Alternative Energy Sources in Ghana – The Case of Solar Photovoltaic

By

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DECLARATION

I hereby declare that this project is the result of my own work undertaken under the supervision of the undersigned and all works have been referenced.

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ACKNOWLEDGEMENT

In many developing countries, like Ghana, the “3Rs” of Sustainability - Reduce, Recycle and Reuse are hard to implement due mainly to financial constraints and competing national development priorities. The current environment in Ghana as it pertains to achieving its sustainability goals particularly in the energy sector have shaped my research interest and was a major driver in my pursuit of the master’s in environmental studies (MES). The past two years have been filled with valuable experiences. I met my beautiful wife Dr. Sandra Adjei and I started my consulting company. I am grateful to the professors in the Faculty, especially Professor Jose Etcheverry and Peter Love, as well as my classmates and other student mentors (PhD candidate James Boafo from Queensland University, Australia). I am also grateful to my parents for their prayers and emotional support. I want to thank God almighty for the strength and wisdom he granted me to achieve such a great accomplishment. I will be the first in my family to receive my master’s degree. A big thank you to Mr. Stephen Ryder from Q9 for his contributions to my company NigelEnergy Consulting. Above all, I dedicate my Masters to Patience Ashie, without her my Masters wouldn’t have become a reality.

ABSTRACT

The Renewable Energy (RE) landscape in Ghana has received considerable attention over the last few years. Much of this attention is the result of the on-going energy crisis, chiefly, the rising cost of supplying power to meet domestic and commercial demand in the country. Lost government revenues from businesses as many reduce operations, and overall public dissatisfaction with the governments' management of the energy sector has given further impetus to discussions about renewable energy. Though Ghana remains heavily dependent on fossil fuels, the country, given proper investment, and research and development could harness energy from renewable sources such as solar, wind, biomass and hydroelectricity. These renewable energy sources would help Ghana diversify its energy sector and improve its energy security. This major research paper adopts a case study methodology to critically explore renewable energy projects in the West African sub-region namely, Ghana. The paper focuses on a pilot project that seeks to electrify five local police outpost in the Greater Accra Region using photovoltaic cells, and uses that analysis to understand better how to expand the renewable energy sector in Ghana.

FOREWORD

In the last few years, there has been significant changes in the energy sector. Of note, is the growing relevance of renewable energy technologies as a substitute for fossil fuel. Developments include the introduction of smart grids and grid-tied systems and policies such as feed-in-tariffs that allows entities and individuals generating their own electricity to sell to utility companies or energy retailers. In light of the above, further research and development into more practical and affordable technologies for harnessing energy from renewable sources is needed. Designing national energy strategies that are focussed on exploiting Ghana's renewable energy potential is therefore the best option for delivering sustained and reliable energy supplies that are essential for economic development as well as to meet the energy needs of the growing populace.

This research paper has thus made a case for the deployment of small-scale solar PV technologies to improve electrification rates in Ghana, particularly in rural communities; to provide a more reliable source of electricity to supplement and/or replace reliance on the national grid; and finally, to improve the energy security in the country. This research paper, which emerged from a pilot project, is intimately linked to the goals of my MES plan of study. During my MES, I wanted to develop the skills necessary to develop renewable energy policies that promote the expansion of greener and renewable energy technologies in Ghana. Having experienced Ghana's constant power outages, locally referred to as *'dumsor'*, I worked with RETScreen Expert, a clean energy management software to develop small-scale renewable energy solutions to help minimise reliance on the main grid yet, yet feed surplus energy back to the grid.

The paper explores that status of the energy sector in Ghana, identifies key policy barriers, and puts forward policy recommendations to overcome some of the stated barriers. Further project phases and also new projects will fill in the knowledge and informational gaps, as well as make more concrete suggestions based on verifiable data for the reform of Ghana's current energy sector that sees a greater contribution from the renewable energy sector in the overall energy mix.

TABLE OF CONTENTS

ACKNOWLEDGEMENT ..... *i*

ABSTRACT ..... *ii*

FOREWARD ..... *iii*

TABLE OF CONTENTS ..... *iv*

LIST OF FIGURES ..... *vi*

LIST OF TABLES ..... *vi*

LIST OF ABBREVIATIONS ..... *vii*

Chapter 1 ..... *1*

Introduction *1*

- **Research Question:** **5**
- **Research Objectives:** **6**
- **Scope of the Study** **6**
- **Limitations of the Study** **6**

Chapter 2 – Literature Review *8*

- **Energy Landscape in Ghana** **8**
- **Challenges Facing the Energy Sector in Ghana** **13**
  - Intermittent & Severe Droughts 14
  - High Cost of Crude Oil 15
  - Lack of diversity in the electricity generation mix 16
  - High levels of losses plaguing the Distribution Systems & Free-riders 17
  - Debt to the Electricity Company of Ghana (ECG) 18
  - Tariffs and Subsidies 18
- **Overview of the Renewable Energy Landscape in Ghana** **19**
  - Hydro-power 23
  - Biomass 25
  - Wind Power 26
  - Solar Energy 27
- **Barriers to Renewable Energy Sources** **29**

Chapter 3 - Methodology *32*

- **Case Study Methodology** **32**
- **Research Methods** **33**
  - RETScreen International Expert 33
  - Analysis of Secondary Data 35

Chapter 4 – Case Study – Ghana *36*

- **Pilot Project Design** **37**
  - Load Calculation 41
- **Financial Feasibility Assessment** **42**
  - Project Cost 42

Simple Payback Period 44
Chapter 5 – Findings & Conclusions **..** ***49***
Discussion 49
Recommendations...51
Conclusion 52
References*……………………………………………………………………………*52

LIST OF FIGURES

FIGURE 1. ESTIMATED RENEWABLE ENERGY SHARE OF TOTAL FINAL ENERGY CONSUMPTION, 2015 2
FIGURE 2: ESTIMATED RENEWABLE ENERGY SHARE OF GLOBAL ELECTRICITY PRODUCTION, END-2016 3
FIGURE 3: DISTRIBUTION OF IDENTIFIED RENEWABLE ENERGY POTENTIAL IN AFRICA 4
FIGURE 4: MAP OF GHANA 8
FIGURE 5: STRUCTURE OF GHANA'S ELECTRICITY SECTOR. 11
FIGURE 6: STAKEHOLDERS IN GHANA'S ENERGY SECTOR. 12
FIGURE 7: ELECTRICITY CONSUMPTION PATTERNS – 2006-2016 13
FIGURE 8: AVERAGE ANNUAL BRENT CRUDE OIL PRICE FROM 2008 TO 2018 (IN U.S. DOLLARS PER BARREL) 16
FIGURE 9: HISTORIC ELECTRICITY GENERATION MIX FROM 2006 TO 2016 17
FIGURE 10: MAP SHOWING THE LOCATION OF THE AKOSOMBO DAM 23
FIGURE 11: RAINFALL TRENDS IN THE LOWER VOLTA BASIN FROM 1970 TO 2010 24
FIGURE 12: ENERGY MATRIX IN GHANA IN 2007 25
FIGURE 13: POTENTIAL HYDRO AND WIND POWER SITES IN GHANA 26
FIGURE 14: GHANA'S AVERAGE ANNUAL TOTAL DAILY SUM OF GHI IN WH/M^2/DAY (3YEAR AVERAGE) 28
FIGURE 15: DAILY SOLAR RADIATION AND CLIMATIC DATA FOR GHANA CAPTURED ON 2018-03-04 34
FIGURE 16: LOCATION OF THE FIVE POLICE STATIONS IN THE PILOT PROJECT 37
FIGURE 17: ILLUSTRATION OF A SOLAR PV AND POWER PACK GRID-TIED SYSTEM 38
FIGURE 18: FINANCIAL ANALYSIS OF THE FIVE PILOT PROJECT 45
FIGURE 19: SHOWS THE CASH FLOWS OF THE PROJECT 46
FIGURE 20: ANTICIPATED GHG EMISSIONS REDUCTION 47
FIGURE 21: THE SENSITIVITY ANALYSIS OF THE PROJECT 48

LIST OF TABLES

TABLE 1: ELECTRIFICATION RATES IN GHANA 9
TABLE 2: GENERAL ELECTRICITY CHARACTERISTICS (2015 EST.) 10
TABLE 3: INSTALLED GENERATION FACILITIES IN GHANA AS OF 2016 10
TABLE 4: THE DEVELOPMENT OF RENEWABLE STRATEGIES AND POLICIES IN GHANA 21
TABLE 5: FEED-IN-TARIFF RATES IN GHANA. 22
TABLE 6: PROVISIONAL LICENSES ISSUED FOR RENEWABLE ENERGY ELECTRICITY AS OF MARCH, 2016 29
TABLE 7: BARRIERS TO RENEWABLE ENERGY DEPLOYMENT IN GHANA 30
TABLE 8: INVENTORY ANALYSIS – APPLIANCES USED ON SITE AT THE POLICE STATIONS 42
TABLE 9: PV COST FOR EACH POLICE STATION 43
TABLE 10: ENERGY PRICE SOLD AND INFLATION PRICE 44

LIST OF ABBREVIATIONS

ECG – Electricity Company of Ghana

ECOWAS – Economic Cooperation of West African States

FIT – Feed-in-Tariffs

FSRU - Floating Regasification and Storage Unit

GDP – Gross Domestic Products

GHG – Greenhouse Gas

GoG – Government of Ghana

GMA – Ghana Meteorological Agency

GRIDCo - Ghana Grid Company

GWh – Gigawatt hour

IPP – Independent Power Producers

IRENA – International Renewable Energy Agency

IRR – Internal Rate of Return

K/Wh/m2/day - Kilowatt hour per meter square per day

kWp – Kilowatt peak

MW - Megawatt

NED – Northern Electricity Department

NPV – Net Present Value

PV – Photovoltaic

RE – Renewable Energy

RESPRO - Renewable Energy Services Project

SHEP - Self-Help Electrification Project

SLT - Special Load Tariff

SWERA – Solar and Wind Resource Assessment

UNCED - United Nation's conference on Environmental and Development (UNCED)

