have been planned but not implemented. Some RE projects are painstakingly planned and intensely hyped but never get implemented. An example is the so-called largest solar project in Africa to be implemented in Ghana (Blue Energy, 2015) which, until now, is still yet to take off, if not already abandoned. There are also those projects (*stalled projects*) which although take-off, get stalled and never reach completion. For these kinds of failed projects, implementation is incomplete. Furthermore, some RE projects get appropriated (*appropriated projects*) in such a way that their implementation succeeds but deviates from the original plans and intents. Most appropriated projects come by due to imminent threats of failure that planned projects experiences. Hence, they usually take on a scale smaller than the original project. Other appropriated projects may result from lack of appropriate technology for original projects. *Malfunctioning* projects are those projects that have already been implemented but are defective. This may result from either technical or non-technical factors. RE projects may malfunction due to technical breakdowns or due to turbulent socio-economic circumstances in their context that affect their proper functioning. Malfunctioning projects are those that are not completely broken down but only function on irregular basis. Finally, *nonfunctioning projects* are broken down and cease to be of any use. This is rather common in SSA countries. For example, it is not uncommon to see solar systems installed but not functioning (Sebitosi & Pillay, 2007; Bawakyillenuo, 2009). Reasons for failure of RE projects in SSA are diverse. In addition, a multiplicity of factors can combine to result in a project's failure. Nevertheless, many of the causes of RE project failures lie in project management processes and practices. Different challenges emerge at different stages of the project management process that contribute to RE project failures. Below, we discuss a number

of challenges – incompetence of project managers, stakeholder dynamics and designation of responsibilities – with special focus on poor designation of responsibilities (or lack of traceability in order words).

2.3. Public RE Projects Management Challenges in SSA

One of the major problems that affect the effective and efficient implementation of public projects in some SSA countries is incompetence of project managers (Ofori D. , 2014; Ofori D. F., 2006). Project managers are not adequately equipped with the comprehensive skill set and competence to allow them to see projects through to the end with success. The project managers sampled displayed varying levels of competence in the various project management skills. Stakeholder management is considered a critical aspect of project implementation which has a significant impact on the success or failure of public projects. The members of society are usually the major stakeholders in most public projects. As a result, different approaches and strategies take into account the social costs and benefits of public projects as well as the level of engagement of the public in public projects. For example, the Social Discount Rate (Kossova & Sheluntcova, Evaluating performance of public sector projects in Russia: The choice of a social discount rate, 2016) is an approach for conducting cost-benefit analysis of projects. Also, community engagement methods have been used to ensure that members of communities participate in public RE projects (Alvial-Palavicino, Garrido-Echeverría, Jiménez-Estévez, Reyes, & Palma-Behnke, 2011).

When it comes to public RE projects in SSA countries, some of these community engagement methods are applied. However, engagement is often limited to the acquisition of land for the project, assembling people for the often festive inaugurating or commissioning of projects. Rarely do project managers handover ownership and management responsibilities to the public. As a result, some communities neither assume any responsibility for the functioning of the project nor see themselves as significant players in the projects' successes or failures. As such, they assume a neutral position when it comes to project monitoring. But such neutrality usually transforms to opposition in some cases as some reports have pointed to the public acting as saboteurs to the success of some RE projects in SSA (Omisore, 2011). The news article outlined the contradictions in the implementation and management of renewable energy projects by contrasting the case of a failed project implemented and managed by government with that of a successful government-funded but privately implemented project. Opaque bureaucracies, lack of a sustainability plan, sabotage, are some of the reasons contributing to failure.

It is common in some SSA countries to delegate project management responsibilities to local oversight or monitoring agencies such as district or regional monitoring offices. The problem with this form of delegation is that it diffuses the actual responsibility for managing the project among stakeholders who consider themselves as passive participants of the projects. This is because some of the agencies' oversight duties cover all active projects within their jurisdiction. The forgoing shows that the designation of responsibilities for managing RE projects gets murky when it comes to public RE projects. We consider this a key challenge in most SSA countries. We therefore commit the next section to exploring available knowledge on the challenges that RE projects within the public domain face because of poor designation of responsibilities.

2.4. The Problem of Designation of Responsibilities

Within the stated scope of our research, there are no existing peer-reviewed publications that explore, in particular, the impact of lack of proper designation of responsibilities on the performance of renewable energy projects in SSA. Nevertheless, there are a number of fragmented sources of literature that identify the inability to trace responsibilities as a major cause of failure of public renewable energy projects. Most public projects in SSA are implemented without a clear structure or unambiguous structuring of relationships among stakeholders. As a result, key factors such as maintenance, protection of project infrastructure and functioning are not clearly allocated. Hence, loafing is common among stakeholders (ownership), as it is not clear who is responsible.

The lack of clear designation of responsibilities makes it impossible for RE projects to be supervised and continuously maintained. In addition, it complicates the process of tracing to the exact person who can be held responsible in case projects fail. Moreover, it leads to problems with ownership. For most public RE projects, it is not clear whether the projects belong to the government or to the people. Hence, needed management frameworks and local management systems cannot be actively sought in most cases. These problems make public RE projects vulnerable to contested ownership among interest groups, political manipulation by politicians, and outright ignorance by members of the public and other stakeholders. We further note that the challenges faced by improper designation of responsibilities, and for that matter traceability, link with the lack of transparency in project design and implementation, inadequate project management competence, lack of explicit commitment to sustainable management, and the hasty co-optation of PPPs. Some researchers have suggested that these factors are common within public sector management practices (Kossova & Sheluntcova, 2016), and in some cases

intentional acts by officials to cover up financial malfeasance (Laryea, 2010; Alutu & Udhawuve, 2009).

The next section outlines our focus on ‘Sustainable Management’ as a way forward in securing RE projects in SSA against failure.

2.5. Sustainable Management

Our literature review identified a likely ambiguity in the use of the term ‘sustainable management’ of renewable energy projects. This is due to the plethora of literature that focuses on the technical strategies used in optimizing the efficiency and effectiveness of renewable energy technologies. Let us make a distinction between technical infrastructural management” and “administrative-bureaucratic management” in RE projects. Technical-infrastructural management entails technology optimization techniques whilst administrative-bureaucratic management entails the largely non-technical management process in RE projects. These two categories are equally important in managing RE projects. Yet, more existing research is focused on technical aspects to the detriment of non-technical aspects (Polatidis & Haralambopoulos, 2007). Hence, our research focuses on identifying the ‘administrative-bureaucratic management’ aspects of RE projects which can foster sustainable management of public RE projects.

3. Analysis of the Current State of Affairs

In this section, we present an overall analysis on the current state of affairs. We begin by restating the main objective of the research in Section 3.1. Next, Section 3.2 presents our research method. In Section 3.3 we outline our analysis of collected data and interviews. Section 3.4 presents the current state of affairs of the projects analyzed.

3.1. Objective of the Research

The goal of this research is to develop a management method that is sustainable to manage renewable energy projects within Sub-Saharan Africa. This study investigates the failures of past projects by analyzing the structure of the overall project experience utilizing a strategy of "tell it how it is". In addition, this study proposes several points to effectively manage publicly implemented RE projects. To the best of our knowledge this is the first study that focuses on developing a sustainable management method for renewable energy projects in Sub-Saharan

Africa. It also presents conditions for future studies and provides applicable solutions towards the problem of managing implemented projects.

3.2. Research Method

This research uses an *ethnographic* approach (as explained in Chapter 1) in the sense that we physically observe (and interview) the stakeholders (governmental and local). A typical ethnographic study requires that the researcher becomes part of, or in one way or the other attains proximity to the society or group being studied (Gupta & Awasthy, 2015). Moreover, we visually inspect the installations involved (cf Table 4.1). This allows us to focus on the nature and interaction of particular social phenomena rather than testing hypotheses about them (Atkinson & Hammersley, 1994). As described in the subsequent section data obtained this way is often unstructured. It has not been coded at the point of collection along a pre-defined set of analytic categories. Instead, analysis of this data involves explicit interpretation of the meanings and functions of human actions, the product of which mainly takes the form of verbal descriptions and explanations, with quantification and statistical analysis playing a subordinate role at most. This is further presented and elaborated on in Section 3.3 and 3.4.

3.3. Research Data Analysis

In this study, available data on 29 publicly funded projects from ten countries was collected and analyzed thoroughly. The data was collected from countries within the Sub-Saharan region of Africa. The countries include: Nigeria, Ghana, Kenya, Gabon, South Africa, Tanzania, Mozambique, Ethiopia, Malawi and Uganda. The projects analyzed in this report have been randomly selected based on their familiarity and visibility to the locals. Due to the limited openness of government officials and lack of information within most of these countries, data collected is not differentiated into multiple classifications. Furthermore, given that the hype presented towards the implementation of renewable energy projects is far below actual implementation (i.e planned & discussed projects is substantially higher than implemented projects), it is necessary to treat each project differently rather than classify them into categories and later combine corresponding responses. The types of projects recorded are micro-grid rural electrification, street lights, city electrification, electrification of public institutions such as: health care centers, public schools and government offices. To obtain a general and an unbiased perspective of the implemented projects, interviews were carried out with the locals benefitting

(or expected to benefit) from the project, “some²” project developers/implementers and “willing³” government personnel. The states of the projects are analyzed based on physical evidence and interviews with the beneficiaries due to the absence of audit reports. In this way, the collected information is authentic and unbiased.

Furthermore, to accurately analyze the compiled information, we utilized a template that encompasses information such as country, project type, project expectations and project predicament. Information on project costs, implementing organizations and exact project location has been omitted from this chapter so as to avoid any future ramification on government personnel or implementing organizations that have participated in the provision of data for this study. For each project we analyzed the data collected by the research team and identified corresponding characteristics between each of the projects such as expected goals of the project and their perspective on the causes of failures if applicable.

As earlier indicated, the projects analyzed in this study have been accumulated from different countries. Ten of the projects have been executed in Nigeria, four in Ghana, three in Kenya, two in Gabon, one in South Africa, two in Tanzania, two in Mozambique, three in Ethiopia and two in Malawi. These projects have also been implemented within different infrastructures and by different Local Governments within the respected countries. Ten of the projects constitute the lighting up of streets within the community with at least 30 street lights to 100 street lights. Two of the projects were implemented to power up a local hospital. One of the projects was implemented to power up a local school. Three of the projects have been implemented to power up public offices. Nine of the projects have been implemented to electrify public infrastructures such as water borehole to provide clean drinking water to communities, powering of security traffic cameras, water heaters in government housing projects and minor local connections. Finally, four of the projects were implemented in remote villages without access to the grid (see Table 4.1: Project & Data Information).

² “Some” in this context indicates that not all project developers whose implemented project was physically observed and examined agreed to partake in the study. In such cases, further interviews was carried out with the beneficiaries and financing government.

³ “Willing” in this context refers to the fact that, not all government personnel contacted and involved in this study was fully compliant or enthusiastic towards the provision of all required information.

Table 4.1: Project & Data Information

Project Number	Project Location	Project Type	Physical Analysis	Method	Timeline
N1	Nigeria	Street Light	Yes	II, FI, GD	December 2015 - January 2016
N2	Nigeria	Public Hospital	Yes	FI, TC	February & March 2016
N3	Nigeria	Public Office	Yes	FI	March 2016
N4	Nigeria	Street Light	Yes	II, GD	December 2015 - January 2016
N5	Nigeria	Street Light	Yes	II	December 2015 - January 2016
N6	Nigeria	Public School	Yes	II, GD	January 2016
N7	Nigeria	Public Infrastructure	Yes	II, FI	January 2016
N8	Nigeria	Public Infrastructure	Yes	FI, TC	March 2016
N9	Nigeria	Street Light	Yes	II, GD	December 2015 - January 2016
N10	Nigeria	Public Hospital	Yes	II, FI, GD	February & March 2016
G1	Ghana	Public Office	Yes	FI	February 2016
G2	Ghana	Street Light	Yes	FI, GD	March 2016
G3	Ghana	Remote Village Off-Grid	Yes	II, GD	December 2015 - January 2016
G4	Ghana	Public Infrastructure	Yes	II, TC	March 2016
K1	Kenya	Remote Village Off-Grid	Yes	II, FI, GD	March 2016
K2	Kenya	Public Infrastructure	Yes	FI, GD	February & March 2016
K3	Kenya	Street Light	Yes	GD	March & April 2016
GA1	Gabon	Street Light	Yes	II, GD	February & March 2016
GA2	Gabon	Public Office	Yes	FI, TC	February & March 2016
S1	South Africa	Public Infrastructure	Yes	FI	December 2015
T1	Tanzania	Remote Village Off-Grid	Yes	II, GD	January 2016
T2	Tanzania	Public Infrastructure	Yes	FI, GD	January 2016
M1	Mozambique	Public Infrastructure	Yes	II, FI, TC	March & April 2016
M2	Mozambique	Street Light	Yes	TC, GD	April 2016
E1	Ethiopia	Public Infrastructure	Yes	II, FI	February - April 2016
E2	Ethiopia	Public Infrastructure	Yes	II, GD, TC	February - April 2016
E3	Ethiopia	Street Light	Yes	TC, GD	February - April 2016
MA1	Malawi	Street Light	Yes	TC, GD	March 2016
MA2	Malawi	Remote Village Off-Grid	Yes	II, TC	March 2016
Key					
Public Infrastructure	Methods	Code			
Borehole	Informal Interviews	II			
Water Heater	Formal Interviews	FI			
Minor Connections	Telephone Conversation	TC			
	Group Dialogue	GD			

3.4. State of Affairs of the Analyzed Projects

Of the 29 projects studied in this research, 26 possess a predicament that has somewhat been attributed to them, ranging from low maintenance to total failure and sabotage. The remaining three projects have only been recently implemented prior to the execution of this research and as such focus is placed only on the planning of those projects and their expectations. Although the projects discussed in this study remain anonymous, some of the projects already gained media coverage and scrutiny. The physical deterioration of these projects is easily comprehensible and visible to the naked eyes. However, the aim of this study is to understand the reasons for these failures and to provide sustainable management methods to curb the failures. Therefore, we combine the interview responses collected into three different categories: (i) local benefitting recipients, (ii) “some” developers/implementers of the project and (iii) “willing” government

personnel. This is done to distinctly comprehend the issues affecting the success of renewable energy projects. Further breakdown in analysis of the projects are further presented and explained within the three different categories below.

Local Benefitting Recipients

In this section, the responses collected from interviews and dialogues with the locals benefitting from the project are compiled and analyzed. Two sets of interviews with the locals benefitting from implemented projects were carried out. One based on a one-on-one interview and the other based on a dialogue involving multiple groups within a tightly knitted community. The most recurring issue from dialoguing with the locals is the aspect of public acceptance, sabotage and the maintenance of the project after its implementation. Responses focused on 17 of the projects indicated that after six months of implementation the projects ceased to function whilst nine of the projects lasted less than three months. A disturbing response provided by one of the locals indicated that, although crime is known to be rampant within their region and the solar street lights and security camera that was implemented to curb the situation has broken down, yet for over three years nothing has been done towards its maintenance and repairs. 92 percent of the responses compiled from 26 out of the 29 projects complained heavily about not receiving any responses and sometimes responses coming after as long as six months after complaints of failures have been lodged with the respective local government. Other issues presented by the locals indicated that since these projects are implemented by either the local or state government from a specific cluster, indigenes from other clusters sabotage these projects, envious of the fact the project has not been implemented within their local government. This makes the absence of securing these projects one of the many local reasons for their failures. In a discussion with competent solar technicians who reside within some of these communities, an indication was made that maintenance was the main problem attributed to the projects' failure. However, a clear path to understanding the institution responsible for the maintenance of the project doesn't exist. In addition, public acceptance of the technology also affects the whole system. When the implementing organization does not clearly explain the system to the locals, then people tend to overload the system or utilize in ways that are not advisable.

Some other project failures (Omisore, 2011) focused on the perspective of the locals not included in this study possess similar traits to the responses provided. One project was implemented approximately five years ago with the goal of electrifying water borehole pumps, fish driers and street light, providing the community with access to drinking water, securing their streets at

night and positively improving the local fishing economy. However, three months into its operation it ceased to function and all failure reports sent to the authorities were never acknowledged after an initial repair session on faulty cables was carried out. This process has caused a domino effect in such a way that it has tainted the effectiveness of the technology and its acceptance. Several state governments have renounced all renewable energy projects to focus on grid connection, a situation that could take more than a century to accomplish.

Project Developers & Implementers

Responses were compiled from an interview with 15 project directors that have to some extent controlled or managed the implementation of these projects. As noted earlier, “some” developers/implementers. The “some” has been highlighted to indicate that of the 29 projects indicated in this study only 15 of the implementing organization personnel agreed to participate in this study. All interactions in this section were carried out on a one-on-one basis. Of the 15 interviews 33 percent of the respondents indicated that the project was outsourced to them by a different organization, 53 percent claimed to have been awarded the project via the public tendering process and 13 percent preferred to avoid the question. It is imperative to note that not having the full co-operation of the awarding local governments it is difficult to ascertain what the original values may present when all awarded projects are analyzed per country. These values are only based on the responses provided by the implementing project organizations in this context.

Although some project directors were cautious and conservative in providing the implementation and maintenance plan, some others were profound and open-minded with such information. It was gathered that at most times no preliminary studies were carried out. Instead utilizing the assumption that wherever the sun shines, solar energy could be harnessed and thus missing out on very important information that affects the sustainability of the system in general. Discussing about the management of the system, all various participating project directors indicated that indeed there is at most times no clear planning with respect to that, whilst some indicated that it is the responsibility of the awarding local government to deal with the management and maintenance of the system. However, in instances of a PPP, the implementing organization is usually responsible for the management of the system. However, funding for its maintenance is where misunderstanding arises from as the implementing organization claims the government should be responsible for that whilst the awarding government indicates the opposite. This clearly shows that situations of this case arise only when inadequate planning occurs. One fact presented by one of the project directors indicated that there is usually no

cooperation in terms of understanding the technology better with the benefitting community and as such problems are bound to arise when systems are overloaded or mismanaged by the local community themselves.

In a study on the major reason for failure of most solar street lighting projects in Nigeria (Asiegbu, 2012), it was indicated that most of these projects fail due to system sizing whereby the output of the panels fail to match the battery size for effective charging, therefore causing the battery to deteriorate within a couple of months. In some cases, the opposite was recorded, where the load of the batteries was higher than their output capacity. It is evidently clear from the dialogue that most of the implementing organizations studied in this report are mainly focused on the profit of the business and in turn losing sight of the sustainability of the system and its effect on the future generation to adopt the technology.

Government Personnel

Several studies, papers and news reports (Otaru, 2014; Salihu, 2012; Isine, 2014; Okoduwa, 2011; Muhammad & Adaramola, 2015) have reported on the corrupt nature of the process of awarding projects in SSA countries with audit reports presenting findings that do not exist so as for political parties to implement their specific agenda. Given the evidence of rampant corruption in Africa (Sanders, 2015), it is not difficult to ascertain to what extent corruption infiltrates the process of how projects are awarded to implementing organizations. However, in this case we approached the dialogue with a blank frame of mind. In an attempt to extract direct answers on the existence of corruption in awarding projects with the participating personnel, neither was there a direct response nor indirect response provided. Towards the aspect of the maintenance and management of renewable energy projects, some of the participants made it clear that inadequate planning was the main issue that affects the sustainability of the projects and the process in which projects are awarded doesn't necessarily affect the implementation of the project.

Some of the participants during the interview also indicated that due to the failures of these projects, their respective governments have decided to focus on electrifying communities and local infrastructures via the grid connection. Although having in mind that this process might take a very long time to complete and requires billions in financing. They state that it is the main option and some of the hidden political driven agendas include limiting the use of renewable energy to support the organization of lobbyist as a favor to their support of the government. The

absence of a clear responsibility of participating stakeholders is one that plagues the control and management of the projects, whilst the ethical responsibility of the government is lost in the process. This results in the loss of trust within the masses towards the government.

Deducing the responses gathered from our data collection and interviews with the relevant stakeholders for public projects in Sub-Saharan Africa, we are able to excerpt that the failures of renewable energy projects in SSA are linked to the political agenda of the government, the process of awarding projects, the participating stakeholders, inadequate planning and implementation, maintenance and management of implemented projects and finally, the public acceptance and sabotaging of the technology.

4. Findings and Conclusions

The energy problems experience in Sub-Saharan Africa today can only be solved by the decentralization of energy generation to the smallest subset possible. To achieve that, renewable energy must be considered and utilized. This supports the generation of clean energy and would contribute enormously to the “unofficial economy” that is the backbone of the Sub-Saharan economy. However, the reason of failures gathered from the survey, interviews and physical inspection of the projects should be taken seriously as this negatively influences the further dissemination of the technology. In part 2 of this study (The Sustainable Management of Renewable Energy Projects in Sub-Saharan Africa: Failures & Generic Recommendations), we further provide an in-depth analysis of the problem and subsequently provide recommendations that must be considered by implementing government, organizations and locals expected to benefit from renewable energy projects in Sub-Saharan Africa.

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Chapter 5

Failures & Generic Recommendations towards the Sustainable Management of Renewable Energy Projects in Sub-Saharan Africa

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*“If you are building a house and a nail breaks, do
you stop building or do you change the nail?” –*

Rwandan Proverb

1. Introduction

The true development of the Sub-Sahara is principally hinged on the possibility of the provision of clean energy. Within the countries in Sub-Saharan Africa (SSA), energy is the backbone that to some extent supports all existing sectors. Despite this, so many locations remain without connection to the grid while those connected to the grid experience regular power outages that have become arduous to fathom. Renewable Energy (RE) has been tapped to become the future of energy generation in SSA due to its robustness, cleanliness and sustainability. More importantly, the decentralization of energy generation in order to reach communities in areas without a grid connection or infrastructure is the only viable solution to Africa's energy problems (Ikejemba & Schuur, 2016). However, the sustainable management of these publicly funded development projects has not provided the expected results as projects more often than not fail after their commissioning (Omisore B. , 2011).

The sustainable management of RE projects in developing locations such as SSA is one of the important conditions that must be met for projects to attain their sustainability repute. However, few to no studies have been carried out on the sustainable management or the failures of renewable energy development projects in Sub-Saharan Africa. Nevertheless, in Chapter 4, we presented the study analyzing the failures and absence of sustainable management attributed to RE development projects in SSA. Not only do the failures of RE projects affect their sustainability, they further diminish the belief that the people from the region possess in the technology. Several reasons are attributed to the failures of renewable energy projects in SSA.

Deducing from Chapter 4, the main reasons attributed to these failures include: the political agenda of the financing government, the process of awarding RE development projects, the encumbrance of participating stakeholders, inadequate planning prior to the implementation of projects, maintenance and management of implemented projects and finally, the public acceptance and inclusion of the technology. This Chapter aims to further analyze the reasons of failures impacting the sustainability of renewable energy development projects. Furthermore, we aim to provide applicable solutions and recommendations and also to create awareness towards the problems and how to potentially eradicate them.

In this chapter, we provide an in-depth analysis of the overlooked problems hindering the progress and sustainability of renewable energy projects in SSA. The rest of the chapter is outlined as follows. In Section 2 we present related work on the failures of RE development

project. In section 3 we recall and present our research methods and analysis. In Section 4 we present further analysis on the failures of RE development projects. In line with that, Section 5 outlines the subsequent potential solutions. Finally, Section 6 presents conclusions and further recommendations.

2. Related Work

The leading question in this literature review is “*which relevant guidelines towards success in the sustainable management of RE projects in SSA does existing literature provide?*”. We have determined that upon the considerably large amount of research conducted on renewable energy and project management no clear interest has been shown by researchers in studying the factors that affect the *sustainable management* of RE projects in SSA. Concerns have been raised among scholars which point to the gap between project management theory and practice, in response to which some attempts have been made to “rethink” project management (Devine-Wright, 2005). Indeed, having a good understanding of theoretical and practical aspects of project management is absolutely necessary in all projects, including RE projects in SSA, and we aim to do so here.

On the failure of RE projects

Project management has reached advanced stages in both theory and practice, but the risk of failure in projects has always been a cause for concern in professional settings. Earlier research in the field of project management focused more on measuring the failure of projects (Belassi & Tukel, 1996). This has been part of an entire research concentration on identifying critical factors which cause projects to succeed or to fail (Cooke-Davies, 2002). The management of RE projects has proven to involve high complexity due to the myriad of factors underpinning the adoption of renewable energy (Cass & Walker, 2009; Wüstenhagen, Wolsink, & Bürer, 2007; van der Horst, 2007).

RE projects face a lot of unique challenges. Primarily, the adoption of renewable energy technologies (RETs) follows the need to substitute sustainable energy sources for fossil fuel sources in the wake of climate change and global warming. This transformation from fossil sources to RE sources faces systemic challenges which require the intervention of governments, international organizations and corporations. Significant progress has been achieved in efforts to address the systemic changes. This is evident in the intentional formulation of directives and policies for a global transformation towards sustainable development and the investments in research, development and implementation of renewable energy technologies worldwide

(Cooper, 2016; Kern & Rogge, 2016). However, progress in the area of research, development and implementation of renewable energy technologies is not equal among nations. On the one hand, developed countries have advanced in research and development of RE technologies and thereby rely less on technology transfer in the implementation of their RE projects. On the other hand, developing countries rely more on technology transfer to implement their RE projects. This makes it even more demanding to take sustainable management practices more seriously in RE projects in SSA.

Roadmap for Sustainable Management of RE Projects in SSA

Sub-Saharan Africa is one of the parts of the world with a high concentration of developing countries. The proportion of renewable energy produced in these countries is comparatively low. Causal factors include lower investment into research and development of renewable energy technologies, high costs of technology transfer and, more importantly, the failure of renewable energy projects. This last factor – failure of renewable projects – has been at the center of our inquiry and extensively discussed in the previous chapter. Chapter 4 in this two-part series on sustainable management of RE projects focused on evaluating the empirical situation in SSA and identifying some of the faults which steer RE projects towards failure. This second part (Chapter 5) discusses the factors which can contribute to long-term success of RE projects in SSA. We proceed by first recapping the methodology adopted in the empirical research.

3. Methodology

This chapter utilizes the ethnographic approach as explained in Chapter 1 to obtain primary data. It involved the direct observation and analysis of 29 public RE projects in ten SSA countries (see Chapter 4, Table 4.1: Project & Data Information). Ethnography allows for researchers to go into analysis of specific areas, identify contextual factors and examine the cultural and institutional dimensions of a topic. RE projects in SSA are not entirely private affairs, but involve different players such as communities, corporations, research institutions and governments. Ethnography brings the researcher into direct contact with the empirical situation and the actors therein. The main reason for the utilization of this approach was the absence of up-to-date reports about the conditions of the RE projects. Additionally, data on the management of renewable energy projects is scarce and only ethnography offers the opportunity to get into direct contact with the people and institutions involved in the project. The countries include: Nigeria, Ghana, Kenya, Gabon, South Africa, Tanzania, Mozambique, Ethiopia, Malawi and Uganda. To

recall, due to the instability in Uganda at the time of the study, none of the projects studied in the country was directly observed. Hence, Uganda is excluded from Table 4.1.

Although each project we investigated had peculiar challenges, most of the problems with sustainable management were common among all projects, and pointed to the possibility of identifying common solutions. We did engage project managers who indicated the sensitivity of the information they provided and requested that we uphold anonymity of their projects. Their responses mainly corroborated the observations we made and assumptions we formulated based on the literature review we conducted on the failure of renewable energy projects in SSA.

4. Analysis of the Attributed Failures

In this section, we present the findings of this study and the relevant discussions (Section 4.1 – 4.6) associated to understanding why renewable energy projects fail in Sub-Saharan Africa. Foremost, we begin by highlighting in Fig.5.1 the main focus on the failures of these projects and their interconnection with the participating stakeholders that has been presented in the previous sections.

Fig.5.1: Issues and interconnection affecting the Sustainable Management of RE Projects in SSA

In Fig. 5.1, the interconnection between stakeholders (financing government, implementing organization, public) and the issues connected to each of them has been indicated. With the government awarding the project, one issue that affects the overall management of an RE project is the specific political agenda that the government harbors. This affects the process by which the project is awarded to the implementing organization and as such the issues of planning,

implementation and maintenance are not clearly defined and enforced. This results in an unsustainable implemented project that creates a negative mannerism towards the adoption and acceptance of renewable energy projects by the public. In addition, this affects the relationship between the implementing organization and the local communities. The following sections discuss the issues in-depth and subsequently provide solutions to the problems and the interconnections.

4.1. Political Agenda

We cannot rule politics out of public RE projects in SSA countries. Political influence is pervasive in RE projects and usually translates into authority and decision making power embodied in public sector officials. Conflicts of interest are common in RE projects where political interests are not synchronous with project goals. We found political agenda to have both constructive and destructive effects on RE projects. Constructive political agenda prompted attempts to establish efficient management systems, mobilize and allocate resources for successful implementation of projects. For example, some politicians authorized the disbursement of funds allocated to projects in time, managed and mediated conflict resolution. Also, politicians who are mainly the lawmakers and policymakers in SSA, formulate the laws and policies for renewable energy development. Nonetheless, some politicians exploit public RE projects to attain or further their political goals which, in most cases, are divergent and contradict project goals (Bratton, 1989; Ika, 2012). Having divergent political goals negatively affects the sustainable implementation of RE projects in SSA.

A project manager we interviewed expressed that *“to some politicians, RE projects are nothing more than symbols of their efforts to ‘bring development to the doorstep of the people’”*. This expression underscores the symbolic importance of RE projects. Most politicians in SSA bear the perception that RE projects must demonstrate their party’s fulfillment of campaign promises or support their pleas to beneficiaries for re-election. For this reason, the significance of a public RE project transcends its basic functions such as lighting streets, powering homes, hospitals and schools. Because RE projects possess more symbolic importance than functional importance to politicians in SSA, less importance is given to proper implementation. The projects are only as good as they help them to convince voters and win elections.

Majority of project managers agree that politicians are a major distraction to their professional practice. They pointed out the existence of substantial political wrangling and cynicism in most

RE projects. Analogous to the proverb “when two elephants fight, it is the grass that suffers”, different political parties (elephants) with opposing interests, openly (or clandestinely) use public RE projects (grass) to get at their opponents. According to some project managers, it is not always the success of the project which matters to some politicians. Instead, they seek conditions of projects (successful or failed) which corroborate their own competence and/or the incompetence of their opponents. These findings inform us that the combination of political agenda with RE projects may initially suggest a win-win situation which leads to mutual benefits between politicians and the public, but such is not the case because of the difference in strategic outlook between public interests and political interests. Whilst the public is interested in projects that solve their energy and energy-related problems in a long-term manner, politicians are interested in enticing the public to elect them. Thus, the influential but short-term, exploitative and divergent political agenda in public RE projects contributes to their failure. In most SSA countries, public projects are implemented not entirely on rational strategic reasons for the so-called greater public good (Devine-Wright, 2005). Most of the RE projects found in the midst of many political innuendos, fail.

4.2. Process of Awarding Projects

The process of awarding contracts for RE projects links with the influence of politics in public RE projects as discussed above. In some SSA countries, legal procedures have been established to ensure that the awarding of contracts is objective, transparent and free of nepotism or favoritism. For example, Ghana has a functioning Public Procurement Process where legal tenders for government projects are advertised through mass media. The public procurement practices are expected to be anonymous and contracts awarded meritoriously. Despite the existence of a compressive procurement process, corruption still occurs (Osei-Tutu, Badu, & Owusu-Manu, 2010). Several project developers indicated that *“the awarding of contracts is not meritorious or based on competence and ability to carry out the project. Instead, it is based on personal ties”*. This is the case as presented in Chapter 1, Section 1.3.2 and also represented in Fig 1.1: An Outline of Project Disbursement Based on the Analysis of Fraudulent Projects. Instead, it is based on personal ties. There is no consistent maintenance of high professional standards in how contracts are awarded. We found that most contracts are awarded to allies and cronies as rewards for either their allegiance to the ruling party or contribution to political campaigns. These allies are either individuals acting on their own or lobbyists associated with organizations or companies. Thus, the influence of these individuals and institutions on the performance of public RE projects is

even super-ordinate to the influence of the project manager. We further analyzed the process of awarding contracts and outlined the authority structure involved in project disbursement. The first is the government which initiates the project and allocates funding to it. Second is the recipient of the project manager in charge of implementation. Fig. 1.1 presented in Chapter 1 illustrates the flow among parties in the contract awarding process in most of our research areas and explains the general perspective on how projects are disbursed.

The management of projects should be the responsibility of an entity, either the awarding government or the implementing organization. In Nigeria for example, so many small solar projects have been implemented around the country ranging from solar boreholes to thousands of street lights. However, despite the potential of these projects, most of them have been left to deteriorate with no maintenance, no cleaning, no repairs and no sustainable management that encompasses them all. This situation has created a negative attitude towards the acceptance of sustainable and clean energy usage within the minds of the masses making it difficult for developing governments to adopt the technology.

4.3. Stakeholder Co-operation

We identified three major stakeholders in public RE projects in SSA: government, project implementing organizations, and the public. The amount of political wrangling, nepotism, and opacity in the awarding of public contracts affects the level of trust that the stakeholders involved in RE projects share among one another. Research has shown that the management of public sector projects falls short of efficiency which links with inefficient project governance methods (Bawakyillenuo, 2009; Ika, 2012; Muriithi & Crawford, 2003; Ofori, 2006; Patanakul, Kwak, Ofer, & Liu, 2016).

As earlier indicated in the literature review section, stakeholder participation is considered an important part of implementing and governing projects. Hence, Public-Private Partnership (PPP) implementation strategies are often preferred, especially in developed countries (Alvial-Palavicino, Garrido-Echeverría, Jiménez-Estévez, Reyes, & Palma-Behnke, 2011). Our findings show that most public projects in SSA are neither jointly owned nor under the management of properly co-opted PPP management bodies. Rather, ownership is contested among stakeholders in some projects, and outright denied by stakeholders in others. For example, in some projects we ethnographically observed, it was not clear which stakeholder(s) owned and had direct responsibility over the projects. Some project developers attributed this occurrence to the

application of generic implementation models from the top government level which pays little or no attention to peculiarities in the project implementation areas. Furthermore, some project managers stated – *“We see a lot of potential in stakeholder cooperation. At best, cooperation makes everyone responsible and brings all hands on board which can facilitate project performance. However, cooperation exists in principle but not in practice”*. The shadiness in distribution of responsibility among stakeholders makes it difficult to determine whether they consider their engagement a privilege or burden. We learned that success or failure of a project is the simple yardstick for determining the competence or incompetence of project managers. This is problematic because it excludes other stakeholders. Consequently, most stakeholders are insulated from any direct responsibility for failure. This is unlike private RE projects where all stakeholders have much to lose or gain.

4.4. Planning/Implementation

Amongst other reasons for the failure of RE projects in Sub-Saharan Africa is the planning of the project and its implementation. The implementation plan of renewable energy projects constitutes of actions such as, but not limited to: plan for resource utilization (human, infrastructure), plan for location selection, management plan prior, during and after implementation of projects. However, the focus of this Chapter is on the general planning of the projects. It is difficult to measure the actual time the implementing organizations spend on creating an effective plan, but based on the nature of the failed projects and private discussions with project implementers, it is effortless to assume that an ineffective and an inadequate plan was executed (Ikejemba, Mpuan, Schuur, & Van Hillegersberg, 2017). The simplicity of some projects may not appear as it seems, but the complexity of the projects may not appear as it seems, either (Giezen, 2012). This case is accurate for RE infrastructural projects and as such planning is an important element especially in developing countries.

Burke et al. (2001) investigate the success and failures of implementing new systems based on human behavior. They indicate that the success of any implementation project has little to no attribution to technology. Thus, this indicates that the failures of RE projects are more attributed to the inability of the implementing organization and other connected stakeholders. It is important to make sure that approval is received from all participating stakeholders, distinctively defining the roles of all parties involved, knowing how resolutions will be reached in the project and comprehending how expected outcomes will affect the success of the project. It is a representative case of this study as earlier indicated that failure of the projects in terms of

planning in Sub-Saharan Africa is dependent on the political agenda, the process of awarding the projects and the cooperative capability between all participating stakeholders. Whilst the potential definition of project success is based on, for example, patronage, economic spin-off, public acceptance and appreciation, most literature bases large projects' successfulness on time and cost aspects (Shenhar, Dvir, Ofer, & Maltz, 2001). This differs when the focus is on renewable projects in Sub-Saharan Africa because the success of a project is based on its ability to deliver the expected outcome. In this case, energy to homes, street lights, bore holes etc. If this is not achieved, it simultaneously affects the maintenance of the projects (i.e., when an inadequate implementation plan is executed, this contributes automatically to an inadequate maintenance plan) and further deteriorates which causes a negative surge within the public perception of accepting the technology and projects associated with it.