USD – US Dollars

WAGL - West African Gas Limited

VRA - Volta River Authority

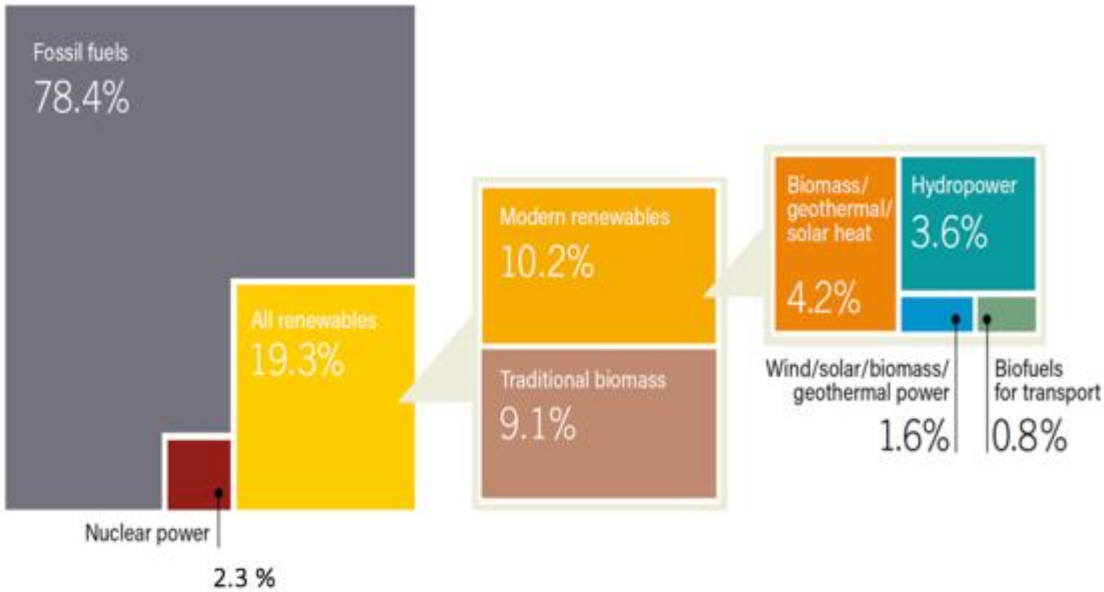
Chapter 1

Introduction

Achieving sustainability in energy supply on a global scale is one of the key challenges facing the twenty-first century. Since the industrial revolution, economies worldwide have consistently depended on fossil fuels (i.e., coal, oil and natural gas) as the driver of economic growth. Over-reliance on fossil fuels is still reflected in the global energy market, despite adverse environmental effects, dwindling supply, geopolitical tugs-of-war, political destabilization and civil unrest in major oil producing countries and threats to national security as global leaders expand their reach into sovereign states. To alleviate the global environmental impacts, such as climate change, groundwater contamination and biodiversity loss, to name a few, and combat fears of inevitable peak oil, more resource efficient, low carbon and environmentally sustainable, economic policies are expected to be implemented by even the most reticent countries.

The green economy model is a potential remedy to some of the key market and institutional failures that characterize conventional development models based on fossil fuel consumption. It is hailed as a more effective pathway for advancing economic, social, and environmentally sound development policies, especially in developing countries where energy consumption is increasing (Lucien, Mark, & Martyn, n.d.; REN21, 2017). These interventions cut across all sectors of the economy, with the energy sector receiving considerable attention and investment as we transition towards renewable energy sources. Rickerson (2012, p. 3) proposes that investment in energy efficient technologies and renewable energy technology could potentially result in 20 per cent increase in employment by 2050, while delivering robust economic growth and reduced greenhouse gas (GHG) emissions (p.1). Renewable Energy (RE) is can be as a positive shift to environmentally sustainable energy consumption and economic growth.

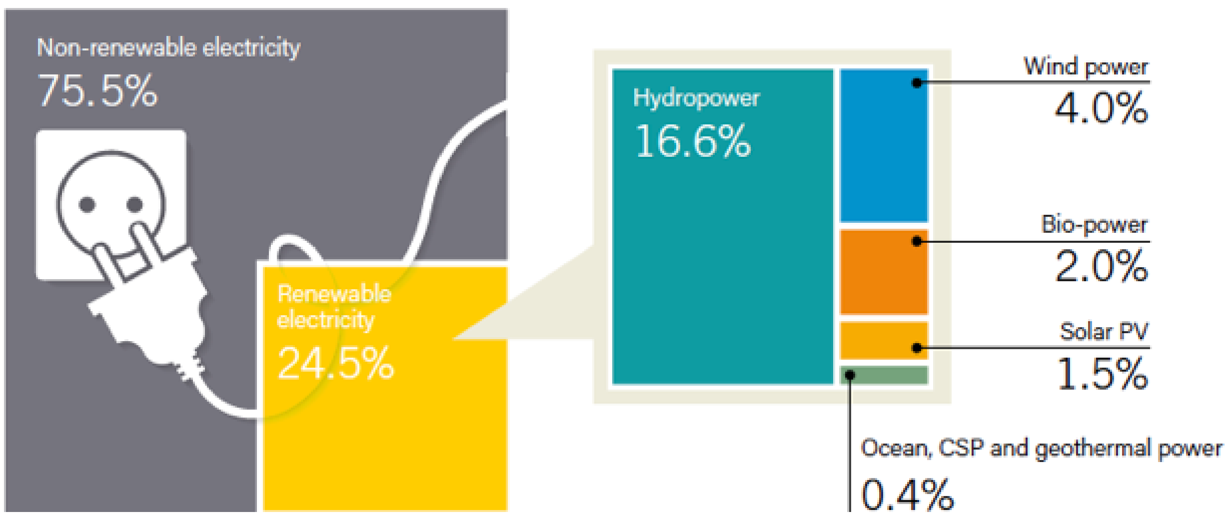
Figure 1. Estimated Renewable Energy Share of Total Final Energy Consumption, 2015



Source. REN21 (2017).

Figure 1 above shows the breakdown of renewable energy as a percentage of total final energy consumption in 2015. RE accounted for an estimated 19.3 per cent of global final energy consumption. Of this total share, traditional biomass accounted for about 9.1 per cent; modern renewables approximately 10.2 per cent with hydropower accounting for 3.6 per cent, other renewable power sources 1.6 per cent, renewable heat energy 4.2 per cent, and transport biofuels 0.8 per cent (REN21, 2017, p. 30). RE is therefore positioned as a viable alternative that can meet the energy needs of consumers, with the additional benefit of enhancing energy security and mix in vulnerable and emerging economies (Rickerson, 2012). Because of its affordability, RE is also gaining more traction in many developing countries seeking to expand citizen access to reliable electricity and attaining higher rates of electrification. Renewable power capacity has continued to increase annually. In the most recent report by REN21 (2017, p. 33), RE accounted for about 62 per cent of net additions to global power generating capacity. By year's end, renewables comprised an estimated 30 per cent of the world's power generating capacity – enough to supply an estimated 24.5% of global electricity, with hydropower providing about 16.6 per cent (REN21, 2017). (see figure 2).

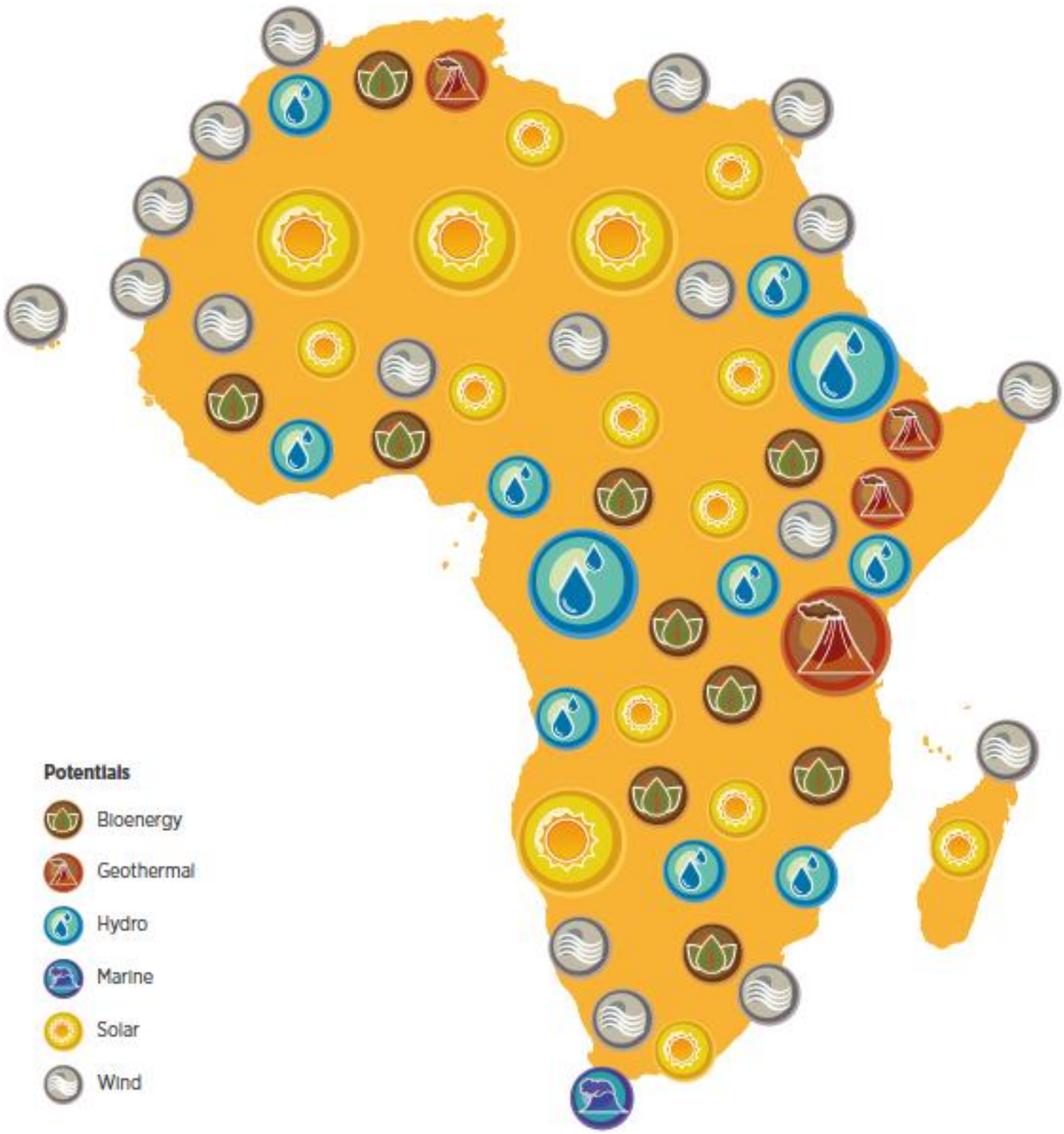
Figure 2: Estimated Renewable Energy Share of Global Electricity Production, End-2016



Source. REN21 (2017).

Growing interest and investment in Renewable Energy (RE) can, therefore, be linked to volatility in the oil and gas industry; fears of energy insecurity as oligarchic producers control supply and manipulate demand and; more recently, a wave of greater environmental awareness.

Figure 3: Distribution of identified renewable energy potential in Africa



Source: International Renewable Energy Agency (IRENA), (2013) - analysis based on the Global Atlas.

In addition, “comparatively low global fossil fuel prices; dramatic price reductions of several renewable energy technologies (especially solar PV and wind power); advancements energy storage” have further shaped the discourse around RE (REN21, 2017, p.29). Taken together, these factors have propelled discussions and strategies geared towards energy efficient technologies and the exploration of RE sources e.g., solar, wind, hydropower and biomass. These statistics augur well for developing countries, particularly in the West African sub-region that are plagued by the high cost of fuel globally, over-reliance on hydroelectric power (Ghana), lack of investment, inadequate infrastructure (Moujaled, 2014), widespread energy inefficiencies due to systemic challenges, and poor rates of electrification that have created a non-ending energy crisis. These challenges can be overcome given Africa’s renewable energy power potential. Figure 3 shows the distribution of identified renewable potential in Africa. In 2013, the RE potential of the continent was estimated to be substantially larger than current and projected power consumption needs. Though hydropower and wind are significant sources of RE, geothermal, solar and bioenergy have an important role to play in covering future demand (IRENA, 2013).