An example can be drawn from the project implemented in Lagos, Nigeria (Omisore B. , 2011) also taken into account in our research. Its failure is attributed to the planning and implementation of the system and follow-up maintenance on the system (encompassing the overall management of the system). Thus, we propose that projects that are being implemented should possess a clear definition of ownership of the project and the entity responsible for the project maintenance (project responsible differs from the owner of the project). Solutions towards the issue analyzed are presented under potential solutions in Section 5.

4.5. Maintenance

One other determined reason for the failures of renewable energy projects in Sub-Saharan Africa is the maintenance of the projects after their implementation. This is a problem that is attributed to the overall planning and implementation of the project. Maintenance of renewable energy infrastructures is twofold. This includes the physical maintenance of the infrastructure and the organization that is responsible for executing this maintenance. This could either be the financing government, the implementing organization or the local beneficiaries. A compelling correlation must exist between the physical maintenance and the organization implementing the maintenance. However, in the projects analyzed in this study neither was a maintenance plan available nor was maintenance carried out on most of the implemented projects, making it effortless for the projects to deteriorate.

Maintaining renewable energy projects entails mainly the inspection, the cleaning and the performance monitoring of the whole system. Of all the projects inspected no monitoring

systems were installed. This includes the recently implemented projects. Thus, stipulating the fact that even the new projects may be doomed to fail in the near future. Nevertheless, this is just one of the reasons under the aspect of maintenance that results in failure of renewable energy projects in Sub-Saharan Africa. *The principal reason for failure under maintenance is the selection of incompetent organizations to implement, manage and maintain renewable energy projects.* Findings from our physical interactions with the local community and implementing organizations indicate that there is no clear distinction as to whose responsibility it is to keep the system under maintenance. This whole situation traces back to the starting point on how organizations are selected and the projects awarded. This suggests that when there is the slightest perception of obscurity in a renewable energy project, it may be hard to succeed.

Most of the project directors interviewed for this study expressed their concerns at the impossibility of realizing a sustainable project within the budget presented to them by the financing government. In most of the cases, the issues surrounding the designation of responsibilities towards maintenance are said to stem from financing government as this is not discussed prior to the implementation of the project. This is actually the instance for 25 of the 26 projects investigated in this study. This actually, is the opposite case in terms of privately implemented projects. There, management and maintenance plans are readily available and important to the success of the project as a breakdown in the system causes the organization to lose profits. However, this is totally different and not the case with respect to publicly funded and implemented projects.

4.6. Public Acceptance and Inclusion

Another important finding from our analysis on the reasons why solar projects fail in Sub-Saharan Africa is the absence of public acceptance and the non-inclusion of the public as stakeholders within the overall project. The public acceptance of renewable energy technologies is convincingly correlated to the inclusion of the corresponding community in implementing renewable energy projects. Practical ideas exist on how local communities should be involved in the implementation of renewable energy projects. However, it is arduous to comprehend why these recommendations have not been taken into consideration prior to the implementation of the projects analyzed in this study and other implemented projects. Only three of the 26 project directors interviewed for this study indicated that the inclusion of the locals was taken care of. However, the way the locals were included was not made convincingly clear. Discussion with the locals in one of the villages where a solar borehole water system was implemented indicated that,

although the villagers were used as laborers towards the implementation of the project, yet after the implementation of the project, no real dialogue was executed between the implementing organization and the local community. As of the documentation of our findings, the implemented project currently has experienced no problems, but one has to envision the future when practical problems arise and maintenance is required on the system. Similar problems discerned from other projects are forecasted to arise in this case.

Public acceptance of renewable energy projects in Sub-Saharan Africa is low compared to other parts of the world. This can be attributed to multiple issues such as: (i) the financing government failing to firmly accept the technology and shortcoming in the aspect of awareness creation towards its adoption and implementation, (ii) the high level of ignorance amongst the people with respect to RE and finally (iii) the failure of the implementing organization to unerringly include the local community through a combination of training and resource provision. If the local community does not accept the technology or is not included as stakeholder in the implemented projects, the sustainability of such projects is at towering risk. When projects experience problems or unplanned downtime, the locals aren't equipped with the necessary skills and thus unable to address the problems. Reporting the problems to the implementing local government is a situation that most locals try to avoid because in most cases nothing is ever done to solve the problem or it takes a long time for the problem to be rectified.

Now that we discussed the key causes for failure, we investigate in the next section how to achieve adequate sustainable management of renewable energy projects in SSA.

5. Proposed Solutions

In line with Section 4, this section presents the subsequent solutions (Section 5.1 – 5.4) to assist in the sustainable management of RE projects in SSA. The proposed solutions are based upon our physical analysis, interviews, limited existing literature and practical experiences in SSA. They are focused on solving the issues raised above in such a way that they can be adopted by project managers, government agencies and private organizations involved in RE projects in SSA. We present and discuss the proposed solutions under these topics: Transparency; Ownership; Shared Responsibility and Community Involvement.

5.1. Transparency

Transparency is a critical aspect of projects in general, and renewable energy projects in particular. Transparency is not merely the absence of opacity, but also the active pursuit of clarity in how public projects are designed and implemented. In our recommendation, the requirements for attaining transparency in public projects are captured in the following points:

- Defragmenting administrative and bureaucratic procedures in public projects
- Implementing checks and balances in stakeholder relationships
- Prioritizing public interests over other interests

Defragmenting administrative and bureaucratic procedures in public projects is important to ensure that projects are planned and implemented sustainably. We identified the bias of current research on RE projects where researchers tend to focus on technical aspects of projects to the neglect of the administrative aspects (Polatidis & Haralambopoulos, 2007). We learned that most RE project managers have a blind side when it comes to the administrative processes that lead to the initiation of the projects they manage. In most SSA countries, project managers are outsiders to how public projects are assigned because they are involved mainly at the implementation stage rather than at the planning stage of projects. In some countries, the process of awarding contracts is fragmented and involves the participation of different government bodies. The involvement of these different bodies is not particularly problematic because it offers the platform for applying checks and balances on one another. However, the overlap of the roles of bodies involved in the awarding of contracts inclines them towards compromising standard procedures. We recommend that relationships be streamlined and clearly delineated to avoid overlap and, thereby, promote transparency. In addition, it is important that checks and control should be conducted on these bodies or organizations participating in promoting transparency in awarding renewable energy projects in Sub-Saharan Africa, so as to avoid any sort of corruption or nepotism. This should however be done in a seamless manner to avoid any unwanted bureaucratic situation, that could potentially lead to loss of time and unwarranted discussions that in turn lead to projects not being implemented or delayed unnecessarily.

Enforcing checks and balances is a crucial mechanism for promoting transparency in most democratic processes. Similarly, checks and balances in public RE projects are necessary to ensure transparency. In most SSA countries, checks and balances are unidirectional, occurring from top to bottom. This allows higher level officials to monitor and control the actions of their

subordinates without the opportunity for subordinates to monitor and control the acts of superiors. Here, we propose that a bi-directional or multi-directional approach be adopted to allow persons from the bottom to be able to hold top-level officials responsible. In this way, the interests of the public stakeholders are highly considered. Moreover, the interests of the locals are guaranteed to be considered since they are participating as stakeholders. The focus should be on the established goals of public projects and, accordingly, *prioritize public interests over private, political or financial interests*.

5.2. Ownership

We deem ownership a critically important component of factors which facilitate project success as several other researchers do (Wüstenhagen, Wolsink, & Bürer, 2007; Urmee, Harries, & Schlapfer, 2009; Brent & Kruger, 2009). However, our findings pointed to lack of clarity to which degree stakeholders have authorized ownership of most RE projects. For example, it is the case that for one particular project, views on its ownership range from shared ownership, to government ownership or public ownership. It is even more common for stakeholders to deny ownership in the event of a malfunctioning project in order to evade responsibility over maintenance. In recognition of this challenge, we make the following recommendation which will contribute to assigning ownership and, in effect, responsibility of public renewable energy projects:

- Disambiguate ownership of public renewable energy projects at the project design stage.

A common trend among the projects in Sub-Saharan African countries we assessed is ambiguity regarding the ownership of public projects. Consequently, we recommend that every public project should actively pursue the disambiguation of ownership of public projects. To this end, the question “who owns this public renewable energy project?” merits a clear answer. If ownership is established from the point a project is conceived, it will translate into a clear idea of designation of responsibilities during implementation and management.

Some researchers and practitioners advocate the importance of community ownership and the role of community engagement (Alvial-Palavicino, Garrido-Echeverría, Jiménez-Estévez, Reyes, & Palma-Behnke, 2011). However, community ownership comes with limitations. In particular, projects locally owned cannot withstand the rigors of in-fighting and in some cases sabotage. This is evident in some of the cases we studied and also cited in some of the reports. As such, we recommend that the body responsible for implementing the project – which in most public

projects is the government itself – should own the project. In the event that ownership is shared, the ownership should be clearly communicated to other stakeholders. For public renewable energy projects in Sub-Saharan African countries, we recommend that the implementing organization (whether public or private, governmental or non-governmental) take ownership of the projects and thereby secure the responsibility over the functioning of the project. Consequently, the participation of other stakeholders will not be mistaken as their real or potential ownership.

However, it is important that – next to the transparency discussed in 5.1 - also transparency in awarding projects is enforced. In that way government bodies can enforce rules that implementing organizations must adhere to and accept responsibility of any drawback that may arise towards the ownership and or failure of the project as the case may be. If transparency is negatively influenced, difficulty would arise in the enforcement of rules towards the sustainable management of the corresponding renewable energy projects. Therefore, clear project ownership functions only if transparency is taken into account.

5.3. Shared Responsibility

In practice, all public projects involve multiple stakeholders (Asiegbu, 2012; Chaurey, Krithika, Palit, Rakesh, & Sovacool, 2012; Alvial-Palavicino, Garrido-Echeverría, Jiménez-Estévez, Reyes, & Palma-Behnke, 2011). Common interests shall unite these stakeholders. We mentioned the need to provide and improve the public services as a common reason for the implementation of most public renewable energy projects in Sub-Saharan Africa. The different stakeholders should therefore share the responsibility of promoting sustainable management of public projects for the public good. Here, we present three key factors to consider in ensuring that this shared responsibility be realized:

- Establish and maintain communication amongst stakeholders
- Collectively ensure that project infrastructure is safe and protected
- Bolster ‘responsible project management’

It is essential that stakeholders share the responsibility for *establishing and maintaining good communication* in public renewable energy projects in Sub-Saharan Africa. This is in response to the observation in the cases of failed projects where communication was either entirely broken down or incoherent amongst stakeholders. In some projects, communication deteriorated with the progression of time whilst in other failed projects, the public beneficiaries were hit with

obstacles in efforts to communicate problems to government representatives. We recommend that channels for communication should be constantly refreshed, which would result in an efficient problem-solving process. Maintaining a good communication line also contributes to hedging administrative and bureaucratic processes of bottlenecks. *Protecting project infrastructure* is a key recommendation in this Chapter. Public renewable energy projects are huge investment projects and it is appalling to learn about vandalism, intentional damage and sabotage of these projects in some Sub-Saharan African countries. This suggests negligence of the public in ensuring the physical safety and protection of renewable energy projects. When the public and other stakeholders do not actively ensure that the infrastructures are protected, all other efforts aimed at ensuring sustainability are pointless. It is imperative that the public should own the responsibility of protecting the infrastructures. A great sense of ownership must be felt by the benefitting recipients.

All of the recommendations discussed so far culminate into “*responsible project management*” (*RPM*). In this scenario, RPM requires that all stakeholders act in the interest of maintaining renewable energy projects instead of destroying them or allowing them to fail. It indicates that the active involvement of all project stakeholders is only but beneficial to sustaining projects. Hence, we propose that stakeholders involved in public renewable energy projects be responsible towards the implemented or planned project and contribute to its management for sustainability. RPM integrates the essentials of sustainable project management and requires that all stakeholders act in the interest of maintaining RE projects instead of destroying them. It is important that the implementing organization accepts responsibility towards the management of shared responsibilities of the corresponding renewable energy project being implemented. In addition, the implementing government should endeavor to create awareness on the acceptance and dissemination of the technology to the local communities.

5.4. Community Involvement

One of the potential solutions to the failures and unsustainable management of renewable energy projects in Sub-Saharan Africa is the involvement of the corresponding local community. Several studies (Terrapon-Pfaff, Dienst, König, & Ortiz, 2014; Rogers, Simmons, Convery, & Weatherall, 2008; Walker, Devine-Wright, Hunter, High, & Evans, 2010; Walker, 2008; Alvial-Palavicino, Garrido-Echeverría, Jiménez-Estévez, Reyes, & Palma-Behnke, 2011) have discussed the importance of involving the local community as stakeholders in renewable energy projects. However, this has both benefits and drawbacks as indicated in a report titled: Microgrids for

Rural Electrification (Schnitzer, et al., 2014). Several case studies were presented that indicated the success of community involvement. Nevertheless, in some cases the sharing of responsibilities resulted in operational inefficiencies and sometimes the community members were uncooperative. However, other projects were sustainable and success soared through the prioritization of planning, training and community-building from the commencement of the project.

Building trust between all stakeholders involved in the project is the most important aspect of involving the local community towards a potentially successful project. A study (Walker, Devine-Wright, Hunter, High, & Evans, 2010) has shown that trust is an important element when one aims to achieve change in the implementation of RE projects. Trust between the implementing organization and local beneficiaries is an element that can assist projects to meet their potential and for the corresponding local community to believe and participate fully as stakeholders in the process of project development. Alvial-Palavicino et al. (2011) present a methodology that involves three different stages that include the building of trust with the local community, co-construction with the locals and finally, ensuring sustainability of the implemented projects via the engagement of the local community into renewable energy projects. The technique presented is expected to be applicable to rural communities in developing countries, where suppositions about technological relations differ from traditional ones in urban communities. However, a limitation in this is the time required to engage all participating stakeholders, an endeavor that may not be applicable for all types of renewable energy projects.

In addition, for community involvement to translate into implemented project success, trust isn't the only issue that must be handled. The implementing organization or financing government must endeavor to educate the local community stakeholders on the technology, its operation and the corresponding primary benefits. This is achieved through a combination of training and resource provision. As such, the local beneficiaries should not only be told what to do, but they should be provided with the tools to do it and gradually build their knowledge and understanding through that process. One other issue as discussed earlier that contributes to the failure of projects is the absence of maintenance, sabotage and the vandalism of infrastructures. If community involvement is unerringly executed and the recommendations provided are taken into account, the local community knowing the benefits of the project will be able to execute routine maintenance on breakdowns and participate in the protection of the implemented

infrastructures in their community. This will in turn create multiple direct and indirect jobs through the enhancement of local economic activities.

6. Conclusions & Recommendations

The future of electrification of Africa's more than 600 million individuals without access to electricity is decentralized generation via renewable energy. Many of the households without access reside in rural areas. Moreover, the urban areas with access to electricity have problems of power outage where under-capacity power is generated with substantial loss during transmission (Ikejemba & Schuur, 2016). Although many small and large RE projects have started across the Sub-Sahara, little evidence may exist for their proper realization. This study engages directly (ethnographically) with the local communities benefitting or expected to benefit from the projects, the implementing organizations and government. This was done to clearly and collectively understand the failures and mismanagement that may exist in 29 implemented projects across ten Sub-Saharan African countries and to develop a sustainable management method that encompasses the entire process from awarding the project to its commission, continuous maintenance and management.

Findings of our study, based on our engagement with the participating stakeholders (local beneficiaries, implementing organizations and the financing government) and physical examination of the projects, indicate multiple reasons for the failure of implemented renewable energy development projects across these countries. Despite the differences in culture and understanding, the reasons for failure of the projects were similar across the different countries: (i) political agenda, (ii) process of awarding projects, (iii) stakeholder co-operation, (iv) planning & implementation, (v) maintenance and (vi) public acceptance & inclusion. Combining our findings with literature and practical experience with the implementation of RE projects in Sub-Saharan Africa, we propose the following solutions: (i) transparency, (ii) ownership, (iii) shared responsibility and (iv) community involvement (see Fig. 5.2: Study Overview). Our analysis shows that the failure of a project originates from how it is awarded, which creates a snowball effect that becomes difficult to deal with when the project derails. For example, a project that is awarded from the government to an organization based on personal relationship creates a difficult situation when the project fails. Based on this relationship, it is difficult for the government to speak out or enforce rules. As such, rule enforcement only works when transparency is the order of the day. For implemented RE projects to meet their goal, it is important that the solution provided in this study be considered by all involving stakeholders in

the corresponding project. In addition to the solutions presented in Section 5.1 to 5.4, we present the following recommendations:

- The implementing government must ensure that the process of awarding projects is transparent and projects are awarded to only competent organizations. More importantly, the organizations selected to implement projects must have a strong network and relationship to the corresponding community. In cases where this is not possible a strategic stakeholder relationship must be actualized.
- Subsequently, there must be a clear distinction with respect to the ownership of the project and the responsibility of maintenance and management. Otherwise, this will lead to the failure and deterioration of any implemented project. This is the case in some of the projects investigated in this study.
- Implementing organizations must provide adequate planning and implementation strategies that include the corresponding local communities participating in task and shared responsibilities. This has proven to be a successful strategy in several implemented renewable energy projects.
- Local community stakeholders should be educated on the technology, its operation and benefits. Our recommendation is that sustainable development is achieved through a combination of training and resource provision. Thus, implementing organizations should not only tell beneficiaries what to do or what is good, but actually provide them with the tools to do it, start doing it with them, and gradually build their knowledge and understanding through that process.
- Stakeholders involved in the project should create a documentation listing out the minimum expected benefits within the local context for the implemented renewable energy projects. This could be used as a guideline for all future projects. In this way, it is easier to hold a specific stakeholder accountable for any drawbacks.
- Experienced independent monitoring and auditing should be carried out on the implemented projects and all documentation related to the project should be available publicly. In this way, a knowledge database of best practices and statistics for reference as an outcome of the project will be created. Thus, potentially leading to other successful projects.