Research Question

Energy, as the backbone of economic development, is also essential for the alleviation of poverty (Kumi, 2017). With nearly half of the world’s poor residing in developing countries, there is a need for reliable, clean and affordable energy supply from sources other than fossil fuel e.g., such as wind, solar and geothermal. These renewable sources are easily accessible and amenable to decentralization, particularly to countries in Sub-Saharan Africa. Despite the noted benefits, developing countries stand to gain through the adoption of renewable energy, there are barriers that hinder its development. This major research paper, therefore, adopts a case study methodology to critically review the status of renewable energy projects in the West African sub-region, namely, Ghana. To provide practical context, I analyze a pilot project that seeks to electrify five local police outpost in the Greater Accra Region using photovoltaic cells. The aim of that case study is to assess the feasibility of deploying RE technologies, particularly, solar power in Ghana – for domestic and commercial purposes. To this end, my specific research questions are:

i) What are the principal challenges that developing countries, in particular, Ghana face in attempting to transition to renewable energy?

ii) What is the role of the government in RE deployment?

iii) What lessons can Ghana learn from RE projects in the West African sub-region?

Research Objectives:

The main objectives of this major research paper are:

i) To identify and explain the barriers to the development and adoption of renewable energy in Sub-Saharan Africa – West African sub-region, particularly, Ghana;

ii) To assess the viability of RE development in Ghana;

iii) To assess the experience of the rooftop solar photovoltaic pilot project; and

iv) To propose recommendations for improving RE deployment in Ghana.

Scope of the Study

This major research paper has five (5) chapters. Following the introductory chapter, chapter two details the energy landscape in Ghana and draws attention to the challenges facing the energy sector in Ghana. That background is provided as, context for the adoption of more progressive RE policies and a full transition towards RE. The second chapter provides a more detailed discussion of the importance of RE development. Chapter three explains the methodology that guides the research. The fourth chapter focuses on an analysis of a pilot solar project in Ghana. The fifth chapter concludes the research paper and includes a summary of key findings, recommendations and areas for future research.

Limitations of the Study

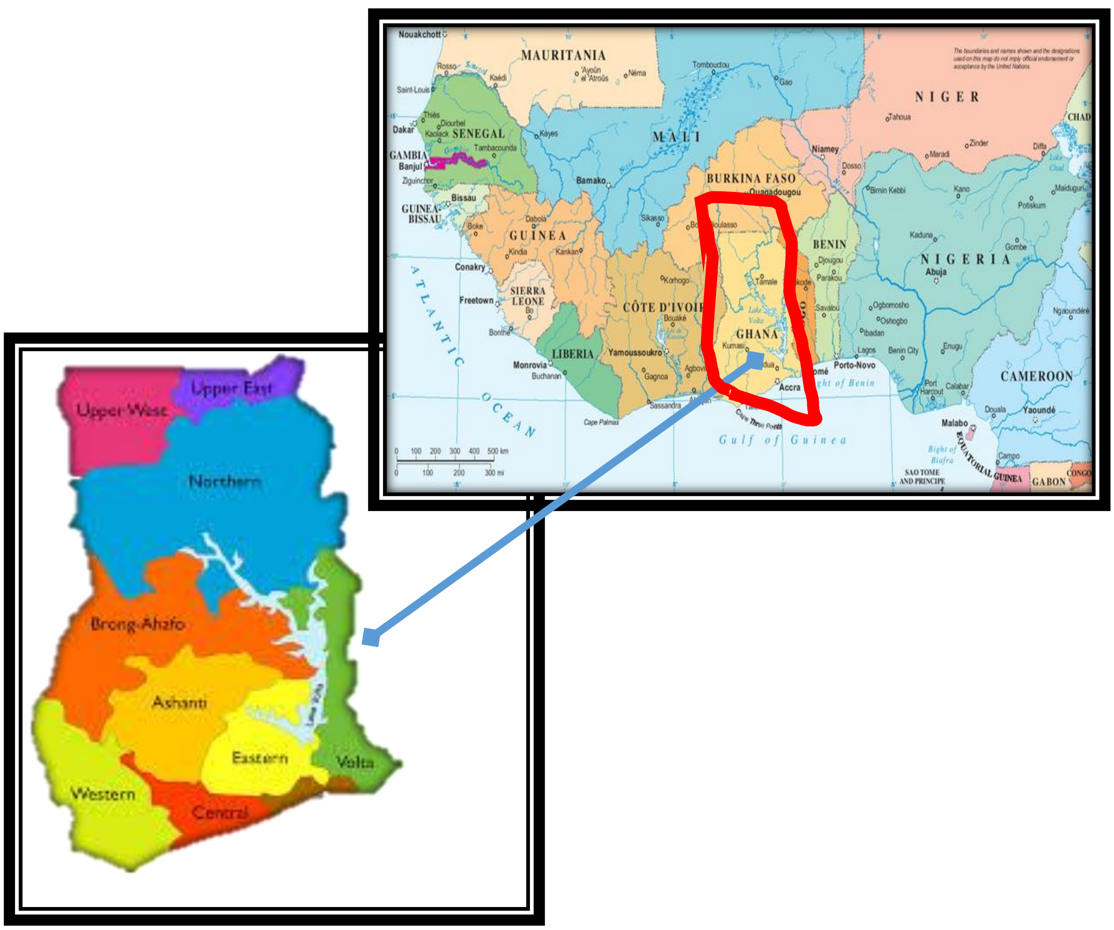
While every effort has been made to maintain methodological rigour, I note that the pilot project is still on-going and as such a comprehensive accounting of all the benefits (short, medium and long-term), cannot be fully known at this time. Furthermore, lack of electricity consumption data (due to the absence of electricity meters) for the five Police Stations prior to the commencement of the study have made it impossible to undertake a comparison of usage rates, electricity cost and savings before and after the project.

Chapter 2 – Literature Review

Energy Landscape in Ghana

This chapter focuses on the key features of the energy sector in Ghana. It makes specific reference to electricity production and distribution, as this is one of the more pressings problems plaguing the country. Ghana, a former British colony, is located in West Africa. Its size is approximately, 238,533 sq. km and it shares borders with Burkina Faso, Cote d'Ivoire, and Togo. In 2017, the population was estimated to be about 27 million (Central Intelligence Agency (CIA), n.d.).

Figure 4: Map of Ghana



Source: Google Maps.

Ghana has an open market-based economy with relatively few barriers to international trade and investment. In comparison with other countries in the region, Ghana is well-endowed with natural resources e.g., gold, timber, industrial diamonds, bauxite, manganese, fish, rubber, hydropower, petroleum, silver, salt, limestone (Chizoba, 2017). Major industries include: mining, lumber, light manufacturing, aluminium smelting, food processing, cement production, small commercial shipbuilding and petroleum (Central Intelligence Agency, n.d.). Ghana's emerging oil industry has boosted economic growth; however, the fall in oil prices in 2015 reduced by about half of Ghana's oil revenue. Production at Jubilee (Ghana's first commercial offshore oilfield), began in mid-December 2010 (Central Intelligence Agency, n.d.). Production from two more fields, TEN and Sankofa, started in 2016 and 2017 respectively. The country's first gas processing plant at Atuabo is also producing natural gas from the Jubilee field, providing power to several of Ghana's thermal power plants (Central Intelligence Agency (CIA), n.d.).

Table 1: Electrification Rates in Ghana

ELECTRICITY ACCESS	ELECTRIFICATION RATE
Total Population	72%
Urban Areas	92%
Rural Areas	50%
Total Population without electricity	7,300,000

Source: (Central Intelligence Agency (CIA), n.d.).

Tables 1 and 2 summarise the energy landscape in Ghana. As of 2015, 72 per cent of Ghana's population had some access to electricity. Higher rates were recorded in urban areas at 92 per cent compared to rural areas at 50 per cent.

Table 2: General Electricity Characteristics (2015 est.)

GENERAL ELECTRICITY CHARACTERISTICS	2015 (ESTIMATES)
Electricity Production	11.09 billion kWh
Electricity Consumption	8.377 billion kWh
Electricity Exports	552 million kWh
Electricity Imports	223 million kWh
Electricity installed generating capacity	2,839 MW

Source: (Central Intelligence Agency, n.d.).

Ghana continues to experience challenges with its electricity supply despite the fact that electricity production surpasses electricity consumption and the country exports more electricity than it imports. Total installed capacity is mainly from the hydropower facilities at Akosombo, Bui, and Kpong and fossil fuels which power thermal plants at Takoradi, Sunon, Tema and Kpone. Ghana's potential for renewable energy is great including: biomass, solar, wind and hydropower. Despite these abundant and environmentally sound energy options, little has been done to spearhead the development and adoption of renewable energy technologies (Please see table 3).

Table 3: Installed generation facilities in Ghana as of 2016

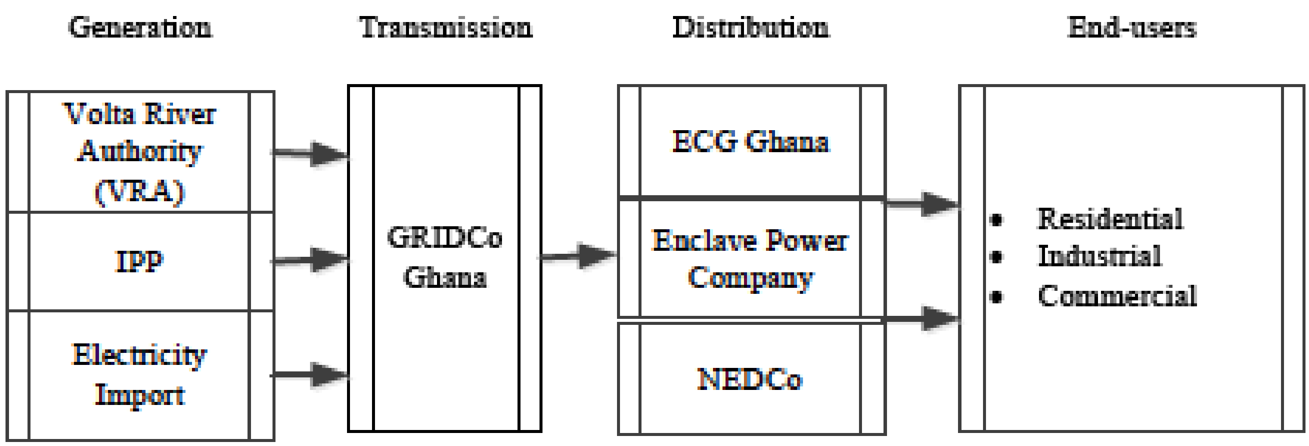
ENERGY SOURCE/PLANT	INSTALLED CAPACITY MW	DEPENDABLE CAPACITY MW	% OF INSTALLED CAPACITY
Hydro (water)	1580	1508	41.6
Thermal (natural gas, oil, diesel)	2192	1995	57.8
Renewables (biomass, solar, wind, hydro	22.6	22.1	0.6
Total Capacity	3795	3525	100

Source: Adapted from Kumi (2017).

According to Gyamfi et al., (2015, p. 6), 88 per cent of Ghana's electricity generation capacity and assets (excluding renewables) are owned by the state-owned Volta River Authority (VRA), Ghana

Grid Company (GRIDCo), with the remaining 12 per cent owned by Independent Power Producers (IPP). Ghana Grid Company (GRIDCo) operates the national grid and manages the power system as System Operator. The Electricity Company of Ghana (ECG) is responsible for electricity distribution in the south and the Northern Electricity Department (NED) is responsible for distribution in northern Ghana. Enclave Power Company, a small power company, has a contract agreement with the Electricity Company of Ghana to supply electricity to the Tema Free Zone Enclave (Gyamfi et al., 2015). The Free Zone provides focal points for the production of goods and services for foreign markets (Energy Commission of Ghana, 2017; Gyamfi et al., 2015; Kumi, 2017; Ministry of Energy, 2010). Please see Figure 5 below which summarizes the structure of Ghana's Electricity Sector.

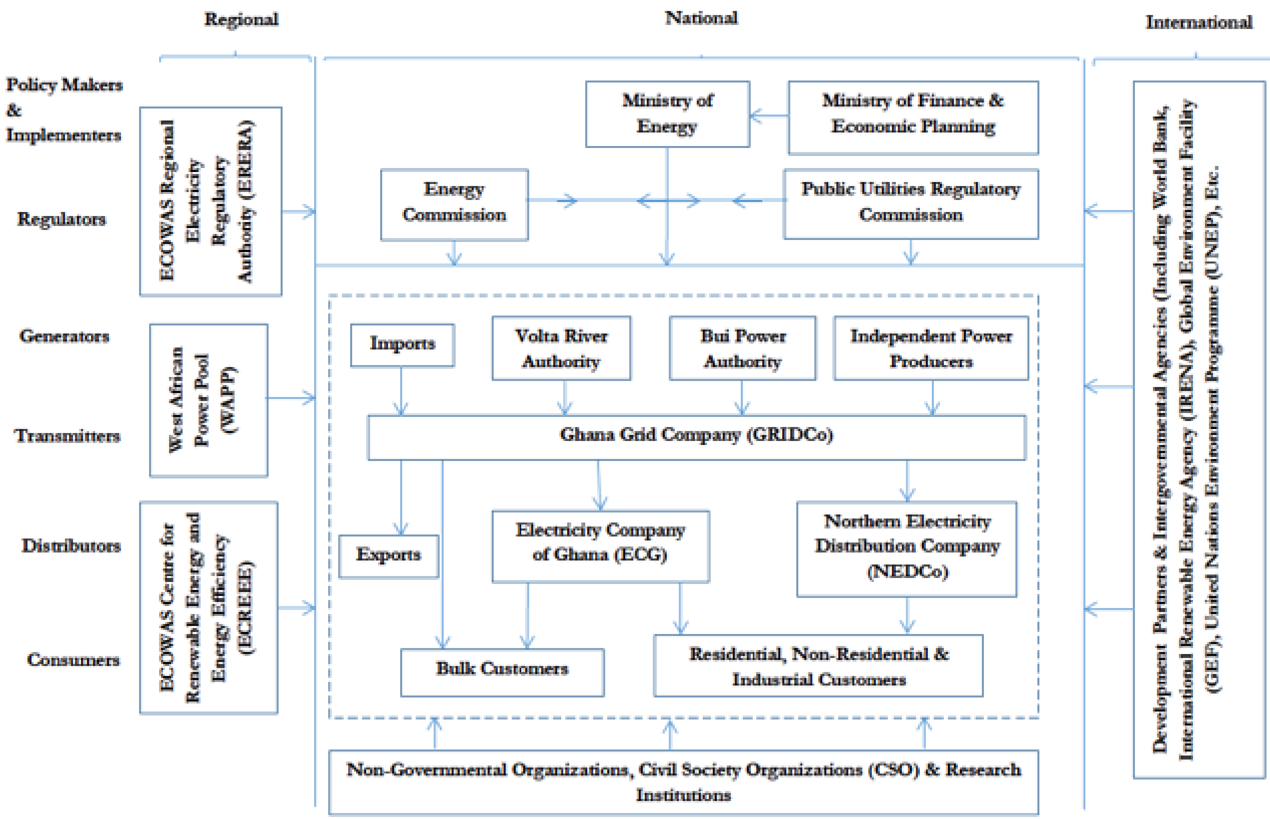
Figure 5: Structure of Ghana's Electricity Sector.



Source: Gyamfi et al., (2015).

Stakeholders in Ghana's power sector cut across national, regional and international institutions (Please see Figure 6). They include policy-making and implementation institutions, regulatory agencies, generation, transmission and distribution companies, consumers, research and advocacy groups, as well as, financial institutions (Kumi, 2017).

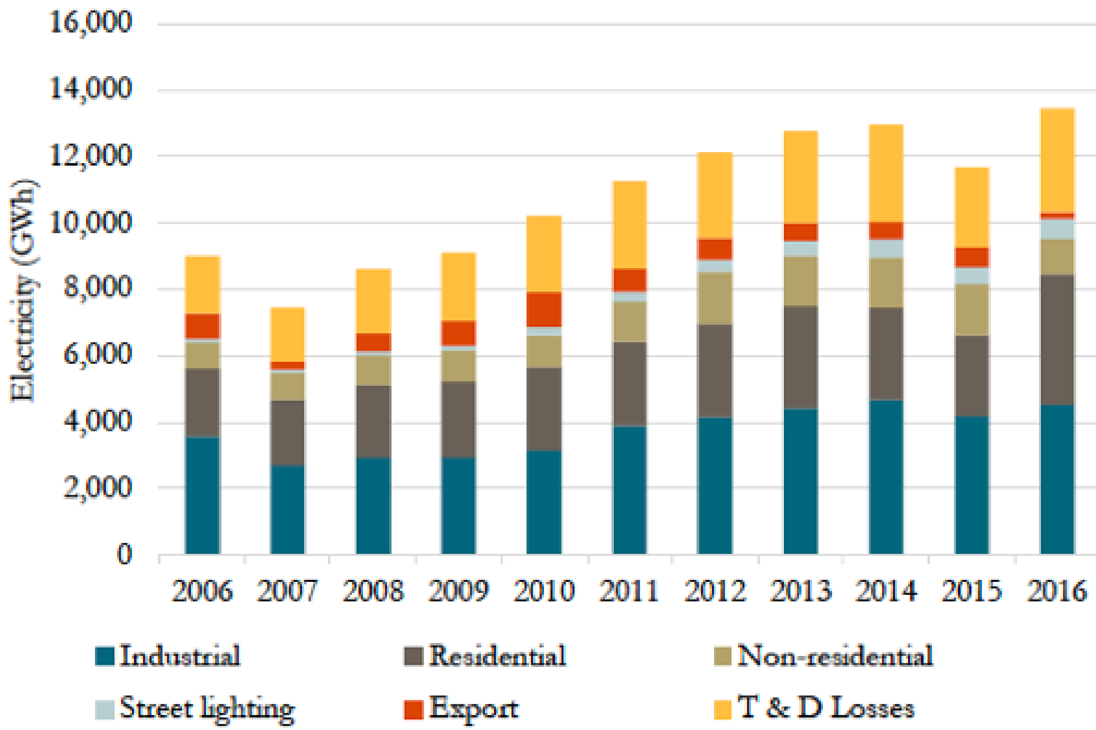
Figure 6: Stakeholders in Ghana's Energy Sector.



Source: Kumi (2017).

Ghana's demand for energy continues to increase in direct relation to expanding economic activity and population growth which feeds household demand (Mensah, Marbuah, & Amoah, 2016). The country's energy supply mix, biomass, hydropower and thermal feeds into its energy – demand economic sectors namely residential, commercial, service sector, agricultural and fisheries, transport and industries (Kofi-Opata, 2013; Mensah et al., 2016). Electricity consumers in Ghana are classified into industrial, residential, non-residential and street lighting by the Energy Commission of Ghana (Kumi, 2017). Industrial, sometimes referred to as Special Load Tariff (SLT) consumers are those who use electricity for industrial purposes (Kumi, 2017). Figure 7 shows that the industrial, residential and non-residential sector are the three top consumers of electricity; whereas export and street lighting account for the least. Losses in transmission and distribution (including commercial losses) were higher than the consumption in the non-residential sector. On average, transmission and distribution losses accounted for 21.9 per cent of total electricity consumption annually (Kumi, 2017, p. 9).

Figure 7: Electricity Consumption Patterns – 2006-2016



Source: Kumi 2017 (data extracted from Energy Commission of Ghana 2016-2017).

Challenges Facing the Energy Sector in Ghana

Ghana's commitment to universal access to electricity by 2020 is documented in its *National Electrification Scheme of 1989* (Gyamfi et al., 2015). The main objective of the scheme is to expand electricity supply to all parts of the country by 2020. The National Electrification Scheme also supports research and development in renewable energies, mainly solar, wind, biomass, and hydro in an effort to diversify the country's energy mix and reduce reliance on high-cost fossils fuels (International Energy Agency, 2012). Despite this roadmap towards 100 per cent electrification, Ghana is facing an ongoing energy crisis which commenced in the late 1970s. Various institutional reports and academic research papers have pointed the finger at the country's dependence on its poorly functioning and inefficient hydro-dams, high cost of oil to power thermal plants (which were introduced as a stopgap measure and as a backup for the hydro plants), unavailability of cheaper energy sources e.g., natural gas, coupled with a lack of consistent investment in the energy sector (Gyamfi et al., 2015; Kemausuor, Obeng, Brew-Hammond, & Duker, 2011; Kumi, 2017; Mensah et al., 2016). In a bid to quickly curb the deleterious effects of the crisis, the Ministry of Energy and the Energy Commission developed various policy and regulatory instruments to guide the operation of the electricity sector. As of 2018, the lack of affordable electricity still remains a major economic challenge for Ghana. Some of the major challenges facing the energy sector in Ghana including intermittent and severe drought conditions, high cost of crude oil, lack of diversity in the electricity generation mix, high levels of losses plaguing the distribution systems, debt to the ECG and a poor tariff structure impacting on the financial stability of the utility companies (which are described in more detail below).

Intermittent & Severe Droughts

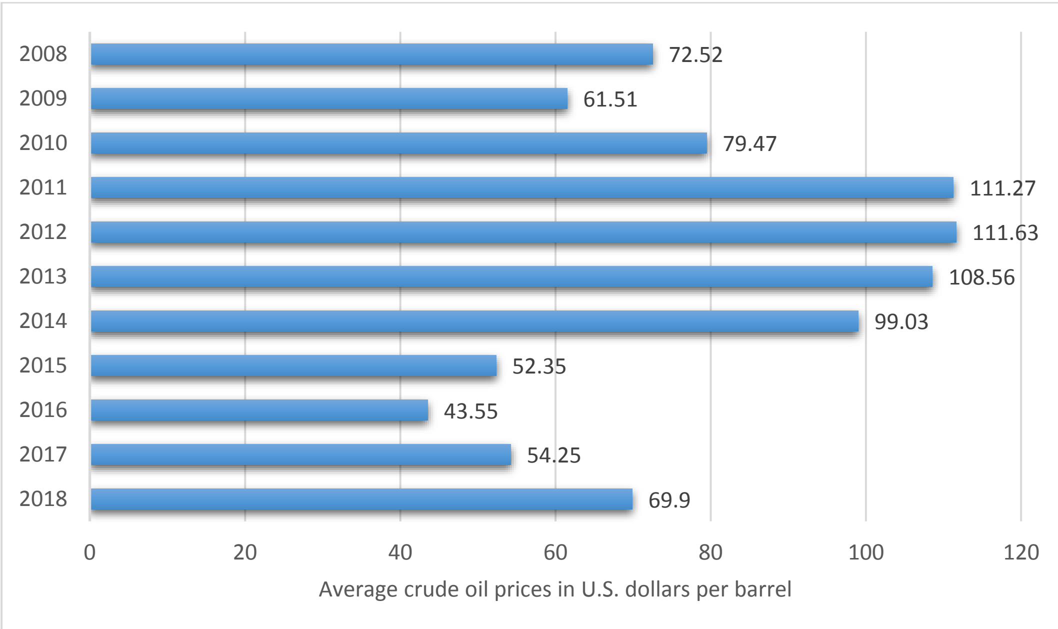
Research has shown that climate change effects, especially alterations in evaporation, river discharge, and temporal precipitation patterns, have the potential to negatively impact hydroelectric production (Arndt, Asante, & Thurlow, 2015; Blackshear et al., 2011; Gyamfi et al., 2015; Schaeffer et al., 2012). Since 1998, Ghana has experienced severe droughts that have resulted in low water inflow into its hydro-dams (Ministry of Energy, 2010). The hydro potential, already seasonal in nature, is therefore further limited by changing climatic conditions. This situation has led to a load-shedding program to manage the demand for the entire country. This has impacted the electricity supply to the industrial and commercial sectors, resulting in reduced production and in some instances, the closing down of vulnerable small to medium size businesses, exacerbating further, already high unemployment rates. Domestic consumers are also negatively affected by constant power outages. Areas with water shortages could look into sea water desalination as a substitute source (Oyoh, 2016, p.5).