The failed projects found during the course of this study are below their expected goals based on the responses and physical examination of the projects. After identifying the causes for their

failure, this Chapter has been able to provide a sustainable management method to mend shortcomings of renewable energy projects in Sub-Saharan Africa. More importantly, we have presented applicable recommendations that should be taken into account by stakeholders towards implementation of any sustainable renewable energy project.

Figure 5.2: Study Overview based on both Chapter 4 and Chapter 5

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Chapter 6

Analyzing the Impact of Theft and Vandalism in Relation to the Sustainability of Renewable Energy Development Projects in Sub-Saharan Africa: A Mathematical Analysis Approach

“Every morning in Africa, a gazelle wakes up, it knows it must outrun the fastest lion or it will be killed. Every morning in Africa, a lion wakes up. It knows it must run faster than the slowest gazelle, or it will starve. It doesn't matter whether you're the lion or a gazelle - when the sun comes up, you'd better be running.” – African Proverb

1. Introduction

Across Sub-Saharan Africa (SSA), the dissemination of renewable energy technologies (RETs) is currently soaring. The sustainability of the publicly implemented projects is being questioned as vast numbers of these projects are deserted after their commissioning (Ikejemba, Mpuan, Schuur, & Van Hillegersberg, 2017). Factors that affect the sustainability of these projects range from the utilization of inexperienced personnel during and after the implementation, the unsustainable management of the project after implementation, inappropriate location selection, absence of protection of the infrastructure from theft and vandalism, unsuitable technological utilization etc. However, in this study, our focus is on the protection of RE infrastructure and the impact of theft and vandalism on the sustainability of the implemented projects. Furthermore, our research is focused on developing a mathematical model based on stochasticity to model the offenders' career path and to identify beneficial levels of interference measures based on the type of projects. In this study, the level of interference is described as the level and type of security an offender may encounter based on project type and location when attempting to vandalize or purloin RE related infrastructures. The level of interference is expected to deter offenders, increase difficulty and prolong the time spent on attempting to vandalize or loot RE related infrastructures. It is paramount to ascertain the instigators that lead to the theft and vandalism of these projects and incorporate those into the model. In this way interferences can be designed to effectively counter the operations of the offenders taking into account the project type and locations.

This study aims to analyze the impact of theft and vandalism in relation to the sustainability of renewable energy development projects in Sub-Saharan Africa. In addition, we attempt to further determine the actions and interferences that could hinder the sustainability of these projects being thrown into disarray, whilst taking into account the principal instigators, project types and already existing levels of interference. Given that no data exists in line with our study, we utilize a clinic approach in generating the data required to validate our model. A Markov theory approach is utilized which contains (i) three different instigators (government inequality, crime to survive and sabotage), (ii) five different states (theft of RE infrastructures from small projects, vandalism of small projects, theft of RE infrastructures from large projects, vandalism of large projects, and a rest state), and (iii) K stages (i.e., the progressive career of the offender[s]). This research determines optimal interferences that should be utilized per project type and location and in turn

further prolongs the lifeline of the projects thus attaining their sustainability statute. This study is further motivated by the state of the current energy infrastructure that has also been marred by ill-management, theft and vandalism. Since the aspect of sustainable development is an important characteristic of RE development projects, our aim is to analyze the impact that disturbance could have on these projects when not considered prior to implementation.

Contributions of this study are the following:

- A mathematical model of the career of any offender ruining the sustainability of renewable energy development projects.
- An analysis of the impact of theft and vandalism to RE development projects taking into account realistically defined instigators.
- A measurement approach to calibrate the career model of an offender(s), despite the absence of pre-existing data, via a clinical data generation technique.
- The provision of interference levels based on project type and location to prolong the sustainability of the project.
- The introduction of the concept of attraction in order to determine the effectiveness of a specific level of interference.

The remainder of the paper is structured as follows. In Section 2 we present related work that has been carried out within the scope of our study. In Section 3 we describe our model formulation and we further present an in-depth analysis. Section 4 presents our model experiment, analysis and the corresponding discussions. In Section 5 we present our conclusions and recommendations for the future. Finally, in Section 6 we provide the possibilities for future research.

2. Related Work

The planning and implementation of theft and vandalism prevention techniques to RE development projects in Sub-Saharan is a topic that has been circumvented. Nonetheless, it is an important characteristic that must be considered for these projects to be sustainable. To the best of our knowledge, there currently exists no literature that focuses on the aspects of disturbances such as theft and vandalism to RE development projects in SSA. However, numerous papers and

mathematical models have been published with respect to disturbances such as theft and vandalism in general. In addition, there are multiple reports (O'Donnell, 2010) on the protection of RE projects from theft and vandalism as the issue plagues not just the developing countries in SSA but is also felt in the developed countries (Enkhardt & Zaripova, 2016). The issue of theft and vandalism has also resulted in the slow phasing out of PV projects in some countries in Southern Africa (Utonih, 2001).

One important method as discussed by Stander et al. (1989), is the utilization of Markov theory in discrete-time to analyze the specialization of offenders. Markov theory has long been utilized to model and predict criminal behavior, whereby it also elucidates the occurrences of events through time (Bijleveld & Mooijaart, 2003). Modeling the criminal career and characteristics of an offender has always been a major challenge for criminologists (Zhang, et al., 2016). Bartolucci, Pennoni & Francis (2007) utilized a multivariate latent Markov model to analyze the drawback associated with ascertaining behavioral patterns of offenders from historically available data, whilst focusing on the categorization and classification of crimes committed by offenders.

Most criminal studies are based on the availability of historical data. However, since the availability of data in our study is infeasible we chose for the generation of our own data via the implementation of a clinical study. This is crucial in our study as it also presents the basis for the development of the transition probabilities. In doing so, we adapted the classical approach by Hauser et al. (1990) that uses a consumer clinic to obtain data to calibrate the sales trajectory of a new car. Where these authors use advertising to increase sales, we use interference to reduce offences.

3. Model Formulation

The main focus and interest of this paper is to analyze the level of impact that theft and vandalism could potentially possess on the sustainability of renewable energy development projects in Sub-Saharan Africa (SSA) and more importantly to provide solutions and recommendations to be utilized by government bodies and organizations towards future attacks (vandalism and theft) on publicly and or privately funded renewable energy (RE) projects in Sub-Saharan Africa. Given the past history in most SSA countries with respect to the inequitable distribution of wealth, these circumstances have more often than not led to the vandalism of public infrastructures (Olamosu & Wynne, 2015) and in some cases theft, which is a product of

rioting and protest against the ruling government. In South Africa for example, over 380 million Rands (approx. 24 million Euros) is spent per year on security guards to curtail the issue of theft and vandalism (Sibanda, 2015). However, the problem of theft and vandalism still persists. In Nigeria where oil is the main source of revenue, the vandalization of pipelines and theft of crude oil costs the country billions in revenue per year and in turn drastically affects the generation of electricity (Igbinoia, 2014; Udofia & Joel, 2012; Adebayo, 2015).

The model formulation presented in this research amalgamates multiple quintessential factors. Government inequality (GI), crime to survive (SU) and sabotage (SA) are the most influential instigators that lead to the vandalism and theft of renewable energy related infrastructures. These instigators have been carefully selected as they are representative of reality to the situation of theft and vandalism of public infrastructures in Sub-Saharan Africa. The basis of this selection has been on interviews with project developers, financiers and project beneficiaries as also described in Ikejemba et al (2017). In our model, we further demarcate the aspect of theft and vandalism to both small and large implemented RE development projects. We briefly explain each of the three instigators considered in this study below and further explain in the section of our generic model conception about the delineation of our model.

Government Inequality: With the unfair distribution of national wealth and resources happening often in SSA, this usually leads to unrest around most nations. As such, people tend to express their frustration by vandalizing infrastructures and engaging in illicit activities that could provide them with the resources to survive on a day to day basis. In this scenario, we refer to the theft and reselling of solar panels and other RE related infrastructures. However, this is not to say that government inequality totally stimulates the vandalism and/or theft of public infrastructures, or in this case renewable energy development projects. Nonetheless, the ineffectiveness and failures of the government to effectively create jobs, social security and other basic necessities arouses the anger within the people and as such leads to the vandalization of implemented public projects of which RE development projects are not spared.

Crime to Survive or Survival: The issue of committing a crime to survive has always been debated in several African countries, most notably, South Africa (Gqirana, 2015). Several cases have been reported about the theft and vandalism of RE related infrastructures in countries like Nigeria, Kenya, Ghana, South Africa and Gabon, (Lamiley, 2013; Masinga, 2015; AllAfrica, 2013) where solar panels have been taken off project sites. One very surprising incident was reported in

Botswana where a telecommunication corporation utilizes RE to provide access to telecommunication networks for people in rural areas. Nevertheless, for every three panels implemented or replaced two of the panels were reportedly stolen (Moeng, 2011). This unfortunately leaves most of the villages without access to telecommunication network and more importantly diminishes their belief in RE. Nevertheless it is believed that these circumstances are a product of government inequality.

Sabotage: Ikejemba et al. (2017) indicated that the failure of RE projects is caused by various issues. One of them is sabotage, where projects that are locally implemented cannot withstand the rigors of in-fighting amongst locals. In this instance, RE projects implemented in a specific community are attacked by individuals from a neighboring community out of “jealousy”. The result of sabotaging these RE projects is the larceny of the related infrastructure implemented in a specific community. Just as with respect to crime to survive, sabotage is not necessarily influenced by government inequality. However, the likelihood of projects being sabotaged cannot be ruled out to being influenced by government inequality. This theory is based on the assumption that if every community possesses the basic energy needs that should be provided by the ruling government, the need for sabotaging implemented projects in other communities would reduce or cease to exist.

Government inequality, sabotage and the committing of crime to survive with respect to both public and private RE development projects are not necessarily the only instigators that exist but are predominantly the main causes of theft and vandalism. Another contributing factor to the problem is the aspect of non-inclusion, which is the situation whereby RE projects are implemented without the involvement of the local communities. One of the consequences of non-inclusion as described by Ikejemba et al. (2017) is the unsustainable management of the projects which also in turn could lead to desertion and ultimately, theft of the RE related infrastructures. The instigators presented above are the predominant instigators that lead to the vandalism and theft of RE related infrastructures in SSA. However, it is important to note that vandalism is usually considered the secondary option to theft or a crime of resentment. The factors presented above were considered so as to be able to model the nature of the situation in SSA. In the next section we present our generic model conception and provide further analysis on the vandalism and theft of RE related infrastructure in SSA.

3.1. Generic Model Conception

Several studies have been carried out using Markov theory to analyze criminal offences and prevention. However, none of the studies have been published in the aspect of modeling the impact of offenders in SSA that vandalize and purloin RE related infrastructures thereby negatively influencing the sustainability of these development projects. In a study by Stander et al. (1989), it is indicated that the probability of offenders switching from one crime to another being constant over time is questionable: the past does influence the future, thereby violating one of the supposition of a Markov theory. In addition, little to no study takes into account the aspect of interferences in transiting from a prior stage to another.

In this study, we intend to model the career of an RE criminal. We employ Markov theory, but we add memory to it in the following way. We mimic the career of a criminal by introducing the concept of stages. These are natural steps in the criminal career. Instead of using only states like ‘an offender vandalizes an RE project’ we add maturity to it by discriminating between stages. So our state definition may e.g. be ‘an offender vandalizes a RE project in the third stage of his career’. Transition probabilities will be reflecting criminal maturity.

We distinguish five basic types of offence:

- SP_v – (shorthand ($i=1$)) (attempt to) vandalize a small RE project.
- SP_t – (shorthand ($i=2$)) (attempt to) steal from a small RE project
- LP_v – (shorthand ($i=3$)) (attempt to) vandalize a large RE project.
- LP_t – (shorthand ($i=4$)) (attempt to) steal from a large RE project.
- **Rest** - (shorthand ($i=5$)) no attempt to vandalize or steal from any RE project.

The *level of interference* is the level and type of security an offender may encounter when attempting to vandalize or purloin RE related infrastructures. It is important to note that the probability of impeding theft and vandalism to a specific project is influenced by the level of interference encountered at the specific project. In this study we consider three types of interferences:

- **Human Security** – refers to the usage and application of individuals or groups (human beings) to protect against theft and vandalism of RE development projects. Familiar situations include the outsourcing to security organizations.
- **Societal Security** – refers to the utilization of the local communities as interference towards protecting against the theft and vandalization of RE development projects implemented towards the development of the corresponding communities.
- **Technical Security** – refers to the application of technological infrastructures such as, cameras, sensors, GPS trackers etc. to protect locations of implemented RE development projects from being breach and the related infrastructures from theft and vandalism.

The way an offender reacts to a specific interference is depending on the stage of his career. A first offender may be expected to react stronger, than a recidivist. Below it is shown how we model the influence of interference in the transition probabilities associated with the various stages.

3.2. Model Development

In this section we present our Markov model including the assumptions utilized in the development of the model. We further illustrate with an example on the operation of our model.

3.2.1. Model Assumptions

- Between offences committed from the third attempt on (in stage 3, $k=3$) up until the final stage ($k=K$), very little substantial difference exists. (i.e., we assume that an offender isn't likely to change his decision over that period of time).
- Majority of offenders are likely to become offenders instigated by the inequality of the government via failure to create jobs and provide basic necessities to survive. Nonetheless, we present this as a hypothesis of which we test in the data generation section.

Further assumptions utilized in the model & data generation are presented in Section 4.

3.2.2. Introductory remarks and notation

Throughout, we use the following notation:

Indices

i : (type of) offence ($i = 1, 2, \dots, 5$), defined above

k : stage of criminal career ($k = 1, 2, \dots, K$)

States

(i, k) : with i type of offence and k stage of criminal career

Parameters

Δ_i : level of interference performed for type of offence $i = 1, 2, \dots, 4$

$q_{(i,k)(j,k+1)}$: offence transition probabilities with no interference

$p_{(i,k)(j,k+1)}$: offence transition probabilities in case of interference

The corresponding transition matrices are denoted by $\mathbf{Q}^k$ and $\mathbf{P}^k$, respectively.

We write

$$p_{(i,k)(j,k+1)} = q_{(i,k)(j,k+1)} A_{ij}^k(\Delta_i) \quad \text{for } i, j = 1, 2, \dots, 4, k = 1, 2, \dots, (K-1)$$

where

$A_{ij}^k(\Delta_i)$ denotes the attraction of committing offence j in stage $k+1$ after committing offence i in stage k given that offence i has a level of interference Δ_i

All parameters are non-negative.

It seems plausible to expect that the attraction $A_{ij}^k(\Delta_i)$ is non-increasing with increasing level of interference Δ_i . In Section 4.2.3 we test this hypothesis.

3.2.3. Initialization Stage

Fig.6.1: Model Illustration of the Initialization Stage and Stage I

As shown in Fig. 6.1, the initialization stage consists of the initial rest $[I]$ with specific probabilities transitioning to any of the three instigators (Government Inequality $[GI]$, Crime to Survive $[SU]$, Sabotage $[SA]$). Given that the weighted impact of government inequality on the issues of vandalism and public disturbance is the highest of all instigators, we expect that the transition probability $p_{I_{GI}}$ from initial rest (I) to government inequality (GI) will be greater than the transition probability $p_{I_{SU}}$ from initial rest (I) to crime to survive (SU) and also greater than the transition probability $p_{I_{SA}}$ from initial rest (I) to sabotage (SA). Summarizing: $p_{I_{GI}} > p_{I_{SU}}$; $p_{I_{GI}} > p_{I_{SA}}$

In the first stage, we distinguish four states, $i=1,2,3,4$. State 5 is excluded, since our aim is to model the career of a criminal which is not supposed to start off as a rest state. In the other stages, as shown in Fig. 6.2, the rest state is present. Note that as of state 1 all transitions are between states in subsequent stages.

Fig. 6.2: The Complete K-Stage Model

3.3. Illustrating the model

Let us exemplify our model. Consider the following simple problem instance. Let $\mathbf{Q}^k$, the matrix of offence transition probabilities with no interference, be stage independent and given by:

$$\mathbf{Q}^k = \begin{Bmatrix} 0.5 & 0.2 & 0.1 & 0.05 & 0.15 \\ 0.15 & 0.5 & 0.2 & 0.1 & 0.05 \\ 0.11 & 0.2 & 0.4 & 0.1 & 0.19 \\ 0.09 & 0.1 & 0.2 & 0.45 & 0.16 \\ 0.1 & 0.05 & 0.1 & 0.05 & 0.7 \end{Bmatrix}$$

Let the probabilities in stage 1 be given by the row vector $\mathbf{p}_1 = \{0.3 \ 0.2 \ 0.3 \ 0.2 \ 0\}$

It is interesting to see how these initial probabilities propagate under the influence of interference. For convenience, let us focus on stage 4. In that stage the probabilities are given by the row vector

$$\mathbf{p}_4 = \mathbf{p}_1 \mathbf{P}^1 \mathbf{P}^2 \mathbf{P}^3$$

with $\mathbf{P}^k$ given above. Let the attraction $A_{ij}^k(\Delta_i)$ be given by

$$A_{ij}^k(\Delta_i) = 1 - \alpha_i^k \Delta_i.$$

Let the coefficients α_i^k for the first three stages be given by:

$\alpha_1^1 = 0.01$	$\alpha_1^2 = 0.008$	$\alpha_1^3 = 0.006$
$\alpha_2^1 = 0.005$	$\alpha_2^2 = 0.003$	$\alpha_2^3 = 0.002$
$\alpha_3^1 = 0.015$	$\alpha_3^2 = 0.009$	$\alpha_3^3 = 0.007$
$\alpha_4^1 = 0.007$	$\alpha_4^2 = 0.004$	$\alpha_4^3 = 0.003$

Let us now explore the influence of interference. Specifically, we examine two cases: (i) mild (so-called min) interference and (ii) severe (so-called max) interference.

(i) (*min interference*) Let the level of interference Δ_i , $i=1,2,3,4$ be given by:

$$\Delta_1 = 7$$

This yields in stage 4:

$$\Delta_2 = 80$$

$$\mathbf{p}_4 = \{0.176548 \quad 0.146429 \quad 0.163464 \quad 0.07444 \quad 0.439118\}$$

$$\Delta_3 = 9$$

$$\Delta_4 = 85$$

(ii) (*max interference*) Let the level of interference Δ_i , $i=1,2,3,4$ be given by:

$$\Delta_1 = 3$$

This yields in stage 4:

$$\Delta_2 = 20$$

$$\mathbf{p}_4 = \{0.187021 \quad 0.198965 \quad 0.18331 \quad 0.106939 \quad 0.323765\}$$

$$\Delta_3 = 5$$

$$\Delta_4 = 25$$

The effect of severe interference is noticeable. In particular, some 44% of the offenders are now at rest, as opposed to 32% under min interference.

4. Model Experimentation

In this section, we present our data analysis and generation. We further calibrate our model and provide an in-depth discussion about the analysis and findings from our experiments.

4.1. Data Generation & Analysis

As earlier indicated, with respect to the fact that no historical data is available, we engaged in the implementation of a clinical data generation. This approach provides data that pragmatically represents the situation in Sub-Saharan Africa and is thus expected to provide solutions in the same regards. Furthermore, it is used to calibrate our model to analyze the impact of disturbance such as theft and vandalism to renewable energy development projects within the region. Our clinic involved the questioning of individuals across SSA. This was executed individually with each participant in an uncontrolled environment so as to avoid the contamination of our data generation. To make sure that our data is representative, we selected participants randomly on

the basis of their socio-economic situation. We selected 144 respondents. Once selected, participants were physically interviewed at a designated location for an interview for approximately thirty minutes to an hour. The participants were paid €40 for their participation. The dialogue was implemented in two phases. In the first phase we questioned the individuals in a structured manner without the implementation of interference. In phase 2 we introduced the aspect of interference.

Commencing phase 1, the participants are asked, from three different selections of instigators (Government Inequality (GI), Crime to Survive (SU) and Sabotage (SA)), which is most likely to instigate them into committing an offence of either vandalizing or purloining an RE infrastructure from a project location. Based on the response provided, subsequent questions are asked on what sort of offence they are likely to commit based on four given choices: (1) vandalization of small RE projects (SPv), (2) theft of RE infrastructures from small RE projects (SPt), (3) vandalization of large RE projects (LPv) and (4) theft of RE infrastructures from large RE projects (LPt). An illustration of the process can be seen in Fig. 1. Subsequently, they are asked what offence they are likely to commit next, provided that the opportunity presented itself again, although in this scenario a rest (R) choice is added to the previously outlined four choices. This is repeated for a third and fourth scenario. The participants are subjectively allowed to switch between offences whilst moving from one stage to another. However, in the fourth scenario, also known as the stage K scenario, they are informed that in this scenario the offence committed is indicated as a continuum of offence. The illustration can be seen in Fig. 2.

In phase 2 of the dialogue, although similar to the first phase, we introduce the aspect of interference. The commencement of the dialogue is similar to that of the first phase with the selection of an instigator. Without specifying any interference, we ask the participants which of the four offences they would choose as their first offence if they would suspect some kind of interference. Thereafter, the three types of interference are introduced to the participants. To recall, as indicated in Section 3.1, the interference types are Human Security (HS), Societal Security (SS) and Technical Security (TS). The participants subjectively rank these interferences on scale of least to maximum difficulty. These rankings allow us to clearly estimate the difficulty of each of the interferences. Based on the ranking of the interferences, the individuals are asked to select their next potential offence. However, in this case they choose from the options SPv, SPt, LPv, LPt or R (Rest). This selection procedure is repeated over the rest of the stages and as earlier stated, the last stage is presented as a stage of continuum.

Utilizing the data we generated in the above way, we are able to successfully extract the transition probabilities required to extensively carry out the analysis. Throughout the clinic, we aim to generate data that is as pragmatic and representative as possible. Several comments were made by participants about the choices they made, such as why they were made and how the chosen offences could be different in certain scenarios connected to the original instigator. We sketch some of them in Section 4.2.

4.2. Discussion on Data Generation

Our clinical approach for data generation stems from the fact that no data concerning the study focus was available in any of the countries across Sub-Saharan Africa. Nonetheless, during the dialogue session with participants, approximately 21% indicated that they have previously engaged in the act of either theft or vandalism to RE development projects. From these 21%, 53% were instigated by the choice of survival (i.e., theft and resell of RE infrastructure). Some of the participants told us about the profitability of such activities. In their experience, currently, only very few individuals have any idea of the advantages of such projects. As long as the locals are not involved as stakeholders in the projects, it is an easier avenue for them to purloin RE infrastructure, as several of the participants indicated.

In Section 4.3.1 we show that 56% of the participants were instigated by inequality from the government, whilst 36% and 8% were instigated by the will to survive and by sabotage, respectively. Generally, most of the participants instigated by government inequality and survival indicated that their first choice of action would be to engage in theft rather than vandalize a project since most projects around the region are small scale projects. However, most also indicated that vandalism would be a secondary option if theft isn't possible. Most of the participants instigated by GI stipulated that they were tired of the current economic and political situation, stating that if jobs were present their participation in theft or vandalism of RE projects would be minimal. Furthermore, the fact that in most projects implemented around the region, the locals aren't even considered as stakeholders makes these projects easy targets. Although few participants selected sabotage as an instigator, almost all were focused on the vandalization of either small or large projects. Some indicated that they were worn out from the fact that some of the politicians implement these projects in their own districts while proxy communities are left without options and as such the act of jealousy prevails and leads to the vandalization of projects. Ikejemba et al. (2017) also discuss the aspect of jealousy and sabotage in their study on the

failures of RE development projects in SSA, which is a reflection of the reality portrayed by the participants in this study. Participants of the survival instigator were clear on the fact that their aim is to purloin RE related infrastructure for the purpose of reselling. Some indicated that they were willing to quit committing the offence if the socio-economic situation around the regions changes positively.

In the second phase of the data generation clinic, we asked the participants to rank the security interferences from least to maximum in terms of difficulty. Based on aggregation the societal security (SS) was ranked as the most difficult security with human security (HS) coming in next and then technical security (TS). However, this is based on aggregation - as most individuals are most scared of societal security - and also dependent on the kind of projects. Nevertheless, the aspect of “jungle justice¹” is the reason most of the participants indicated societal security as the most daunting. In cases where we questioned the participants about their choice of action without indicating the type of security present, most were likely to select the same as when interference doesn’t exist. However, on indicating that societal security was the implemented interference in terms of protecting the project, 100% of the participants indicated that they would either go to rest and visit other project locations or just exit the system totally. In comparison to other sort of interferences, some indicated to go to rest and return whilst others indicated they would change their action from theft to vandalism and from small to large projects as the case may be. Participants instigated by survival indicated that although societal security is more often the hardest to bypass, technical security is the most important because vandalization of the infrastructures isn’t profitable to them. Nonetheless, the aspect of societal security is only possible if the local communities are involved as stakeholders and presented with an incentive on the basis of the projects.

4.3. Calibration of our Markov Model

In this section we use the data generated to calibrate our model. Section 4.3.1 gives transition and state probabilities under no to min interference. Next, we discuss in Section 4.3.2 how a mild form of interference influences the behavior of an offender. Finally, we focus on Medium and Max Interference in Section 4.3.3. We derive the associated probabilities and discuss their properties.

¹ “Jungle justice is the concept and act of disregarding the rule of law and taking matters into one's hands; more clearly put, it is the act of handing suspected criminals over to the hands and mercy of an angry mob” (Onuh, 2016).

4.3.1. Transition and State Probabilities for No to Min Interference

Based on the data analyzed and compiled above, we extract in this section the transition probabilities for all relevant stages for the following two cases: (i) no interference and (ii) min interference, i.e., with the least security interference (see Table 6.1 and 6.2).

Table 6.1: Transition Probabilities without Interference

$$Q^{Init} = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t \\ GI & 0.23 & 0.35 & 0.13 & 0.3 \\ SU & 0 & 0.85 & 0 & 0.15 \\ SA & 0.83 & 0.17 & 0 & 0 \end{Bmatrix} \quad Q^1 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.57 & 0.29 & 0 & 0 & 0.14 \\ SP_t & 0.08 & 0.53 & 0.05 & 0.09 & 0.24 \\ LP_v & 0 & 0 & 0.5 & 0.4 & 0.1 \\ LP_t & 0.13 & 0.09 & 0.22 & 0.44 & 0.13 \end{Bmatrix}$$

$$Q^2 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.3 & 0.22 & 0.15 & 0.28 & 0.06 \\ SP_t & 0.26 & 0.19 & 0.08 & 0.39 & 0.08 \\ LP_v & 0 & 0.13 & 0.27 & 0.53 & 0.07 \\ LP_t & 0.02 & 0.08 & 0.33 & 0.5 & 0.08 \\ R & 0.2 & 0.21 & 0.09 & 0.32 & 0.18 \end{Bmatrix} \quad Q^3 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.07 & 0.01 & 0.13 & 0.04 & 0.75 \\ SP_t & 0.07 & 0.04 & 0.09 & 0.04 & 0.76 \\ LP_v & 0.04 & 0.02 & 0.18 & 0.14 & 0.62 \\ LP_t & 0.03 & 0.02 & 0.13 & 0.1 & 0.72 \\ R & 0.07 & 0.07 & 0 & 0.07 & 0.79 \end{Bmatrix}$$

Table 6.2: Transition Probabilities with Least Security Interference

$$P^{Init} = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t \\ GI & 0.18 & 0.45 & 0.08 & 0.3 \\ SU & 0.12 & 0.73 & 0.04 & 0.12 \\ SA & 0.67 & 0.17 & 0.17 & 0 \end{Bmatrix} \quad P^1 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.39 & 0.36 & 0.07 & 0.11 & 0.07 \\ SP_t & 0.24 & 0.41 & 0.04 & 0.14 & 0.17 \\ LP_v & 0.2 & 0.1 & 0.2 & 0.4 & 0.1 \\ LP_t & 0.03 & 0.17 & 0.2 & 0.43 & 0.17 \end{Bmatrix}$$

$$P^2 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.20 & 0.13 & 0.17 & 0.38 & 0.14 \\ SP_t & 0.27 & 0.18 & 0.1 & 0.33 & 0.13 \\ LP_v & 0.04 & 0.07 & 0.36 & 0.32 & 0.21 \\ LP_t & 0.03 & 0.07 & 0.37 & 0.38 & 0.15 \\ R & 0.26 & 0.21 & 0.12 & 0.31 & 0.1 \end{Bmatrix} \quad P^3 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.02 & 0 & 0.04 & 0.06 & 0.88 \\ SP_t & 0.02 & 0 & 0.07 & 0 & 0.9 \\ LP_v & 0 & 0.02 & 0.07 & 0.02 & 0.9 \\ LP_t & 0.01 & 0 & 0.06 & 0.03 & 0.9 \\ R & 0.03 & 0.03 & 0.03 & 0.03 & 0.9 \end{Bmatrix}$$

For the initialization stage - depicted in Fig. 1 - we find from our data analysis the following values for the probabilities transitioning from initial rest $[I]$ to any of the three instigators (Government Inequality $[GI]$, Crime to Survive $[SU]$, Sabotage $[SA]$):

$$\mathbf{p}^{Init} = (p_{I_{GI}}, p_{I_{SU}}, p_{I_{SA}}) = \{0.5556 \quad 0.3611 \quad 0.0833\}$$

Note that $p_{I_{GI}} > p_{I_{SU}}$ and $p_{I_{GI}} > p_{I_{SA}}$. Hence our expectation from Section 3.2.3 comes true. A vast majority of the offenders is driven by government inequality.

Let the state probabilities in stage k be given by the row vector $\mathbf{q}_k$ in case of no interference and by $\mathbf{p}_k$ in case of least security interference. From the above we find the state probabilities for the first four stages (see Table 6.3).

Table 6.3: State Probabilities for No Interference and for Least Security Interference

No Interference					Least Security Interference				
SP_v	SP_t	LP_v	LP_t	R	SP_v	SP_t	LP_v	LP_t	R
$\mathbf{q}_1 = \mathbf{p}^{Init} \mathbf{Q}^{Init} =$ $\{0.1944 \quad 0.5138 \quad 0.0694 \quad 0.2223\}$					$\mathbf{p}_1 = \mathbf{p}^{Init} \mathbf{P}^{Init} =$ $\{0.1945 \quad 0.5278 \quad 0.0695 \quad 0.2083\}$				
$\mathbf{q}_2 = \mathbf{q}_1 \mathbf{Q}^1 =$ $\{0.1804 \quad 0.3473 \quad 0.1111 \quad 0.1736 \quad 0.1874\}$					$\mathbf{p}_2 = \mathbf{p}_1 \mathbf{P}^1 =$ $\{0.2222 \quad 0.3264 \quad 0.0903 \quad 0.2153 \quad 0.1459\}$				
$\mathbf{q}_3 = \mathbf{q}_2 \mathbf{Q}^2 =$ $\{0.1840 \quad 0.1735 \quad 0.1588 \quad 0.3903 \quad 0.0932\}$					$\mathbf{p}_3 = \mathbf{p}_2 \mathbf{P}^2 =$ $\{0.1806 \quad 0.1389 \quad 0.1945 \quad 0.3477 \quad 0.1385\}$				
$\mathbf{q}_4 = \mathbf{q}_3 \mathbf{Q}^3 =$ $\{0.0484 \quad 0.0279 \quad 0.1172 \quad 0.0825 \quad 0.7236\}$					$\mathbf{p}_4 = \mathbf{p}_3 \mathbf{P}^3 =$ $\{0.0139 \quad 0.0069 \quad 0.0554 \quad 0.0282 \quad 0.8958\}$				

4.3.2. Discussion: The Influence of Min Interference

Comparing no interference to min interference, several differences and similarities may be observed. We start on an aggregate level by examining the state probabilities from Table 6.3.

4.3.2.1 The Influence of Min Interference on the State Probabilities

We find the following:

Firstly, although the matrices $\mathbf{Q}^{Init}$ and $\mathbf{P}^{Init}$ differ somewhat, the first stage state probability vectors $\mathbf{q}_1$ and $\mathbf{p}_1$ are nearly identical. In both cases the majority of offenders (around 52%) opt for stealing from a small RE project as their first offence. Secondly, we observe that for the next two stages the state probability vectors $\mathbf{q}_k$ and $\mathbf{p}_k$ display the same pattern:

- In both cases, the popularity of stealing from a small RE project decreases monotonically as stages go on.
- On the other hand, in the third stage, stealing from a large RE project is preferred by 39% and 35%, respectively. In the first stage, this was only 22% and 21%.
- Vandalizing small RE projects is stable over the stages and attracts roughly 20% in both cases.
- Vandalizing large RE projects increases in popularity over the stages from 7% in stage 1 to 16% and 20%, respectively, in stage 3.

Thirdly, the fourth stage state probability vectors $\mathbf{q}_4$ and $\mathbf{p}_4$ differ significantly in the percentage of offenders at rest, 72% versus 90%. This suggests that, in the long run, security interference, even in a weak form, may be effective.

Next, let us examine the influence of min interference on a more detailed level by scrutinizing the transition probabilities displayed in Table 6.1 and 6.2.

4.3.2.2 The Influence of Min Interference on the Transition Probabilities

The matrices $\mathbf{Q}^{Init}$ and $\mathbf{P}^{Init}$ show that offenders instigated by government inequality (GI) are not that outspoken in the choice of their first offence. On the other hand, in both cases, first offenders committing Crime to Survive (SU) are focusing on stealing from small RE projects (for 85% to 73%, respectively). Obviously, the instigator Sabotage (SA) leads the first offender to a preference for vandalizing (primarily for small projects, namely 83% and 67%, respectively).

For the transition between stages we are interested in the behavior of $A_{ij}^k(\Delta_i)$, the attraction of committing offence j in stage $k+1$ after committing offence i in stage k given that offence i has a

min level of interference Δ_i . Purpose of any interference is to reduce that attraction, which is achieved if $A_{ij}^k(\Delta_i) < 1$.

In Table 6.1 and 6.2, the matrices $\mathbf{Q}^1$ and $\mathbf{P}^1$ give the transition probabilities from the first stage to the second under no and min interference, respectively. Let us have a look at $A_{ij}^1(\Delta_i)$ for $i, j = 1, 2, \dots, 4$. Clearly, for only seven pairs (i, j) , it holds that $A_{ij}^1(\Delta_i) < 1$. Among these are all pairs (i, i) . So, here, min interference diminishes the probability of repeating the same offence. However it does not reduce overall criminality.

Next, in Table 6.1 and 6.2, the matrices $\mathbf{Q}^2$ and $\mathbf{P}^2$ give the transition probabilities from the second stage to the third. Now, for only eight pairs (i, j) , it holds that $A_{ij}^2(\Delta_i) < 1$. Among these are all pairs $(i, 2)$. So, min interference diminishes the probability of stealing from small RE projects, regardless of the previous offence. Among these are furthermore three pairs $(i, 4)$. So, for these combinations the probability of stealing from a large RE project diminishes. However, also now, min interference does not reduce overall criminality.

Finally, in Table 6.1 and 6.2, the matrices $\mathbf{Q}^3$ and $\mathbf{P}^3$ give the transition probabilities from the third stage to the fourth. Now, for 15 out of the 16 pairs (i, j) , it holds that $A_{ij}^3(\Delta_i) < 1$. So, at last, min interference is successful in reducing overall criminality.

4.3.3. Transition and State Probabilities for Medium and for Max Interference

Clearly, in practice, min interference is the first step to consider. However, when its effects turn out to be disappointing, then it makes sense to consider medium or even strong (so-called max) interference. In our Clinical Research, we also confronted the interviewees with these two forms of interference. We found out that both have a huge impact already in the transition from first stage to second. Therefore, we confine our analysis to only the transition from first stage to second. Specifically, we take $\mathbf{P}^{Init}$ the same as in Table 2 and only examine how the matrix $\mathbf{P}^1$ is changing on the basis of our interviews. Let $\mathbf{P}_{med}^1$ and $\mathbf{P}_{max}^1$ denote the matrix of transition probabilities from the first stage to the second stage under medium and strong interference, respectively. From the data analyzed, we extract the matrices given in Table 6.4.