The intermittent supply of electricity has had the additional effect of increasing reliance on diesel operated generators to provide power and some level of energy security, considering the state's failed attempts. A recent report has accused European oil companies and commodity traders of exporting dirty diesel to African countries. A recent report by Public Eye Investigation reveals that much of the diesel imported from Europe contains high levels of sulphur, which poses high risks to individuals and the country as a whole (Marc Guéniat, Harjono, Andreas Missbach, & Viredaz, 2016). The report states that diesel with sulphur concentrations that exceed 10 parts per million are regularly sold in Ghana and other countries in West Africa (Guéniat, Harjono, Missbach, & Viredaz, 2016; Stewart, 2017). The use of 'dirty diesel' has directly contributed to air pollution and an increase in cardiovascular and respiratory illnesses generally (Guéniat, Harjono, Missbach, & Viredaz, 2016; Stewart, 2017).

High Cost of Crude Oil

The volatile costs of fuel globally and nationally are also affecting Ghana's energy sector. Crude oil importation accounted for 80 per cent of the trade deficit in 2001 (Armah, 2003). Volatility in the price of crude oil worsens Ghana's energy security as it directly affects the ability of the power companies to supply electricity to all economic sectors and for domestic usage at an affordable price (Ministry of Energy, 2010). Figure 8 below illustrates the volatile changes in world oil prices.

Figure 8: Average annual Brent crude oil price from 2008 to 2018 (in U.S. dollars per barrel)



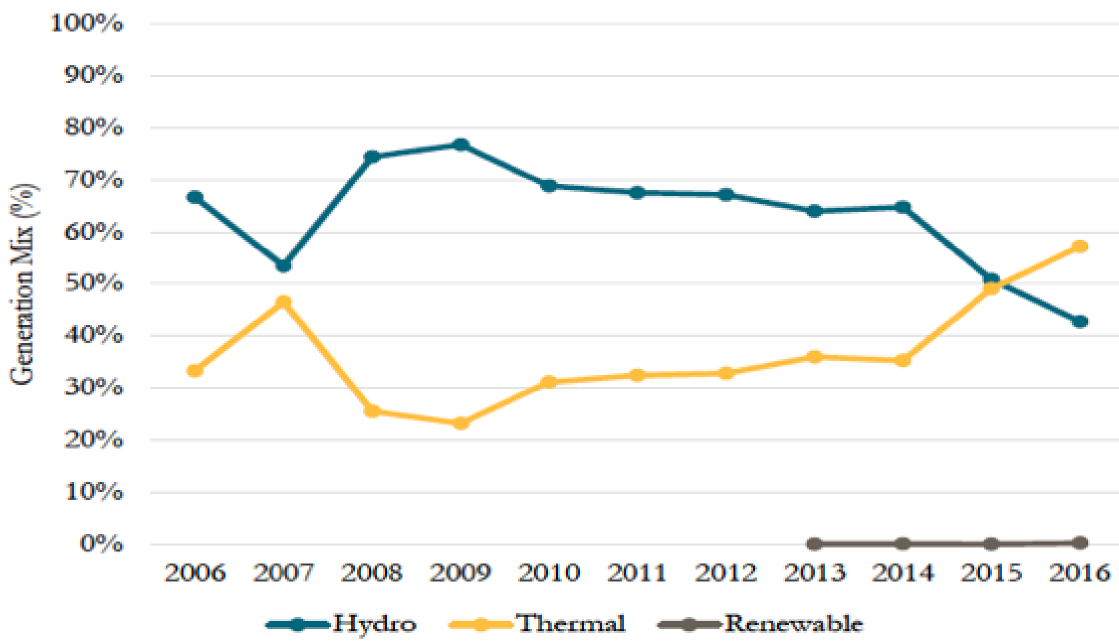
Source: Statista (2018).

In 2017, the average price of Brent crude oil was at 54.25 U.S. dollars per barrel. Brent is the world's leading price benchmark for Atlantic basin crude oils. The price of crude oil influences costs across all stages of the production process and consequently alters the price of producing electricity especially in countries like Ghana which lacks proper infrastructure and efficient distribution system.

Lack of diversity in the electricity generation mix

Figure 9 shows Ghana's electric generation mix. While biomass and other local alternatives are used, the dominant sources of power remain are hydro (cheapest source) followed by more expensive thermal generation.

Figure 9: Historic electricity generation mix from 2006 to 2016



Source: Kumi (2017) adapted from Energy Commission of Ghana.

As of 2015, thermal generation is poised to surpass hydropower. Missing in this mix are renewable sources, which can play a substantive role in diversifying the country's electricity generation mix.

High levels of losses plaguing the Distribution Systems & Free-riders

Ghana's power sector is also besieged with a lot of free-riders and illegal connections. This makes it difficult for the sector to recoup revenues that would cover its costs and support reinvestment. Energy losses amounted to about 26 per cent of the total primary supply in 2000 and increased to about 30 per cent in 2004 (Energy Commission of Ghana, 2016). Energy losses are also tied to the use of obsolete household and industrial equipment and lack of technical capacity to effectively convert and distribute power along ageing and outmoded infrastructure. For example, ECG's power losses are mainly attributed to obsolete cables (Energy Commission of Ghana, 2016).

Debt to the Electricity Company of Ghana (ECG)

In May 2016, officials of the Electricity Company of Ghana stated that the Government of Ghana (GoG) had been unable to repay around USD 240 million it owed the ECG. Additionally, VRA, the main generator and supplier of electricity in Ghana, is reportedly in financial difficulties with banks and supply chain corporations. The GoG's grim financial position has slowed private sector investment and infrastructure development. This problem was exacerbated in 2016 by the Golar Tundra floating regasification and storage unit (FSRU) project (Paisner LLP, 2017; Shillito, 2016). The FSRU project was expected to commence operations by mid-2016 and supply 250 million cubic feet (mcf)/day of regasified LNG to the 230MW Kpone thermal power plant owned by VRA (Paisner LLP, 2017; Shillito, 2016). However, West African Gas Ltd, sponsored by the GoG, was unable to pay its fees which delayed the project.

Tariffs and Subsidies

A report by the African Development Bank group states that the average end user electricity tariff across Africa in 2010 was US $0.14 per kWh though it was produced at an average cost of US $0.18 per kWh (African Development Bank Group, 2013; Kumi, 2017). The case of Ghana is no different from the rest of the continent. Electricity in Ghana is heavily subsidized. Ghanaian public utility companies have struggled to recoup costs due to these low tariffs (Ministry of Energy & World Bank, 2004). This makes it difficult for the electric utility companies to recover the cost of operation – production and distribution. This phenomenon coupled with debts owed to the utilities in subsidies and unpaid bills by the government and other agencies affects their ability to provide reliable electricity to consumers. In 2015, for example, tariffs were set at an average of USD 0.05 per kWh of electricity generated. These rates are around USD 0.09 below Sub-Saharan Africa's average of USD 0.14. Subsidies and low tariffs have left the transmission and distribution authorities crippled due to the inability to maintain or expand the required infrastructure (Paisner LLP, 2017). Since 2004, the Government of Ghana (GoG) has spent over USD 900 million on fuel subsidies to the Volta River Authority (VRA) alone (Paisner LLP, 2017).

Despite Ghana's great renewable energy potential (such as solar, wind and geothermal), the country lacks the financial capital needed to spearhead and tap into these resources which would reduce overload on the national grid and the country's growing reliance on fossil fuels. In addition to the lack of public investment in the renewable energy sector, the government has not been able to incentivize the private sector to participate in renewable energy power and hardware production (ECOWAS, 2015).

Overview of the Renewable Energy Landscape in Ghana

Globally, there has been growing concern on sustainability, pioneered by the United Nations Commission on Environment and Development in 1987. The commission defined sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations, 1987). Sustainability has since become a framework, measurement and evaluative and assessment criteria for development projects globally e.g., universal access to affordable, reliable, sustainable and modern energy (UN Dept of Economic and Social Affairs, 2017). In line with goal 7 "affordable and clean energy", the deployment of renewable energy technologies has expanded rapidly in recent years, first in developed countries and now, more rapidly in developing economies.

Across the globe, renewable energy capacity has increased from 1,037 GW in 2006 to about 1985 GW in 2015 (World Energy Resource, 2016). New investment in green and/or clean energy has expanded from $41 billion in 2004 to $272 billion in 2014 (Jeong, 2017). Much of this expansion has been supported by government policy directives, subsidies, research and development funding, or public-private mechanisms. Governments have promoted the use of renewable energy to address various energy and environmental issues they face such as climate change mitigation, energy security, and air pollution as well as in response to enhance their energy security. Because renewable energy sources and technologies have traditionally been expensive or cost prohibitive compared to conventional fossil fuels, government support was and remains essential to its promotion and broad-based operationalization (Jeong, 2017).

Table 4: The development of renewable strategies and policies in Ghana

RENEWABLE ENERGY STRATEGIES & POLICIES	YEAR	POLICY TYPE	POLICY TARGET
RENEWABLE ENERGY ACT	2011	Feed-in tariff, renewable energy purchase obligations, the establishment of renewable energy fund, tax exceptions,	RE energy for heat and power
NATIONAL ENERGY POLICY	2010	No specifics mention of policy types. Just mentioned energy sector challenges and government objective to overcome them.	Covers the whole energy sectors including waste to energy, solar, Hydropower, Geothermal, Multiple RE Sources, Power, Bioenergy, Biofuels for transport.
NATIONAL ELECTRIFICATION SCHEME	2007	Research, Development and Deployment (RD&D), Research programme, Technology deployment and diffusion, Economic instruments, Fiscal/financial incentives, Grants and subsidies,	Wind, Onshore, Bioenergy, Biomass for power, Multiple RE Sources, Power, Solar, Wind
GHANA ENERGY DEVELOPMENT ACCESS PROJECT	2007	Economic Instruments, Fiscal/financial incentives, Loans, Economic Instruments, Fiscal/financial incentives, Grants and subsidies, Economic Instruments, Fiscal/financial incentives, Tax relief	Wind, Solar, Solar PV
STRATEGIC NATIONAL ENERGY PLAN 2006 – 2020.	2006	Policy Support, Strategic planning	Multiple RE Sources for Power, Heating
RENEWABLE ENERGY SERVICE PROGRAM (RESPRO)	1999	Economic Instruments, Direct investment, Infrastructure investments	Solar, Solar PV
TAX AND DUTY EXEMPTIONS	1998	Economic Instruments, Fiscal/financial incentives, Tax relief, Economic Instruments, Fiscal/financial incentives, Taxes	Wind

Source: Gyamfi et a., 2015.