Table 6.4: Transition Probabilities from First Stage for Medium and Max Interference

$$\mathbf{P}_{med}^1 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.39 & 0.15 & 0 & 0 & 0.46 \\ SP_t & 0.26 & 0.13 & 0.03 & 0.03 & 0.55 \\ LP_v & 0 & 0.2 & 0 & 0.2 & 0.6 \\ LP_t & 0 & 0.06 & 0.19 & 0.19 & 0.56 \end{Bmatrix} \quad \mathbf{P}_{max}^1 = \begin{Bmatrix} & SP_v & SP_t & LP_v & LP_t & R \\ SP_v & 0.13 & 0 & 0 & 0 & 0.87 \\ SP_t & 0.03 & 0 & 0 & 0 & 0.97 \\ LP_v & 0 & 0 & 0 & 0 & 1 \\ LP_t & 0 & 0 & 0.06 & 0 & 0.94 \end{Bmatrix}$$

Let the state probabilities in stage k be given by the row vector $\mathbf{p}_{med,k}$ and $\mathbf{p}_{max,k}$ in case of medium and strong interference, respectively. From the above we find the state probabilities for the second stages (see Table 6.5).

Table 6.5: Second Stage State Probabilities for Medium and Strong Interference

Medium Interference

$SP_v \quad SP_t \quad LP_v \quad LP_t \quad R$

$$\mathbf{p}_{med,2} = \mathbf{p}^{Init} \mathbf{P}_{med}^1 =$$

$$\{0.2137 \quad 0.1265 \quad 0.0528 \quad 0.0667 \quad 0.5406\}$$

Max Interference

$SP_v \quad SP_t \quad LP_v \quad LP_t \quad R$

$$\mathbf{p}_{max,2} = \mathbf{p}^{Init} \mathbf{P}_{max}^1 =$$

$$\{0.0406 \quad 0 \quad 0.013 \quad 0 \quad 0.9465\}$$

From Table 6.5 it is evident that both types of interference are effective. In case of medium interference, the majority of offenders (54%) go to rest after their first offence. In case of max interference, nearly all (95%) first offenders go to rest. Those who stay active, vandalize either small RE projects (4%) or large RE projects (1%).

Next, let us examine $A_{ij}^1(\Delta_i)$, the attraction of committing offence j in stage 2 after committing offence i in stage 1 given that offence i has either medium or max level of interference Δ_i .

In Table 1, the matrix $\mathbf{Q}^1$ gives the transition probabilities from the first stage to the second under no interference. This matrix has to be compared with the matrices $\mathbf{P}_{med}^1$ and $\mathbf{P}_{max}^1$ from Table 6.4, which give the transition probabilities from the first stage to the second stage under medium and max interference, respectively.

Comparing $\mathbf{Q}^1$ with $\mathbf{P}_{med}^1$ tells us that for 14 pairs (i, j) , it holds that $A_{ij}^1(\Delta_i) < 1$. So, under medium interference, almost all transitions between first offences and second offences are less attractive than under no interference.

Comparing Q^1 with P_{max}^1 shows that $A_{ij}^1(\Delta_i) < 1$ for all all pairs (i, j) , So, under max interference, no criminal transitions from stage 1 to stage 2 gain any attraction.

In Section 3.2.2 we deemed it plausible to expect that the attraction $A_{ij}^k(\Delta_i)$ is non-increasing with increasing level of interference Δ_i . Let us test this hypothesis for $k = 1$. Using the matrices Q^1 and P^1 from Table 1 and 2 and P_{med}^1 and P_{max}^1 from Table 6.4, we find that for 11 out of the 16 pairs (i, j) , the attraction $A_{ij}^k(\Delta_i)$ is indeed a non-increasing function of Δ_i .

4.4. Dependence on the Initial Stage (Approach Generalization)

As discussed in Section 4.3.1, our data analysis yields the following values for the probabilities transitioning from initial rest $[I]$ to any of the three instigators (Government Inequality $[GI]$, Crime to Survive $[SU]$, Sabotage $[SA]$):

$$p^{Init} = (p_{I_{GI}}, p_{I_{SU}}, p_{I_{SA}}) = \{0.5556 \quad 0.3611 \quad 0.0833\}$$

The state probabilities for no interference and for least security interference resulting from this initial stage are given in Table 3. One may wonder how the career of a criminal may evolve from a different initial stage. To illustrate this, let us consider two cases. In case (i) we assume that Government Inequality has been reduced by political reforms, whereas Crime to Survive and Sabotage keep the same ratio. Specifically, we choose as initial stage $p^{Init,1} = \{0.4 \quad 0.4875 \quad 0.1125\}$. In case (ii) we assume that Crime to Survive is increasing because of poor living conditions, whereas Government Inequality and Sabotage keep the same ratio. Specifically, we choose as initial stage $p^{Init,2} = \{0.3478 \quad 0.6 \quad 0.0522\}$. Table 6.6 shows the corresponding state probabilities in the first and in the fourth stage for no interference. The first stage shows minor differences in the probability values. In the fourth stage, it is hardly noticeable that the three criminal careers arose from different initial stages. Similar behavior is found for all degrees of interference. Although convergence of the state probabilities is to be expected, it is surprising that the initial probabilities lose their character this soon. So, despite of the initial motivation of the criminal, the expected career pattern evolves in a predictable way.

Table 6.6: State Probabilities with different Initial Stage Probabilities for no Interference

	Motivation			First Stage				Fourth Stage				
	<i>GI</i>	<i>SU</i>	<i>SA</i>	SPv	SPt	LPv	LPt	SPv	SPt	LPv	LPt	R
Base Case	0.5556	0.3611	0.083	0.1944	0.5138	0.0694	0.2223	0.0484	0.0279	0.1172	0.0825	0.7236
Case (i)	0.4	0.4875	0.113	0.1837	0.5712	0.05	0.1951	0.0488	0.028	0.1167	0.0817	0.7245
case (ii)	0.3478	0.6	0.052	0.1217	0.638	0.0435	0.1968	0.0486	0.028	0.1165	0.0819	0.7246

4.5. Recommended Interferences per Project Offence

In the previous analysis we assumed all states to have equal interference. In practice, this will be different. Obviously, large security differences between nearby projects are not recommendable, since word of mouth will direct the offenders to those projects that are least protected. In this section, let us determine adequate interferences per project offence whilst taking into account the rigorously executed analysis.

Section 4.3.2 shows that min interference will only be effective in the long run. So on a project base, the choice will be between med and max interference. Incidentally, this choice has the advantage of diminishing differences between applied interference

As discussed in Section 4.1, we asked the participants of the study to rank the interferences based on difficulty (See Table 6.7).

Table 6.7: Ranking of Interferences

Level	Interference Type	Selections	Probability of Rest or Exit at Stage 1
Max	SS	57%	95%
	TS	7%	
	HS	36%	
Med	SS	28%	54%
	TS	39%	
	HS	33%	
Min	SS	17%	15%
	TS	24%	
	HS	59%	

Combining our findings from the previous sections with Table 6.7, we recommend the following interference types:

- SPv: for no, min and medium (overall) interference, vandalizing small RE projects is stable over the stages and attracts roughly 20%. With max interference this drops to 4% in stage 2. So, we recommend max interference. To achieve this, we aim for SS followed by HS (see Table 6.7).
- SPT: stealing from a small RE project is popular in the first stage (52%) and decreases monotonically as stages go on. We recommend medium interference, which reduces the popularity from 35% to 13% in stage 2. To achieve this, we aim for TS followed by HS.
- LPv: for no to min interference, vandalizing large RE projects increases in popularity over the stages from 7% in stage 1 to 16% and 20%, respectively, in stage 3. Medium interference will reduce this to only 5% in stage 2. To achieve this, we aim for TS followed by HS.
- LPT: for no to min interference, in the third stage, stealing from a large RE project is preferred by 39% and 35%, respectively. In the first stage, this was only 22% and 21%. With max interference this drops to 0% in stage 2. So, we recommend max interference. To achieve this, we aim for SS followed by HS.

5. Conclusions & Recommendations

Sub-Saharan Africa's development is dependent partly on energy provision. The region currently suffers from lack of energy and although various RE development projects have been implemented, the advantages of these projects are yet to be felt on a wide scale. Nonetheless, the region possesses the opportunity to move directly in the era of renewable energy rather than investing in energy generation methods that could be detrimental to the planet. Excluding the funding, there exists a long list of reasons as to why energy projects in SSA fail. This includes management, maintenance, nepotism, disturbances such as theft and vandalism etc. For Sub-Saharan Africa to thrive in any sector the issues of living and planning sustainably must be addressed and this includes planning against disturbances such as theft and vandalism to energy projects in the region. History should be learnt from, as can be seen in various countries around the region where energy infrastructures have been vandalized and purloined during riots of

government inequality and for the sake of survival. As such, to avoid a repetition of the past, these issues must be considered prior to the implementation of any RE development project.

In our study, we engaged directly with participants from the region of Sub-Saharan Africa so as to realistically generate data for the analysis that we present. Throughout the study we carefully analyzed the impacts that disturbances such as theft and vandalism have on the future of RE development projects in SSA whilst directly exploring the impact on both small and large projects. Based on the dialogues, analysis, and practical experiences the following findings and recommendations are provided:

- The implementation of interferences is important to guarantee the sustainability of RE development projects in Sub-Saharan Africa. However, for its successful accomplishment, it is important that the local communities are involved as stakeholders prior to the implementation of the project and after.
- Large scale projects should combine multiple interference approaches. However, it is advisable that energy projects are broken down into the smallest subsets possible so as to guarantee their sustainability. More importantly, solving Africa's energy problems is more feasible via the decentralization of energy generation.
- The implementation of large RE development projects isn't advisable. However, in cases where this is the only feasible option - after exhaustive planning and studies have been carried out - *technical security and human security* are the most effective interference to consider. This is also the case for projects implemented in locations without surrounding habitants as is the characteristic of a large RE project.
- Small scale projects should utilize societal security (SS) as this is considered the most effective class of interference against the persistent threat of vandalizing. However, the local community must be trained in the aspect of maintenance of the systems. More so, a knowledge database must be made available for the local community to learn from best practices that would support the overall sustainability of these projects.
- Individuals not successful in attempts to purloin RE infrastructures from project sites are more likely to deviate into vandalization. However, this is mostly seen in cases where the primary instigator is government inequality (GI). On the other hand, people instigated by survival (SU) are only focused on the theft aspect. When theft is not possible, they are likely to change locations or return to the same project.

- Though technical security (TS) is most widely utilized in western implemented projects, this is a totally different case in Sub-Saharan Africa, since the utilization of TS as a standalone option in RE development projects would more likely lead to vandalization of the project.

Our study looks at the analysis of theft and vandalism on RE development project and how this could affect the sustainability of these projects in the future. By taking into account data from individuals in the region and analyzing the state of energy infrastructures in the countries we are able to provide the necessary analysis and findings required. It is therefore important that financing government and implementing organization consider disturbances such as theft and vandalism prior to the implementation of RE development projects in Sub-Saharan Africa for these projects to be sustainable into the future.

6. Future Research Possibilities

This Chapter analyzes the impact of disturbances such as theft and vandalism on RE development projects in SSA. As in any research, limitations present themselves.

One limitation experienced in our study is funding. As such we were able to only utilize 144 respondents. A larger number would have enabled us to calibrate an extended Markov model in which we incorporate the notion of 'success' and 'failure'. In addition, it would be interesting to follow the actual criminal career of the 21% of actual offenders and compare this with our model. Although we presented realistically implementable interferences, it may be worthwhile to measure the impact of other types of interferences on corresponding projects that may exist in the future.

Financial aspects were out of scope in our research. However, in future research it may be interesting to perform a break-even analysis into the financial consequences of the interferences considered. Finally, we believe that our multi-stage Markov approach is generally applicable to any situation dominated by processes where maturity of human beings as well as reaction to exterior stimuli is essential.

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Chapter 7

Attaining the Upper Bound Societal Benefits of Renewable Energy Development Projects in Sub-Saharan Africa: The Dwindling Reality

“Africans spend so much time being religious. Forgetting in the process that God would never come down from the heavens to solve the problems we create. We must learn to become realistic and also never forget that in the same holy book we read, it states that we perish because we lack common sense” – The Author

1. Introduction

The consumption of energy globally has increased at a fast pace and this has mainly been attributed to the rate of growth in developing countries. Still, there exists very high level of inequality around the world in the access to contemporary energy services (Ahuja & Tatsutani, 2009). Renewable energy could provide significant improvement to developing and under-developed countries within Sub-Saharan Africa (SSA). With vast amount of feasible renewable options, there are numerous opportunities present to be tapped into that can provide positive benefits for the locals within these countries. However, the pace at which renewable energy is being implemented is slower than expected given the failures accumulated by some projects. This has somewhat tainted the opportunities present to some extent. Eradicating poverty in SSA will require substantial growth and development within the economy. To achieve this, energy plays a very important role. As constant energy supply is a problem in almost all African countries within the Sub-Sahara, an affordable and environmentally friendly way of generating energy is crucially important to foster economic growth and eradicate poverty. Nonetheless, the actual societal benefits of utilizing renewable energy infrastructures are an issue that possesses both pros and cons within the mind of an average Sub-Saharan African.

Conservatively, energy is considered a median input in the process of a working economy. This view and presentation de-emphasizes the importance and contribution that the role of energy presents to development. Each and every single activity within the economy needs some form of energy to be executed whether it is executing a transaction or making a business phone call. This efficaciously makes energy an important aspect of the economy and sustainable development (Nnaji & Uzoma, 2012). For developing countries, the rapid rise of energy prices coupled with the rise of food costs generates concerns about the economic and political stability. Such is the case in Nigeria which, although the country possesses an abundant amount of fossil fuels, yet imports most of its refined product causing a rise in the price of petroleum products. Discharge from fossil fuels is known to exceed both local and national levels, thereby negatively influencing the global habitat and contributing to changes in the climate (Omer, 2008). The unfortunate fact about this is that the poorest communities around the world who live in delicate and endangered locations are affected the most by changes such as drought, melting ice caps, floods etc (Nnaji & Uzoma, 2012). The risks faced by the people in such communities are frequently intensified by the unsustainable use of resources. For developing countries with a similar situation, diversifying the domestic energy resources will reduce the dependence on imported fuels and will provide a host of benefits with regards to domestic investment and also reduce the country's dependence on foreign assistance as is visible around the world (Ahuja & Tatsutani, 2009). Renewable energy is considered the way of the future because it releases no harmful gases and it

never depletes (Panwar, Kaushik, & Kothari, 2011). Renewable energy infrastructure has reduced in cost over the past decade, thanks to the continuous innovation within the industry (Ipakchi & Albuyeh, 2009). Some of the potential benefits of utilizing renewable energy are known to include but not limited to its renewability, cleaner environment, economic benefits in terms of manufacturing and job creation, balanced pricing on energy utilized and its reliability (Dincer, 2000). Nevertheless, these technologies still face some problems with respect to its implementation, local acceptance and sustainable management (Ikejemba, Mpuan, Schuur, & Hillegersberg, 2017). Some of their drawback may include - and is not limited to - high investment cost, massive collection of land space and difficulty to generate large amount of energy compared to fossil fuels.

Sustainable development is hinged on the ability of a country to provide uninterrupted power supply. Energy is pivotal to the economy due to the fact that all or most economic activities are dependent on it. This distinction of energy focuses our consciousness to its origination in nature, to operations that transform and retransform this energy and finally to operations that utilize the energy to manufacture goods and services and dissipation for households (Oyedepo, 2012). Several studies have been presented on the potential and benefits for developing countries (Dincer, 2000; Bull, 2002; Walker & Devine-Wright, 2008). However, there are still no clear policies to be implemented by most governments within developing countries. Substantial time is spent on discussions of policies, meetings and other arrangements whilst time is lost on the actual implementation of policies and renewable energy technologies. This often results in the prolongation and incompleteness of projects (Ikejemba, Mpuan, Schuur, & Hillegersberg, 2017). Renewable energy provides an opportunity for developing countries to cross over directly into an environment of clean energy, thereby circumventing the problem that Europe is dealing with currently, possessing an existing grid and an existing energy production, which over time will be substituted and which is expected to require large amount of finances. Developing countries could then utilize renewable energy to satisfy their energy needs and wouldn't require obsolete and polluting infrastructure (Piebalgs, 2007).

The availability of literature on the aspects of societal benefits on RE projects in developing countries such as those in the regions of SSA is minimal to none. Instead, multiple research papers exist with almost all focusing on the technology or its feasibility in a sophisticated context (Menegaki, 2008). More often than not, the general overview of utilizing renewable energy is focused on the positive aspect as earlier stated. Such as: (i) less environmental damage, (ii) supporting the decentralization of energy networks by providing solutions to energy problems faced by isolated communities and (iii) the fact that they are renewable and do not deplete. The negative aspect that may disrupt the social, cultural and economic lifestyle of community is

rarely presented in research. For example, a fishing village in Ghana we visited for this study originally utilized generators to power their machines and stimulate economic activities in the village. Renewable energy was proposed to the village elders and it was adopted. However, after six months of operation, the technology ceased to operate. No maintenance plan or management method was implemented after the initial commissioning of the project, leaving the project to deteriorate before its expected lifecycle. This resulted in an enormous loss within the economic activities of the villagers, a high rise in theft and burglary and overall demotivation in the village. This is not to state that the technology is not applicable and suitable but rather, for the technology to be applicable certain implementation strategies that include the participation of the community members as stakeholders and a sustainable management method must be considered. Due to this loss, the villagers affirmed never to adopt any sort of renewable energy technology. Situations of this nature easily find themselves replicated in other villages with networks to the affected village. Ikejemba et al. (2017) presented a study on the failures of RE projects in SSA from the perspective of management. Although investigating sustainable management of RE projects, it doesn't present on the shortcomings of these projects attaining the upper bound societal benefits. Nonetheless, one could attribute these failures to the corresponding shortcomings.

In general, energy possesses compelling and paramount links to the milieu. A vast number of energy originates directly from the environment, requiring a bona fide sustainable management for these resources to be sustained (Oyedepo, 2012; Ikejemba, Mpuan, Schuur, & Hillegersberg, 2017). Implementing renewable energy technologies is one aspect of sustainable development, whilst attaining the societal benefits of its implementation is another aspect. Although they are expected to be complementary of one another, this is not usually the case as projects that are implemented without adequate planning and a sustainable management method only lead to the provision of little or no benefits, thereby rendering the implemented project useless and a waste of taxpayers' money (Ikejemba, Mpuan, Schuur, & Hillegersberg, 2017). Renewable energy projects are meant to be sustainable and should be designed and implemented in a manner that the project's lifecycle is maximized. Achieving the expected benefits of utilizing renewable energy both now and in the future is very important towards achieving true sustainability.