Ghana, like many other West African countries, has instituted a number of policies designed to promote investment in renewable energy as an alternative and as a complement to conventional energy sources. Table 4 list the major renewable strategies and policies active in Ghana to date. The most recent policy, the Renewable Energy Act (832) was passed on December 31, 2011 with a mandate to increase investment in renewable energy such that power from renewable sources would account for 10 per cent of Ghana's energy mix by 2020. Attendant regulations to the Act make allowances for the introduction of a feed-in-tariff system as well as net metering and creation of a Renewable Energy Fund to aid renewable energy projects.

Table 5: Feed-In-Tariff Rates in Ghana.

TECHNOLOGY	CAPACITY FACTOR	RATE (U$ CENT/KWH
IISolar	19	20.3000
Wind	28	12.5521
Biomass	50	12.2759
Waste-to-Energy	50	12.5900
Hydro	55	11.1336

Source: Renewable Energy Act, 2011.

To entice citizens and investors to increase the commercialization of renewable energy, in particular, renewable energy assessments are undertaken to address the feasibility of renewable energy projects - solar, wind, biomass and mini-hydro generation. To this end, many studies have been done by the Energy Commission to identify hot spots for renewable energy expansion and private investment (Hagan, 2015, p.13). Some of the major sources of renewable energy used by Ghanaians are discussed below.

Hydro-power

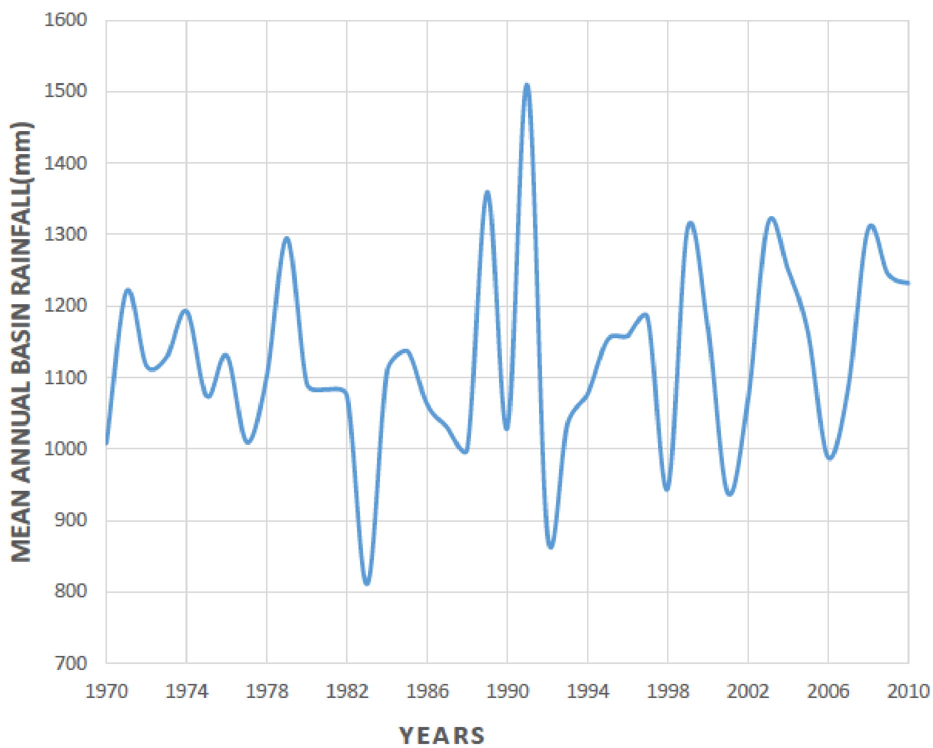
Ghana is home to three major hydroelectric power dams. They are the Akosombo, Kpong and Bui hydroelectric power dams. The Akosombo Dam remains the largest of the three, covering an area of 8,502 square kilometres with an installed capacity of 1,020 MW of power.

Figure 10: Map showing the location of the Akosombo Dam

Source: (Boadi, 2015).

Ghana's second largest dam, Bui, was constructed to increase power supply and meet the growing consumer and industrial demand. It generates 400 MW of hydroelectric power and is expected to increase the installed electricity generation capacity in Ghana by 22 per cent from 1,920 MW in 2008 to 2,360 MW. The Kpong hydro-electric dam is the third largest with an installed capacity of about 160MW (Government of Ghana, 2018). The Akosombo and Kpong dams which are managed by the VRA and provide electricity to much of the country, as well as for export to Togo, Benin, and nearby countries. Like all hydropower plants, these avoid greenhouse gas emissions that would have occurred if thermal power plants had been built instead (Government of Ghana, 2018). The viability of hydroelectric energy production in Ghana is, however, threatened by changing climatic conditions especially variability in rainfall and lake water levels (Boadi & Owusu, 2017). See figure 11 below.

Figure 11: Rainfall trends in the Lower Volta Basin from 1970 to 2010

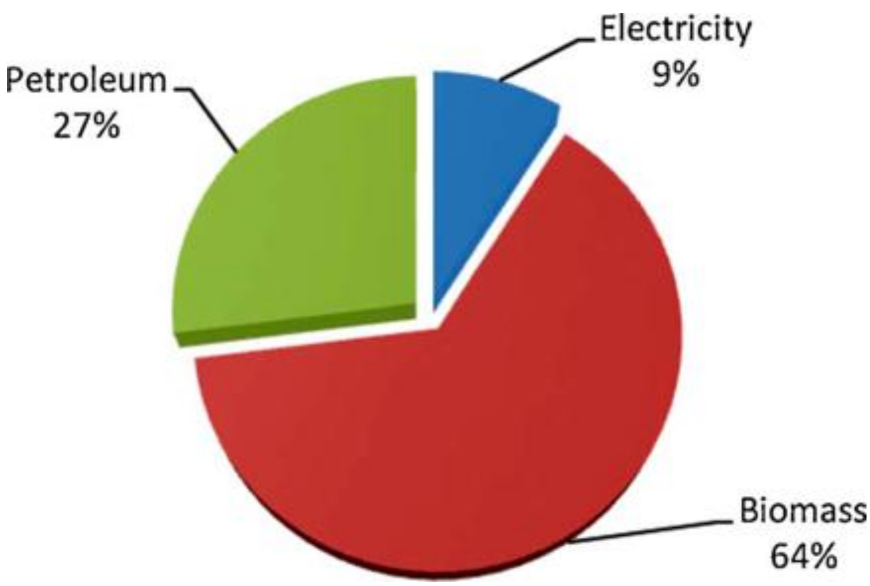


Source: (Boadi, 2015).

Biomass

Countries in Sub-Saharan Africa are largely reliant on biomass as a cheap source of fuel especially when electricity access is unreliable or unavailable (Kofi-Opata, 2013; Ministry of Energy, 2010). Unlike industrial and commercial large-scale enterprises that rely almost exclusively on fossil fuel-based power, many Ghanaians rely on biomass to supplement their energy needs. Biomass consists of a wide range of natural fuels such as wood, charcoal, agricultural residues and animal waste (Duku, Gu, & Hagan, 2011; Kofi-Opata, 2013; Ministry of Energy, 2010; Mohammed, Mokhtar, Bashir, & Saidur, 2013). Over-reliance on firewood for fuel is increasing the incidence of deforestation and soil erosion in rural communities and the use of diesel is also reducing air quality (ECOWAS, 2015).

Figure 12: Energy Matrix in Ghana in 2007



Source: Duku et al., (2011).

Kofi-Opata (2003) also notes that the use of biomass in poorly ventilated cooking stoves reduces indoor air quality which is a major cause of respiratory illness, particularly in Sub-Saharan Africa. In addition to the environmental and health consequences, widespread use of biomass is not a sustainable alternative to conventional sources, as it is increasingly expensive and out of reach of the poorest. Figure 12 shows the energy balance in Ghana as of 2007. Then, biomass accounted for 64 per cent of energy supply and that rose to 72 per cent by 2010 (Kofi-Opata, 2013).

Wind Power

Figure 13: Potential hydro and wind power sites in Ghana

Source: Kumi (2017) adapted from the Energy Commission of Ghana.

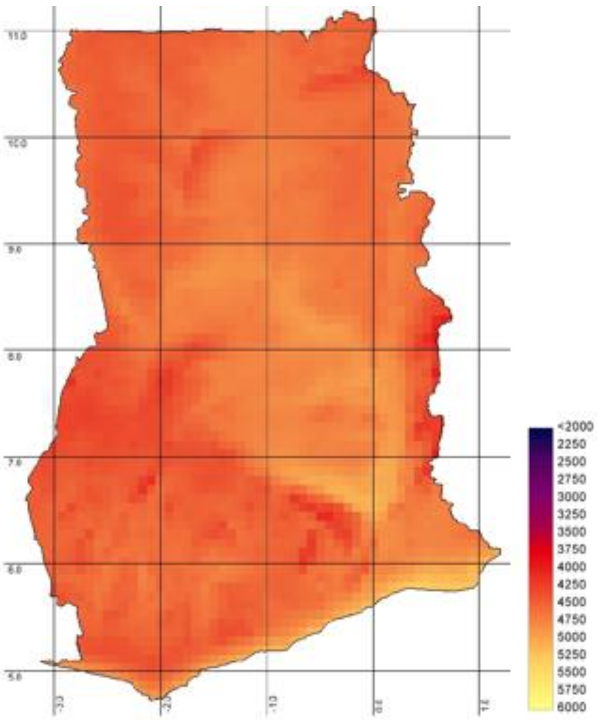
Ghana is described as having consistent, moderate wind speed, particularly along its coast. The availability of wind and its exploitable potential according to the Energy Commission is well over 1,000 MW, which could generate over 1,500 GWh/per year to supplement the nation’s energy supply. While there are no existing wind power facilities presently operating in Ghana, Figure 13 shows potential wind power sites which have been identified by the Energy Commission.

The VRA, as part of its energy diversification program, intends to implement up to 150 MW energy projects of 74 MW capacity each along the cost of Keta in the Volta Region and Ada in the Greater Accra Region (Kumi, 2017).

Solar Energy

Geographically located close to the equator, Ghana is in a position to exploit its vast solar energy potential. Throughout the year, the entire country receives substantial solar radiation between 1800 to 3000 hours. This makes it ideally suited for the development of solar energy projects which has a very high potential for grid-connected and off-grid applications (Kofi-Opata, 2013). Annual solar irradiation in Ghana ranges between 4.4 and 5.6 kWh/m2 -day (or 16-20 MJ/m^2 -day) (Gboney, 2009). See Figure 14. Currently, the installed solar electricity generating capacity is just above 1 megawatts (MW) (Energy Foundation, n.d.). In 2013, Ghana added a 2 MW solar photovoltaic plant in contrast, within the sub-regional level, Cape Verde in 2011 had a solar PV capacity of 7.5 MW while Mali and Liberia had 0.75 MW and 0.89 MW respectively (ECOWAS Observatory for Renewable Energy and Energy Efficiency, n.d.). According to the Energy Commission of Ghana, there are 22 sites that could contribute tremendously to the energy sector.