This study aims to present the realistic societal benefits of utilizing RETs in SSA based on empirical data and to create awareness towards the implementation of sustainable projects within the realm of publicly funded RE projects. We accomplish this by investigating 29 projects that have been implemented in ten Sub-Saharan African countries. While the sufficiency for the number of projects selected for this study may be debated towards the generalization on the actual benefits of the state of renewable energy in Sub-Saharan Africa, it presents actual views of

the locals and implementing organizations. The physical states of the investigated projects are adequately sufficient for solutions to be developed to achieve the expected benefits of utilizing renewable energy.

Contributions of this study are the following:

- It creates awareness towards implementing sustainable, publicly-funded projects.
- It explores the actual societal benefits from the usage of renewable energy in SSA.
- It investigates through empirical research the state of the art of 29 RE projects implemented in ten SSA countries taking into account direct experiences of the local beneficiaries and project implementers.
- It presents crucial generic recommendations to be adopted by all stakeholders participating in RE projects within SSA in order to secure societal benefits in the long run.

The rest of this paper is structured as follows. In Section 2, we present the analysis of the current state. Section 3 presents our dialogues, discussions and findings from the field. In Section 4, we present the recommendations and conclusions towards attaining the actual benefits of RE projects in the region. Finally, in Section 5 we present future research possibilities and the research limitations.

2. Current State Analysis

In this section, we present an overall analysis on the study. We begin by presenting the main objective of the research in Section 2.1. Next, Section 2.2 presents our research method. Subsequently, Section 2.3 presents the analysis of collected interviews and data. Finally, Section 2.4 presents the state of affairs of the analyzed projects.

2.1. Research Objective

The main aim of the research is to probe the so-called theoretical potential benefits of utilizing renewable energy in comparison to the actual benefits based on projects implemented in Sub-Saharan Africa. We analyze different publicly funded RE projects based on the expected benefits towards their beneficiaries. Furthermore, we intend to provide recommendations and solutions to projects with output benefit that is lower than the expected. We also aim to provide conditions for future research and applicable recommendations to be considered by professionals in the field of renewable energy in Sub-Saharan Africa.

2.2. Research Method

This research uses an *ethnographic* approach as indicated in Chapter 1, 4 and 5.

2.3. Research Data Analysis

The results presented in this study are based on the empirical findings of post-implementation appraisal of 29 projects (see Chapter 4, Table 4.1: Project & Data Information) in 10 different Sub-Saharan African countries (Nigeria, Ghana, Kenya, Gabon, South Africa, Tanzania, Mozambique, Ethiopia, Malawi and Uganda). Two methods were implemented in this study, first, a semi-structured interview with project beneficiaries and project implementers and a physical analysis of the implemented project. It is imperative to note that the same projects utilized in this study are also being investigated to develop sustainable management methods and protection methods towards theft and vandalism of renewable energy projects in Sub-Saharan African countries. The types of projects investigated within this study included: micro-grid rural electrification, street lights, city electrification, electrification of public institutions such as, health care centers, public schools and government offices.

The benefits of the chosen method of analysis are its effectiveness to determine the societal benefits by engaging directly with the benefitting society and understanding the perspective and goal of the implementing organization. More importantly, a direct communication with project implementers is time-effective and builds a comprehensive idea of the local societal benefit of utilizing renewable energy. To further accurately analyze the compiled information, a template was utilized that encompasses information such as country, project type and project goals and benefits. Information on the implementing organization, exact location of project and total project cost has been excluded due to a confidentiality clause and to avoid any future implication on project implementers that participated in the provision of data for this study. The data collected by the research team is analyzed and corresponding characteristics are identified such as, the expected benefits of the projects and the reasons projects fall short of attaining the expected benefits.

As earlier indicated, the projects analyzed in this study have been accumulated from different countries. Ten of the projects have been executed in Nigeria, four in Ghana, three in Kenya, two in Gabon, one in South Africa, two in Tanzania, two in Mozambique, three in Ethiopia and two in Malawi. Data from projects in Uganda were not compiled due to the political unrest happening at the time of the study. These projects have also been implemented within different infrastructural types and by different Local Governments within the respected countries. Ten of the projects constitute the lighting up of streets within the community with at least 30 street lights to 100 street lights. Two of the projects were implemented to power up a local hospital. One of the projects was implemented to power up a local school. Three of the projects have been implemented to power up public offices. Nine of the projects have been implemented to electrify public infrastructures such as, water borehole to provide clean drinking water to communities,

powering of security traffic cameras, water heaters in government housing projects and minor local connections. Finally, four of the projects were implemented in remote villages without access to the grid.

In order for us to eliminate the potential of presenting predisposed data, we endeavored to curb the risk by validating the data and information received from interview participants by comparing it to a thorough analysis of the physical nature of the implemented infrastructure and available report on system monitoring in some cases. The questionnaire for both the local beneficiaries and implementing organization were identical in structure but in some cases the questions posed to participants were different.

2.4. State of Affairs of the Analyzed Projects

Some of the projects presented in this study have already gained media attention and negative feedbacks due to the physical deterioration of the renewable energy infrastructure implemented. However, the goal of this study is to determine the actual societal benefits of the projects in comparison to the expected/theoretical benefits whether or not the project is a success or a failure. More importantly, to provide solutions that assist these projects and future projects to meet its societal benefits. We combine the interview responses collected into two different categories as earlier indicated: (i) project beneficiaries and (ii) project implementers. This is done to emphatically comprehend the issues affecting projects from attaining its expected benefits. The main aspects of the questionnaire focused on data that are qualitative, such as local beneficiary satisfaction, expected benefits (this is done to make sure that the local beneficiaries have the average understanding of the system of renewable energy in general) and actual benefits, stakeholder participation and community engagement. Whilst, questions to the implementing organization focused on the organizational goals, specific projects goals and expectations and the organizations' expected benefit towards the local community benefitting from the project. An initial swift analysis of the projects indicated that three of the projects have recently been implemented and currently meet its expected benefits. Of the twenty-six other projects, seventeen of the projects ceased to operate after some months (ranging from three months to 18 months) after its implementation and commissioning, whilst the remainder of the projects remained partially operational and as such only meet some to none of its expected goals.

3. Findings & Discussions

In this section, we present the direct dialogues, discussions and findings with the project beneficiaries (Section 3.1) and project implementers (Section 3.2). Finally, Section 3.3 presents further discussions with respect to the study.

3.1. Project Beneficiaries

Two sets of interviews with the locals benefitting from implemented projects were carried out. One based on a one-on-one interview and the other based on a dialogue involving multiple groups within a tightly knitted community. Respondents were asked if they understood what the corresponding benefits of the technology implemented in their community are. Nearly ninety-eight percent of the respondents had an idea of the expected primary benefit. However, given the intellectual level of the participants it is understandable that the secondary benefits may not be clearly understood. Further questioning on the operation of the implemented project in the corresponding community provided mixed views. Questions were posed to participants about their support on renewable energy projects. Of all the participants (a total of 138 individuals and 16 groups) connected to the 29 projects, approximately 22 percent are willing and supportive of the implementation of clean energy projects, 28 percent indicated that they do not support the projects, whilst 50 percent indicated they have no idea on how the technology works and as such cannot provide any definitive response. Of the 28 percent that indicated that they do not support the technology, 80 percent of the respondents indicated that they have in some way come in contact with failed projects and as such do not support the technology in any way or form, whilst the remaining 20 percent indicated that they are not sure about the efficiency of such projects and as such their dependency on them is impracticable.

Furthering the dialogue into the direct and indirect impact that the implemented projects have provided, some respondents indicated grave anger at the government and the implementing organization. This is due to the fact that some of the projects failed to operate just within months of their commissioning and after all requests that were sent for maintenance nothing was done to rectify the problems. This has been the case in about seventeen of the implemented projects. Two of the hospitals investigated in this study had a similar situation. The systems implemented in these hospitals are partially operating under capacity. According to the doctors who participated in the study, they indicated that the project was commissioned by the local government and shortly after its implementation, problems such as drop in power began to occur.

“This is a very difficult situation because we are a hospital and our back up power of using generators is not so feasible due to breakdowns coupled with the increase in petrol pricing and inconsistent maintenance. We treat a lot of women and children in this hospital and with the implemented technology it is difficult to tell you if I will suggest its usage to other hospitals”

Our attempt to reach the local government was successful with a representative indicating that they had an idea of the problem and they will be contacting the implementing organization. However, further questions regarding their working relationship with the implementing organization were declined. This situation possesses similar traits to a project (Omisore, 2011) that has received media attention due to its failure to provide its expected benefits. The project implemented in a community in Lagos, Nigeria, was implemented to provide a better life to the fishing community. However, three months into its operation it broke down and all reports sent by the community to the local government went unanswered.

Lack of understanding and public acceptance was also visible within some of the community members who own power generators that release harmful substances with them providing combined responses such as:

“We do not care if solar or renewable energy is implemented, we have generators and we would like to keep using our generators since the power companies have decided to keep charging us for power and yet not providing us with adequate power. If in a week you are able to have power for a total of 2 hours then you should be happy but that is not the case. More importantly, everyone talks about this solar of a thing but yet after its implementation it continues to fail. So we are not sure if this is about the panel itself or because of the incompetency of the company implementing it”

In a remote village in one of the locations visited for the study, small solar panels have been implemented in the village to charge torch lights and mobile phones. However, the participants from this village vented their anger at the local government because the products they were provided with according to them were “very useless” and they perceived that this was done so that the same people could be voted in office again and not because the local government cares about them. This is also a problem in some other communities in other Sub-Saharan African countries. In two of the projects implemented to power boreholes and provide water for the community, the status of these projects is regarded as working because the benefit of the projects are being met according to the respondents from the communities. Further questioning in this community indicated that the implementing organization involved the community fully into the project and that also contributes to its further success in terms of management and maintenance. Based on the overall responses received and analyzed in this study, the expected benefits from most of the projects are underachieved and this is attributed to multiple reasons.

3.2. Project Implementers

Responses were compiled from an interview with fifteen project directors that have to some extent controlled or managed the implementation of the projects presented in this study. The interviews carried out with project implementers were done on a face-to-face basis. In cases where physical interviews were not possible telephonic conversation was executed. Questions were asked about the benefits of the implemented projects. Responses such as electrifying the community, reducing theft, enhancing economic activities and reducing poverty, promoting educational activities, saving the environment etc. were provided. This however differs from the output benefit of the implemented projects investigated in this study. Directing the questions towards the physical status of the implemented projects, approximately 87 percent of the respondents blame the government stating that

“They provide us projects to implement but when it comes to the funding of the project, they provide 25 percent less than what is required for a sustainable project and even sometimes 40 percent less in some cases. How do they expect us to provide a sustainable project with that kind of attitude?”

Furthering the dialogue, the respondents indicated that the government is sometimes not really interested in the project and these projects are just done to fulfill the partial obligation of being in political office to be voted in again even though the projects may not be suitable for implementation. Although some project directors were cautious and conservative in providing implementation and maintenance plans, some others were profound and open-minded with such information. It was gathered that in some cases no preliminary studies were carried out. This was blamed on the budget provided by the implementing government. This causes the implementing organization to resort to utilizing the assumption that wherever the sun shines, solar energy could be harnessed and thus missing out on very important information that affects the sustainability of the system to meet its expected benefits.

In some locations where street lights and security cameras have been implemented, a physical inspection of the location provided an example of failure due to system sizing. At this location the appropriate solar panels were not utilized and the corresponding connected battery system did not match the solar panel that was connected. This resulted in the deterioration of the batteries and rendered the project useless. Questioning the implementing project director about this situation, the response was rather vague. This indicates that some of the projects that were investigated in this study were implemented by incompetent organizations, thus validating some of the comments of the locals who participated in this study. Discussing about the beneficial output being lower than expected, 11 of 15 project directors indicated that the problems with the

system are sometimes two-fold: (i) the government and its method of funding projects and (ii) the public understanding and acceptance of the technology. However, it is quite eccentric that these project directors and managers fail to accept the responsibilities of the failed project. Nevertheless, the project directors that have recently implemented the latest projects indicated that they took into account adequate planning and integrating the community members into the project, thus making it a shared responsibility between the implementing organization and the community. A similar response came from the respondents from the community of the corresponding project.

From the analysis of the dialogues, it is indicative that the reasons for these projects falling short and in some cases massively away from attaining their benefits are attributed to their failures. In the next section we present these failures and further discussion.

3.3. Further Discussions

Marie-Louise et al. (2011) present case studies executed in Rwanda, Tanzania and Malawi, focused on analyzing factors that should be taken into account for the selection of sustainable RETs. They further present reasons as to why these projects fail from the perspective of knowledge transfer and technology. In comparison to the study by Ikejemba et al. (2017), the research provides a rather global analysis of the failures of RE projects in the region that includes, *the political agenda of the financing government, the tendering process for projects, the encumbrance of all stakeholders, inadequate planning, poor maintenance and ill-management of implemented projects and the public acceptance and inclusion as beneficiaries.*

The introduction of RE infrastructure to local communities shouldn't be about providing the habitants with power and minimizing the negative impacts of unsustainable fuel use, rather it should be about the dispersion of knowledge on the options of sustainable energy, exhibiting how these infrastructures can be implemented within the context of the locals (Terrapon-Pfaff, Dienst, König, & Ortiz, 2014). The situation encompassing RE projects in Sub-Saharan Africa countries is complicated and the factors that influence the sustainability of these projects are multifarious. As such, these projects cannot be assessed on the development of the technology alone, but the benefits that arise out of its implementation and the denouement it has on the life of the local communities. Therefore, the physical analysis of the implemented projects and dialogues with the project beneficiaries and project implementers present a clear view on the current benefits of these projects and their shortcomings.

Although so many studies have been presented on the technical feasibility of renewable energy infrastructures within projects, it is known that the dependability on only the technical elements does not result in a sustainable project. Rather this is dependent on the overall system

encompassing, the project planning, implementation, sustainable management, maintenance and monitoring. To achieve this, the implementing government, implementing organization and the local community must work together thoroughly. An important aspect to note is that given the heights the locals are willing to go to have the basic necessities to survive, they are willing to participate as stakeholders in these projects and in some cases to take on multiple tasks to ensure their success. Nonetheless, this is not even taken into consideration in many of the failed projects across Sub-Saharan Africa, despite its potential to contribute positively to a successful project.

The aspect of responsibility and ownership is one of the most significant problems affecting the success of these projects. Some project directors expressed their concerns towards the fact that the government provides the funding for the implementation of the projects and not for the maintenance. Therefore, further maintenance that must be carried out on the systems must be funded by the implementing government. Although the local implementing government comprehends the importance of maintenance on these systems yet nothing is being done about it. This is also similar to the problems attributed to the ownership of the projects. In this aspect we refer to the stakeholders' connection to the technology and project in general. A failed sense of ownership from the part of the local community reduces the potential success of the project and could possibly results in its unsustainable management and failure. The ownership of the project should not necessarily be attributed to one institution or entity, but rather should be a shared responsibility between all stakeholders involved in the project. One characteristic all these countries possess is the unavailability of commanding renewable energy policies. Yet so many studies have been completed on the creation and implementation of policies for countries in Sub-Saharan Africa. For example, in developed countries utilizing solar panels on roof tops and feeding off excess energy into the grid or using wind turbines to generate energy could lead to several incentives and support from institutions and government bodies. This is, however, totally opposite when it comes to the case of Sub-Saharan Africa. Given that the current energy infrastructure in some countries is in a state of incomprehensible deterioration, it is impossible to implement such policies. Nevertheless, local governments should support the dissemination of renewable energy technology in the most efficient way possible.

It is imperative to note that there exist some successful projects around Sub-Saharan African ranging from the implementation of solar lighting, solar cookers, micro-grid, rooftop implementations and many more. However, this study has randomly focused on 29 projects across Sub-Saharan Africa and only few of these investigated projects have indicated meeting their expected benefits. The goal of this study is to shed light on failed projects and present

solutions that could help further the process and integration of renewable energy infrastructure into the Sub-Saharan communities to maximize its societal benefits.

4. Recommendations and Conclusion

There exists a significant difference between the theoretical/expected benefits of utilizing renewable energy compared to the corresponding societal benefits in Sub-Saharan African countries based on the 29 projects taken into account in this study. These differences exist based on the different reasons attributed to the failures of implemented projects. Although the projects are implemented in different countries and ranging from micro-grid rural electrification to street lights, rural electrification, electrification of public institutions such as, health care centers, public schools and government offices, there still is a correlation between all these projects based on their failures. Giving the nature of the 29 projects in this study, with only 3 projects currently meeting its expected goal, the principal issue currently is to provide solutions to take into account when implementing future projects. It is possible to present solutions for each project investigated in this study, we provide generic solutions that should be taken into account by government bodies, implementing organizations and local communities benefitting from implemented projects within Sub-Saharan Africa. The *recommendations presented in Chapter 5* of this thesis are based on the analysis, failures and shortcomings on meeting the expected benefits of RE projects in Sub-Saharan Africa should be considered as recommendations for this Chapter.

In conclusion, although the projects investigated in this study are below its expected benefits based on the response and physical examination of the projects. Nevertheless, this study has been able to shed light on the shortcomings of renewable energy projects meeting its expected benefits in Sub-Saharan Africa. More importantly, we have presented applicable recommendations that should be taking into account by stakeholders towards implementation of any sustainable renewable energy project.

5. Future Research Possibilities and Limitations

Renewable energy is only beginning to get its footing within communities in Sub-Saharan Africa and the implications failed projects have on the future of the technology is crucial to its acceptance. We finalize this study by presenting the limitations and future research possibilities within this realm of study. The first issue is the limited number projects investigated in this study. Nevertheless, the results clarify the attention on how projects are susceptible to failure, if the necessary planning and management are not adequately implemented to meet its expected benefits. A second limitation is the absence and limited availability of audit reports and documentation of implemented projects, thus making the validation of collected responses and

interviews only possible through the physical examination of the implemented projects and the cross-sectional analysis of comments from local beneficiaries and implementing organizations. However, it is important that a knowledge database of best practices of successfully implemented projects be created and made available to the public.

Another limitation is the absence of a renewable energy policy in the studied countries, thus making it strenuous to assess the impact of sustainability without specific guidelines. Further study should be executed to design a baseline documentation to measure the impacts and benefits renewable energy projects has on the corresponding community. It is important that the community stakeholders, culture, tradition and all local traits must be taken into account for such study. Furthermore, additional detailed studies should be executed on designing an exceptional stakeholder relationship whereby all participating stakeholders have shared responsibilities towards the success of renewable energy projects in Sub-Saharan Africa.

Finally, future research done on renewable energy in Sub-Saharan Africa should not be sugarcoated. The failures of renewable energy projects can only be solved if recommendations provided by studies are taken into account by stakeholders. Ultimately, such projects and its sustainable success can be replicated in other communities across Sub-Saharan Africa. Nonetheless, the education of the local beneficiaries is paramount to the success of any RE development project in the region.

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Chapter 8

**Conclusions, Thesis Contributions & Future
Research Possibilities**

“The barrier during self-improvement is not so much that we hate learning, rather we hate being taught. To learn entails that the knowledge was achieved on one's own accord - it feels great - but to be taught often leaves a feeling of inferiority. Thus it takes a bit of determination and a lot of humility in order for one to fully develop.” – Criss Jami, Killosophy

The general inspiration of the research presented in this thesis is to create awareness towards the potential failures of RE development projects in Sub-Saharan Africa and to avoid these by thoroughly considering the aspects of sustainability prior to the design and implementation of these “so-called” projects. In the introductory chapter, we introduced the overall research focus, problems and objectives surrounding the aspects of enhancing sustainable development in SSA with a focus on RE development projects that included location analysis, sustainable management of RE projects, protection of RE infrastructures and the societal benefits of utilizing RE in SSA. In the preceding chapters, we presented and analyzed the issues as indicated in the introductory chapter and further provided applicable solutions and recommendations locally within each chapter. A key aspect of this research both from a scientific and pragmatic perspective is to find an equilibrium point, such that the realistic situation and way of life within the studied region is taken into account to the extent that corresponding and applicable solutions and recommendations are developed accordingly.

In this chapter, we culminate this thesis by presenting a global conclusion on the study of enhancing sustainable RE development in SSA whilst revisiting the main focus of this study in Section 8.1. In Section 8.2, we present the main contributions of this thesis based on the four research foci as indicated in the introductory chapter. Excluding the limitations presented locally within the chapters on each research focus, Section 8.3 presents the overall research limitations. Section 8.4 recaps on the mixed-method research approach utilized. Finally, Section 8.5 indicates the possibilities for future research on the topic of enhancing sustainable development.

8.1. General Conclusions

The growth of the economy of the region of the Sub-Sahara is being hindered due to the epileptic power supply crippling the region. Given that renewable energy development is beginning to surge, the sustainability characteristics and aspects must be considered paramount. If not, the growth of the newly developing renewable energy sector would wind up replicating the current deficient energy industry which is a resultant of mismanagement of people and resources, egregious planning and the unsustainable approach to project implementation and solution applications.

In this thesis, we focused and studied four different aspects (location analysis, sustainable management, protection of infrastructure and societal benefits) that contribute to the sustainability of renewable energy development projects across Sub-Saharan Africa. The findings and recommendations presented within the chapters should be considered by all

participating stakeholders (government, financiers, project developers and beneficiaries) within the region.

In addition to the findings, solutions and recommendations confined within the chapters of each research focus, it is important that implementing governments prior to the initiation and design of RE development projects, should understand that these projects are much more than just the generation of power for the corresponding local beneficiaries. It is rather the provision of a better life, jobs, sense of opportunity etc. Thus, the characteristics of sustainability as indicated in Chapter 1 must be further considered. Given that a bottom-up solution approach has been determined as an appropriate strategy, the intuitive multi-step approach, problem owner method (POM) and grid method presented in Chapter 2 and 3 to determine the optimal location for RE development projects based on distinct characteristics should be considered. The interconnection between participating stakeholders of RE projects should be further analyzed by financiers prior to the implementation of these projects, especially if such projects are publicly funded or on loan as most RE projects in the region of SSA. If the current methods of project planning and implementation are continually utilized, RE projects being implemented within the region are doomed to fail.

“We cannot continue to solve today’s evolving energy problems of the region of SSA with the mindset of yesterday or as is done in the developed countries – We must develop our own ways with a bottom-up approach as the infrastructural comparison between SSA and the develop countries differs significantly”

The importance of these projects must shift from the physical implementation to the management ***after cutting the ribbon*** as this is where most failures regularly occur. Notwithstanding, the origin of these failures stems right from the beginning of the project discussion where responsibilities are not clearly allocated to all participating stakeholders as indicated in Chapter 4 and 5 of this thesis.

One of the potential disruptions to the sustainability of these RE projects are disturbances such as theft and vandalism as presented in Chapter 6 of this thesis. Of all projects analyzed in this research not a single project takes these aspects into account prior to the implementation. However, in some cases, local beneficiaries are left in charge of the projects even though they have no idea of its operation. In our analysis in Chapter 6, we present the impact of these disturbances to RE development projects within the region. Our findings indicate that, if these aspects are not considered, RE projects are likely to replicate the current energy situation

marred by theft and vandalism. Feasible solutions and recommendations based on the different types and locations of projects are presented within the chapters.

8.2. Thesis Contributions

This thesis provides extensive contributions towards and within the realm of development and sustainability of RE development projects in Sub-Saharan Africa. It is expected that the contributions are also applicable to developing countries around the world with similar characteristics to the Sub-Sahara. In this section we provide the main contributions of each of the four research focuses as earlier indicated. Subsequent and in-depth contributions are provided locally within the chapters.

Location Analysis: The development of an intuitive multi-step approach and location model that takes into account several characteristics (e.g. population clusters, existing power plants, geographical data etc.) in determining the appropriate locations for RE development projects. It is also the first study that is carried out with respect to renewable energy and location analysis in SSA.

Sustainable Management: Utilizing the ethnographic approach, we deduce the reasons as to why RE development projects fail or are bound to fail in SSA based on the linkages between participating stakeholders. We provide realistic and applicable solutions and recommendations that should be considered by all stakeholders for RE projects to become sustainable in terms of management. It is also the first study of its nature focused on RE and management in SSA.

Protection of RE Infrastructure: In this first study of its kind, we successfully analyze the impact of theft and vandalism on RE projects in SSA. We determine adequate interferences that should be considered for different kinds of implemented projects. In addition, we develop a measurement approach to calibrate the career model of an offender, despite the absence of pre-existing data, via a clinical data generation technique. Furthermore, applicable recommendations and solutions are established to support the sustainability of RE development projects in SSA.

Societal Benefits: We identify the true societal benefits of already existing RE development projects in SSA. Our pioneering study presents the dwindling reality of already implemented projects based on the customs and way of life of the local stakeholders. We further provide important recommendations that must be considered for RE development projects to avoid collapse.

8.3. Research Limitations

The poor availability of research data is one of the most important research limitations. Thus having to resort to obtaining data via clinical data generation is intermittently tedious and expensive. Leading to the limitation presented by the modest funding for this research. More often than not, given that the economic situation within the SSA region is currently adverse, individuals with access to existing data request all sorts of financial incentives to provide such required data. Consequently, the availability of funding for research of this nature would widely benefit all participating stakeholders.

Finally, another limitation of this research is the unavailability of vast research methodologies that are applicable. Historically, most research carried out on the development on of Sub-Saharan Africa is either never implemented or not even considered. This is because more often than not the way of life and the reality of the situation in these regions are not considered or accurately modeled for corresponding solutions to be developed. As such, studies carried out focusing on the development of SSA should consider the realistic circumstances of the region.

8.4. Research Method Recap

As in any research method or approach utilized, there exist strengths and weaknesses. In this section we reflect on these issues. In chapter 1, section 1.5; we presented our research methodology utilized in the corresponding chapters, whereas the research methodologies are locally explained within the chapters. In this section, we placed emphasis on the frailty of the methods. We look at the ILP, ethnography and clinical data generation.

Integer Linear Programming (ILP): Although the ILP approach to location analysis is straightforward, its weakness lies in the fact that not all variables that were required to optimally solve the problem can be quantified easily into a linear mode. Nonetheless, we offset this by the utilization of realistic assumptions. Some of these assumptions include the clustering of population distribution, as the utilization of the original distribution would require an exponential time to solve the problem. More so, such data are nonexistent within the region and would require a large amount of finance to combine. In spite of that, we were able to develop a multi-step approach that could be utilized to appropriately determine the optimal locations for RE projects. We took into account several characteristics with the opportunity for further development as we have shown with our grid method approach and the problem owner method (POM).

Ethnography: The ethnographic approach, being the most pervasive amongst all other methods presented in this thesis, has its own weakness. We considered this approach the most congruous towards finding equilibrium points between acceptable science and the presentation of the situation in the region as is, so as to appropriately develop corresponding applicable solutions that support the sustainability of RE projects in the region. Excluding the disadvantages presented in chapter 1, the ethnographic approach suggests that the researcher must be immersed in the society being studied. To achieve this may require a very long time period. Furthermore, it also suggests that the researchers can easily enhance their study and validate their research when already familiar with the situation. This is because more often than not, the provision of false information to researchers can sometimes be inevitable as the locals being studied are more focused on their own interest. However, as being familiar with the situation provided an advantage, we were able to filter out contaminated data. Yet, this approach bestowed us with the opportunity to present the situation as is whilst utilizing the findings to develop appropriate solutions towards the problems.

Clinical Data Generation (CDG): The CDG, utilized in chapter 6 to generate and structure the data, facilitated in analyzing the impact of disturbances such as theft and vandalism has on the sustainability of RE projects in SSA. Although being a straightforward approach that includes the questioning of participants to retrieve appropriate data, it also possesses some strengths and weaknesses or in other words, uncertainty (in-depth explanation of approach can be seen locally within chapter 6).

Giving that data required for the study is nonexistent this approach provides the opportunity to generate data that is realistically representing the state of affairs within the region. Although the method is time consuming, it is easy to implement when participants are knowledgeable of the situation around them. Thus, the aspects of imagination are ruled out. One principal weakness of this approach in the context of our study is the psychological demeanor (i.e. responses provided by some participants maybe based on the fact that there is financial incentives connected the process and not based on the reality of the true personal viewpoint of the situation), making it strenuous and near impossible to demarcate the so-called contaminated responses of individuals. Precluding the prior, the approach sufficiently presents an in-depth analysis that disturbances such as theft and vandalism possess on the impact of sustainability. It further presents applicable recommendations based on project type and location that should be considered by stakeholders implementing RE projects in the region.

Individually, all these methods possess strengths and weaknesses. However, when combined into one mixed-method approach that focus on enhancing sustainable development in SSA, the complementation of the approaches towards one another becomes notable. The utilization of this approach is however inevitable giving that this research spans across multiple foci (location analysis, sustainable management, protection of infrastructure and societal benefits). For example, the determination of the optimal location for RE projects would only cover a tiny segment of the integrated mechanisms for sustainability. However, if the location of the RE project has been determined and a sustainable management method is developed for the corresponding project, the covered segment of the project being sustainable automatically increases. The addition of mechanisms for the protection of infrastructure and the projects attaining its expected societal benefit stows the project towards prodigious sustainability and substantial benefits.

In contrast, the mixed-method approach utilized in this thesis provides different ways to support the sustainability of RE projects in the region of SSA. The approach presents a unique viewpoint that must be considered in an integrated form for RE projects to be sustainable in the region.

8.5. Future Research Possibilities

In addition to the future research possibilities presented within the chapters, in this section we present future research possibilities on the characteristics of enhancing sustainable development as presented in Chapter 1. This may include technology design, knowledge transfer, system maintenance, project control, framework implementation, economic viability etc. Typically, most RE projects implemented in Sub-Saharan Africa are done by organizations originating from developed countries and after such implementations these organizations leave the management of these projects to the locals. More often than not, the management and training carried out in the perspective of developed countries is introduced to the locals and these knowledge transfer methods are not always compatible. It is important to study how the development in developed countries can be replicated in developing countries whilst taking into account the way of life of the region.

Furthermore, the technological designs destined for SSA are sometimes not sustainable. This is the case as explained in a corresponding paper (not included in this thesis), where solar panels implemented in the northern region of South Africa could not withstand the heat and humidity of the region. Another important consideration for future research is the applicability of the study. Various studies have been carried out with respect to policy implications and applications. However, none of these policies are yet to be implemented

adequately. In other words, the region of SSA has to become realistic towards the realization of sustainable development to provide a better life for the people. To achieve this, better planning is required within the notion of sustainability. Otherwise, future catastrophe will be the result.

As indicated in Chapter 1, we presented the shortcomings of already existing approaches towards mitigating the problems of energy in Sub-Saharan Africa, mainly being – its applicability to mostly developed countries, insufficient in its practical application to the region of SSA and mostly focused on policies. The latter being the most explored but the least implemented especially within the region of SSA. Nonetheless, even without the implementation of RE policies, projects are still being planned and executed. Thus, the sustainability of these projects could be hindered via the inadequate consideration of the corresponding mechanisms presented in this thesis. In addition to the thesis contributions presented in Section 8.2, our research emphasis is placed on the applicability of the mechanisms and solutions to mitigate the incompetence and corroborate the sustainability of RE projects, rather than just the regular theory development that has no applicability towards solving the energy crisis in the region of SSA.

Finally, further research into the creation of an applicable knowledge database should absolutely be considered. As most of the work presented in this thesis is more or less pioneering work, it could be utilized as a basis for future work on both research and practice in terms of enhancing sustainable development in SSA with respect to renewable energy development projects.

List of Academic Work

Core Peer-Reviewed Journal Publications

1. Ikejemba, E. C. X., & Schuur, P. C. (2016). Locating Solar and Wind Parks in South Eastern Nigeria for Maximum Population Coverage: A Multi-Step Approach. *Journal of Renewable Energy* 89, pp. 449-462.
2. Ikejemba, E. C. X., & Schuur, P. C. (2016). Designing a Nation-Wide Network of Solar and Wind-Assisted Parks for Nigeria and for Ghana. *International Journal of Energy and Environmental Engineering* 7 (2), pp. 177-198.
3. Ikejemba, E. C. X., Mpuan, P., Schuur, P. C., & Van Hillegersberg, J. (2017). The Empirical Reality & Sustainable Management Failures of Renewable Energy Projects in Sub-Saharan Africa (Part 1 of 2). *Journal of Renewable Energy* 102, pp. 234-240.
4. Ikejemba, E. C. X., Mpuan, P., Schuur, P. C., & Van Hillegersberg, J. (2017). Failures & Generic Recommendations Towards the Sustainable Management of Renewable Energy Projects in Sub-Saharan Africa (Part 2 of 2). *Journal of Renewable Energy*. [Accepted Article in Press at time of Dissertation Print].
5. Ikejemba, E. C. X., & Schuur, P. C. (2017). Attaining the Upper Bound Societal Benefits of Renewable Energy Projects in Sub-Saharan Africa: The Dwindling Reality. *Journal of Environment, Development and Sustainability*. In Review Process.
6. Ikejemba, E. C. X., & Schuur, P. C. (2017). Analyzing the Impact of Theft and Vandalism in Relation to the Sustainability of Renewable Energy Development Projects in Sub-Saharan Africa: A Mathematical Analysis Approach. *International Journal of Energy and Environmental Engineering*. In Review Process.

Under Review & In-Process

7. Ikejemba, E. C. X. (2017). The Physical Reality Vs. Scientific Reality of Sustainable Development in Sub-Saharan Africa: A Renewable Energy Focus. *Journal of Renewable Energy*. In Process.

Academic Presentations/Lectures at Conferences and Foreign Universities

8. Ikejemba, E. C. X. (2017). The Physical Reality Vs. Scientific Reality of Sustainable Development in Sub-Saharan Africa: A General Perspective. Symposium: Sustainable Development in Africa. University of Twente
9. Ikejemba, E. C. X. (2016). Implementing Renewable Energy Projects to Create Gainful Employment in SSA. Smart Villages: New Thinking for Off-grid Communities Worldwide. Presented 23rd – 25th May, 2016. Accra, Ghana
10. Ikejemba, E. C. X. (2016). Sustainable Project Implementation and the Corresponding Impact in Sub-Saharan Africa. Rotterdam University of Applied Sciences. February 2016.
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About the Author

Eugene Chidiebere Xavier Ikejemba was born in Lagos, Nigeria. In 2006, he completed his high school education at the prestigious Air Force Military School in Jos. Afterwards he studied and completed an associate degree in Computer Science with a specialization in Computer Networking in 2009 (cum laude) from the Institute of Business and Information Technology in Cape Town. Soon after, he enrolled and completed his Bachelor of Science degree in Industrial Engineering (cum laude) in 2012 from Eastern Mediterranean University in North Cyprus.

Further, in the same year Eugene started his Masters of Science degree in Industrial Engineering and Management at the University of Twente with a specialization in Logistics and Production Management. During this time, Eugene developed an attraction for sustainable development in Africa. This appeal led him to further his research on sustainable development within the context of a Doctorate Degree, under the supervision of Prof. Dr. J. van Hillegersberg, Dr. P.C. Schuur and Prof. Dr. J. Junger. This thesis presents the results of the research.

Without doubt the renewable energy (RE) sector in Sub-Saharan Africa (SSA) is currently booming exponentially. More often than not, these projects are designed as just “projects” thus leading to their failure in the shortest possible time. This can be easily seen from numerous already failed projects. Given that energy is the backbone of the economy in the region, the continuous use of unsustainable methods of energy generation coupled with the epileptic power supply and infrastructure, such circumstances cannot continue to prevail.

The long-term sustainability characteristics of these so-called projects are rarely considered during their planning and implementation. Despite the existence and buzz created by the annotation of sustainable development, in the region of SSA, it does seem like these definitions are nonexistent.

This thesis develops and presents integrated sustainability mechanisms that should be considered by stakeholders participating in the development and implementation of RE projects in SSA. A bottom-up approach is utilized that investigates the failures of existing projects while presenting the current state of affairs. Multiple sustainability characteristics - that include location analysis, sustainable management, protection of infrastructure and societal benefits - are presented and their application in the region is further executed. For any RE project implemented in the region of SSA to be successful, the integrated sustainability mechanisms presented in this thesis “*must*” be adopted.