Figure 14: Ghana's Average Annual total daily sum of GHI in WH/m²/day (3year average)



Source: (Gyamfi et al., 2015; Schillings, Meyer, & Trieb, 2004).

Although the combined MW capacity is significant, only two construction permits have been issued (for details see table 6). The process of obtaining these licenses is burdensome and complicated for investors which are responsible for the slow development of Ghana's great solar potential.

Table 6: Provisional Licenses issued for Renewable Energy Electricity as of March, 2016

CATEGORY	PROVISIONAL LICENSES	SITING PERMITS	CONSTRUCTION PERMITS	TOTAL PROPOSED CAPACITY (MW)
Solar	55	20	2	2,748.50
Wind	9	2	1	951
Hydro	5	-	-	208.62
Biomass	2	-	-	68
Waste-to-Energy	10	2	1	570.81
Wave	1	1	1	1,000
Total	82	25	5	5,546.93

Source: (Energy Commission, Ghana, 2016).

Table 6 highlights Ghana's vast renewable energy potential that could conceivably reduce reliance on the expensive and environmentally harmful fossil fuels as well as improve electrification rates and the country's overall energy security situation. While there has been investment in the renewable energy sector, as more technologies are introduced to convert these renewable resources to electricity, more needs to be done if the country wants to benefit lucratively from it. This leads into the section that explains some of the barriers to the expansion of renewable energy as an alternative to conventional power.

Barriers to Renewable Energy Sources

According to Gyamfi et al., (2015, p. 15) and Kofi-Opata (2013) some of the barriers or challenges to renewable energy exploitation in Ghana include:

a) higher electricity costs compared to the non-renewably-sourced electricity;
b) incompatibility with existing transmission and distribution system;
c) the remoteness of resources from key electricity demand sectors;
d) low technological development;
e) institutional inexperience; and
f) lack of skilled technical human resources to oversee renewable energy projects.

Ghana’s RE barriers have been grouped into the following categories: political, technical, social, environmental, economic, institutional, cultural and behavioural (Gyamfi et al., 2015; IRENA, 2013; Kofi-Opata, 2013). See table 7 below which summaries the main barriers identified by Gyamfi et al., (2015).

Table 7: Barriers to Renewable Energy Deployment in Ghana

RES	BARRIERS TO DEVELOPING RENEWABLE ENERGY TECHNOLOGIES	RECOMMENDATIONS TO REMOVE BARRIERS
Solar	High start-up cost, limited access to information, limited financing schemes, small market.	Identify innovative financing mechanism: soft loans, grants and flexible financing schemes. Organize awareness campaign, education and training programs and workshops.
Small Hydro Power	Absence of the necessary policy frameworks, lack of information on available resources, lack of financing mechanism, low electricity tariffs.	Update hydro resource map, demonstration projects, extend the grid for rural electrification.
Wind	High start-up cost limited qualified personnel, low electricity tariff, intermittency.	Private sector participation, advanced forecasting, energy management systems (to minimise intermittency).
Biomass	Water shortages, no promotion policy, financial schemes, high cost, small market, low awareness, competition with the food industry and agriculture about the land use.	Support for promotional and training activities (workshops), finalisation of feasibility studies and business plans, incentives, enforcement of existing environmental laws.

Sources: Gyamfi et al., (2015).

Transformation of Ghana’s energy mix that includes a greater role for renewable energy will only occur when significant policy changes are made, institutional capacity is enhanced, dedicated financial inflows into research and development grow, incentivization for private sector investment develops, public education improvements and behavioural changes and a general revamp in the renewable energy business model. Cost reductions in renewable energy technologies, for example photovoltaic, as well as technology improvements when combined with the excellent renewable resources in Africa, augur a welcome and promising economic outlook for Ghana and the sub-region (IRENA, 2016).

Chapter 3 - Methodology

Case Study Methodology

Case study research is described as a "versatile form of qualitative inquiry most suitable for a comprehensive, holistic, and in-depth investigation of a complex issue (phenomena, event, situation, organization, program individual or group) in context, where the boundary between the context and issue is unclear and contains many variables" Harrison et al., (2017, p. 12) citing Creswell, 2014; Flyvbjerg, 2011; Merriam, 2009; Simons, 2009; Stake, 2006; and Yin, 2014. The authors contend that the main focus or reason for employing a case study methodology is a desire to understand complex phenomenon. Harrison et al., (2017) notes that Creswell's (2007) definition of case study methodology is the one that captures the full depth and breadth of case study concepts and descriptions:

> "Case study research is a qualitative approach in which the investigator explores a bounded system (a case) or multiple bounded systems (cases) over time through detailed, in-depth data collection involving multiple sources of information (e.g., observations, interviews, audiovisual material, and documents and reports) and reports a case description and case-based themes".

Case studies can be exploratory, explanatory, and descriptive(Harrison et al., 2017; Yin, 2009). It is a useful research method to gain an understanding of issues in real-life settings. It is also a valuable framework for answering "how and why or less frequently what research questions" (Harrison et al., 2017, p. 12). As a result, this research paper selected a practical case study of renewable technology implementation in Ghana.

Research Methods

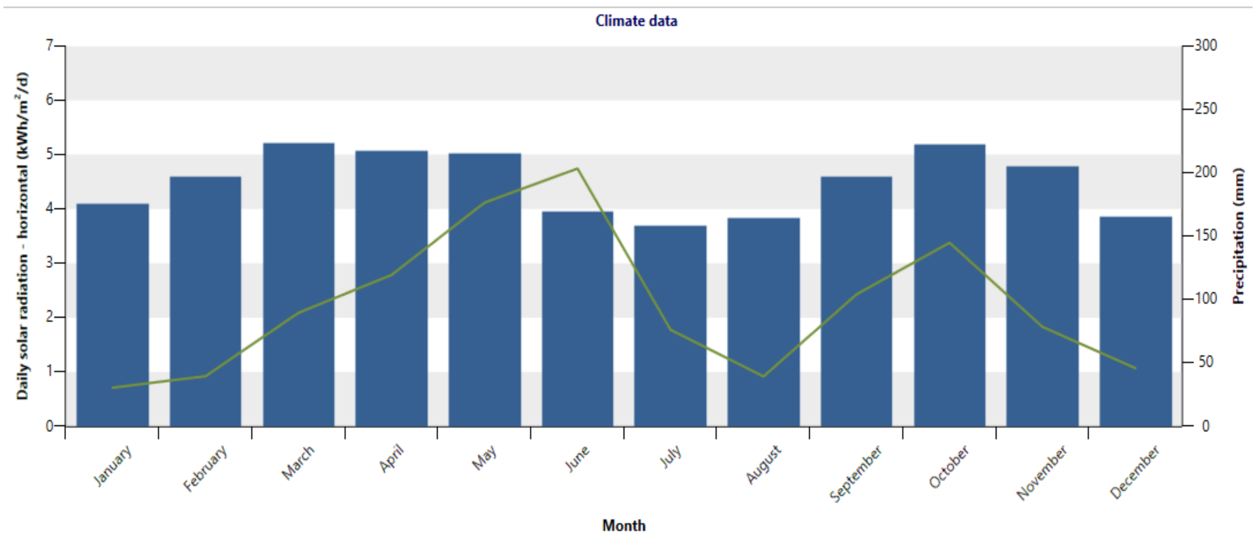
RETScreen Expert

RETScreen is a *Clean Energy Management Software* system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis (Natural Resources Canada, 2018). RETScreen helps to identify the technical and financial viability of an energy project. It also highlights solutions to polluting energy sources like fossil fuel and helps to highlight its ramifications on the environment in terms of pollution, operating costs and greenhouse gas emissions. RETScreen Expert allows its users to measure and verify actual performance of a building/project and identify energy savings. The software was developed by Natural Resources Canada through CanmetENERGY. It relies on 6,700 ground stations location and NASA satellite data covering the entire land mass of the planet where ground measuring stations are not located (Natural Resources Canada, 2018). The software includes climate data and meteorological data (either from ground stations or NASA's satellites). Figure 15 shows screenshots of the RETScreen software, highlighting daily solar radiation and climatic data for Ghana. RETScreen also has the capability of estimating the greenhouse gas savings potential of renewable energy projects as well as simulating key financial indicators (for example net present value and simple payback period) over the entire life of the project. For the purposes of this project, RETScreen serves as a database for the measurement of solar energy and radiation.

Figure 15: Daily Solar Radiation and Climatic data for Ghana captured on 2018-03-04

	Unit	Climate data location	Facility location	Source
Latitude		5.6	5.6	
Longitude		-0.2	-0.3	
Climate zone		0A - Extremely hot - Humid		Ground+NASA
Elevation	m	68	22	Ground – Ground
Heating design temperature	°C	21.8		Ground
Cooling design temperature	°C	32.1		Ground
Earth temperature amplitude	°C	5.0		NASA

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	27.5	78.0%	30.49	4.10	100.5	2.6	27.4	0	543
February	28.1	79.0%	39.55	4.59	100.5	2.6	27.8	0	507
March	28.2	79.0%	89.53	5.21	100.5	2.6	28.0	0	564
April	28.3	81.0%	119.37	5.08	100.5	2.6	28.1	0	549
May	27.7	82.0%	176.37	5.02	100.6	2.1	27.9	0	549
June	26.3	86.0%	203.29	3.97	100.8	2.1	26.6	0	489
July	25.2	87.0%	76.15	3.70	100.9	4.6	25.0	0	471
August	25.0	87.0%	39.35	3.84	100.9	5.1	24.6	0	465
September	25.8	84.0%	104.06	4.59	100.8	5.1	25.1	0	474
October	26.7	84.0%	144.81	5.19	100.6	2.6	26.2	0	518
November	27.5	82.0%	78.44	4.79	100.6	4.6	27.2	0	525
December	27.9	81.0%	45.86	3.86	100.5	2.1	27.3	0	555
Annual	**27.0**	**82.5%**	**1,147.26**	**4.49**	**100.6**	**3.2**	**26.8**	**0**	**6,208**
Source	Ground	Ground	NASA	Ground	Ground	Ground	NASA	Ground	Ground
Measured at					m	10	0		



Source: RETScreen.

Analysis of Secondary Data

Secondary data was an essential means of data collection and analysis. Re-analysis of existing data is considered an established a methodology when conducting research. Data was sourced from governmental institutions e.g., the Ghana Meteorological Agency (GMA), Ministry of Energy, and the Energy Commission, through their annual reports and other commissioned studies. Other sources of relevant data were sourced from international agencies (e.g. International Energy Agency, IRENA and REN21). Academic and other literature was also reviewed to provide a more comprehensive discussion of the energy sector in Ghana.

Chapter 4 – Case Study – Ghana

Across Ghana, Police Stations and divisional units are often impacted by the intermittent supply of electricity. There are currently 1078 Police Stations and 383 divisional sectors in Ghana. Because of the energy crisis facing the country, these law enforcement institutions must either operate without the necessary power supply or source more expensive avenues like diesel gensets to meet their energy needs. There have been noted instances where Police Stations have been without power for more than 18 hours. Problems are exacerbated during power line maintenance and periods of load shedding. The situation is worse in Police Stations located in villages outside the major city centres such as Accra and Kumasi. The cumulative effects of the energy crisis on Ghana's Police Services include: a reduction in service quality, a demoralized police force, and more importantly, compromised national security. In response to the ongoing energy crisis and the current trend towards more renewable sources, a solar PV energy system pilot project was commissioned by the Ghana Police Division. This major research paper focuses on a pilot study for five Ghana Police Stations in the Greater Accra Metropolitan Area. The five Police Stations were selected by the Inspector General of Ghana Police Services. Among the chosen areas were East Legon Police Station, Nima Police Station, Kotoku Police Station, Nungua Police Station and Okpoi Police Station. Figure 16 shows the location of the five police stations in this pilot project. The project ultimately sought to demonstrate the cost-competitiveness of solar PV technologies and its potential to reduce or replace the station's dependence on electricity from the national grid. The project aims at improving police services to the various communities. RETScreen International Expert was used to analyze the feasibility of the solar project for the five police stations.

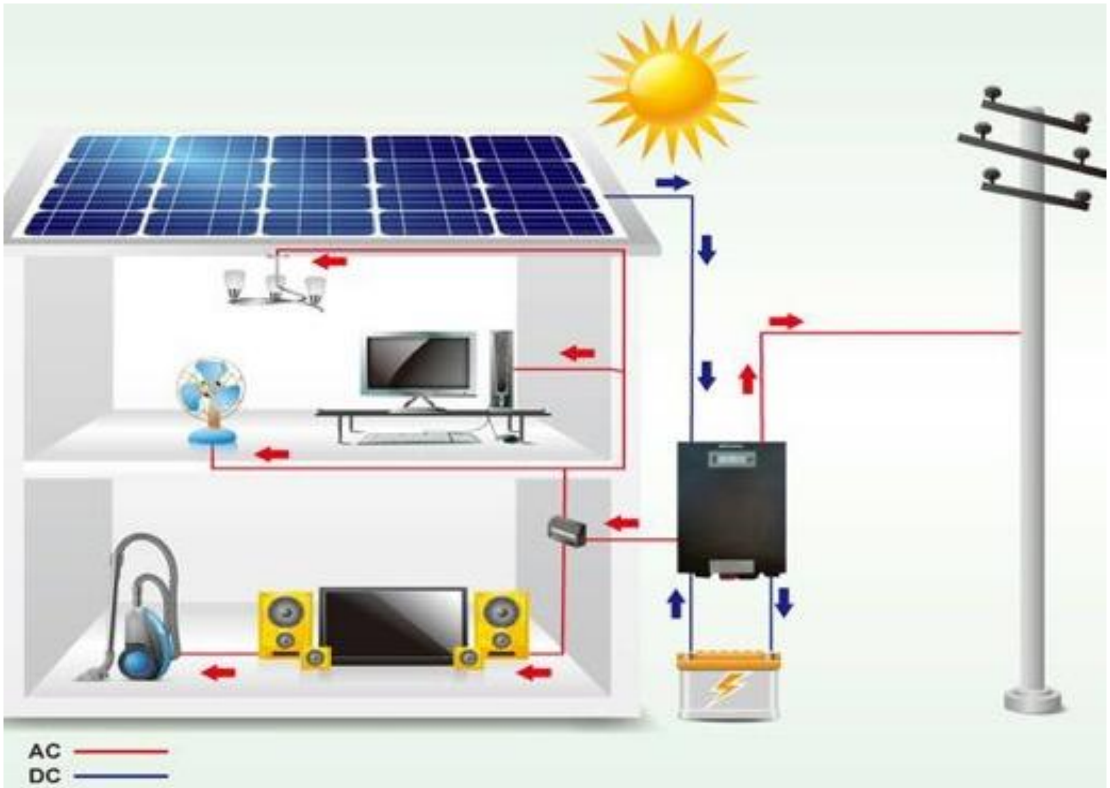
Figure 16: Location of the Five Police Stations in the Pilot Project

Source: Google Maps.

Pilot Project Design

The rooftop solar PV system was designed as a hybrid, such that it relies on the national electricity grid especially during extended periods of reduced sunlight (solar irradiation intensity). Initially, the project was designed to install 2.03kWp solar PV system in each station but this was later changed, and each station installed a 5.3kWp rooftop solar PV grid–tied system with power packs instead. The project is expected to provide uninterrupted power for equipment use such as computers, printing devices and network devices and provide the facility with lighting and other services. See Figure 17 for a schematic representation of the solar PV, grid power and battery power pack system, followed by photos of the completed works for some of the police stations.

Figure 17: Illustration of a Solar PV and Power Pack grid-tied system



Source: Silicon Solar.

Pic 1: Solar PV Installation at East Legon Station

Pic 2: Solar PV Installation at Nima Police Station

Pic 3: Solar PV Installation at Kotoku Police Station

Pic 4: On-going Solar PV Installation at Nungua Police Station

Estimation of the available area for the installation of the solar PV panels was fundamental to the design requirements of the project. The present study focuses on the rooftop area for PV installation. In terms of roof construction, the buildings in this study had either flat or slanted rooftops. Other building infrastructure for the 5 police stations was examined for installation of rooftop solar PV application. The square footage for the 5.3kWp as measured is 4356 square meters and was able to be installed on all 5 buildings. The energy yield from the designed rooftop PV systems was modelled using RETScreen software (which also provides emission analysis).

Load Calculation

The energy sources for the pilot project are: solar PV, grid power and battery backup/storage. When sunlight hits the modules of the solar PV, the modules convert energy from the sun into electricity to power the five Police Stations. Whether the electricity is being drawn from the grid or the solar PV system, the power performance is anticipated to be the same. The direct current produced by the solar PV system is wired into an inverter. This inverter converts the DC power into alternating current or AC. This alternating current is the standard used worldwide. The electrical current then flows from the inverter into the service panels that feed electricity into the police stations. A tracking meter monitors how much energy is used, whether the energy needs are met and how well the system is performing. During the day, excess electricity is stored in the battery and fed to the grid. The solar PV supports load for installed capacity and the balance load operates on the battery. In the event of a power outage the battery runs as the backup. The power pack capacity is 5.3 kWp. The backup power is 8 ~ 24 hours. It should be noted that the installed capacity was determined based on the total wattage required and for what duration. Based on our inventory analysis it was determined that a 5.3kWp solar rooftop system would be adequate in meeting the energy consumption needs of the various police stations. See table 8.

Table 8: Inventory Analysis – Appliances used on site at the Police Stations

DESCRIPTION	NO. OF APPLIANCES	POWER RATING	TOTAL POWER	NO. OF HRS	ENERGY CONSUMED WATT-HRS
Desktop Computer and Accessories	2	200	400	12	4800
LED Lights	10	15	150	12	600
Multi-Functional Printer	2	200	200	12	2400
TV Set	1	100	100	12	1200
Fans	2	70	140	12	1680
Digital Cameras	2	40	80	12	960
TPS 510 Android Desktop Device	2	50	100	12	1200
Biometric Scanner	2	50	100	12	1200
Digital Sender	2	50	100	12	1200
Refrigerator	1	100	100	12	1200
Other Equipment	1	1	400	12	4800
Total Power Rating		**1470**			

Source: Neopower Engineering, 2017.

Financial Feasibility Assessment

Project Cost

Table 9 shows the costs of the entire project for each of the Police Stations.

Table 9: PV Cost for Each Police Station

ITEM	COST	DESCRIPTION
Assumed Start Date	-	April 2017
Equipment Enclosures/ Housings	5.3kWp for each Police Station	This includes the purchase of German-produced products such as inverters, cables, PVs, Panels, racking units.
Specific Investment	$2500 USD/kWp	The cost of kilowatt peak
Warranty	Free	5 years Warranty
Equity		100%
Duration of Solar PV	-	25 years
Energy Price Sold	$0.32	Equivalent to 1.41 Ghana Cedes
Installation Cost	$2250.00 per Police Station	This includes civil works, wiring/electricals, panel washing, mounting structures, vegetation management, racking/tracker, cable installation, PV modelling, environmental monitoring, energy audits, site visits
Project Cost per Project Site	$ 15,500.00	The cost of the equipment enclosures/ housing and installation cost gives you the total cost of the project for one site.

Source: Neopower Engineering, 2017.

10,000kWh is consumed monthly. From the PURC 2017 1st quarter tariffs, the first 300 kWh costs 29,037Gh pesewas, between 301 and 600 kWh the cost is 30,897Gh pesewas and remaining 9400kWh costs 1,527,594Gh pesewas. In Total, 10,000 kWh costs 1,58 pesewas. Each kWh, therefore, translates to 1.58 Ghana cedes which is equivalent to 0.34 USD (as of current, 2018, currency exchange rates). See Table 10.

Table 10: Energy Price Sold and Inflation Price

Energy price sold	0.32USD this equals 1.41 Ghana Cedes •300kWh = 29,037Gh pesewas •301-600kWh = 30,897Gh pesewas •600kWh =1,587,528Gh pesewas
Electricity Price Inflation	5.0 % (inflation average of the last 10 years)

Source: Neopower Engineering, 2017.

Simple Payback Period

Simple payback period is the time in which the initial cost of a project is expected to be recovered from the cash inflows generated by the project. The payback period of a given investment or project is an important determinant of whether to undertake the project since longer payback periods are typically not desirable.

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Cash Inflow Per period}}$$

When cash inflows are uneven, we need to calculate the cumulative net cash flow for each period and then use the following formula to calculate the payback period:

$$\text{Payback Period} = \frac{A + B}{C}$$

A = Last period with a negative cumulative cash flow;

B = Absolute value of cumulative cash flow at the end of the period A; and

C = Actual Cash Flow during the period after A

Figure 18: Financial Analysis of the Five Pilot Project

Financial parameters

General		
Inflation rate	%	5%
Discount rate	%	0%
Project life	yr	25
Finance		
Incentives and grants	$	0
Debt ratio	%	0%
Income tax analysis		☐

Annual revenue

Electricity export revenue		
Electricity exported to grid	kWh	6,974
Electricity export rate	$/kWh	0.32
Electricity export revenue	$	2,232
Electricity export escalation rate	%	2%
GHG reduction revenue		
Gross GHG reduction	tCO_2/yr	2
Gross GHG reduction - 25 yrs	tCO_2	38
GHG reduction revenue	$	0
Other revenue (cost)		☐
Clean Energy (CE) production revenue		☐

Costs | Savings | Revenue

Initial costs			
Initial cost	100%	$	15,500
Total initial costs	**100%**	**$**	**15,500**
Annual costs and debt payments			
O&M costs (savings)		$	159
Total annual costs		**$**	**159**
Annual savings and revenue			
Electricity export revenue		$	2,232
Total annual savings and revenue		**$**	**2,232**

Financial viability

Pre-tax IRR - equity	%	14.6%
Pre-tax IRR - assets	%	14.6%
Simple payback	yr	7.5
Equity payback	yr	7
Net Present Value (NPV)	$	49,445
Annual life cycle savings	$/yr	1,978
Benefit-Cost (B-C) ratio		4.2
Debt service coverage		No debt
GHG reduction cost	$/$tCO_2$	-1,316

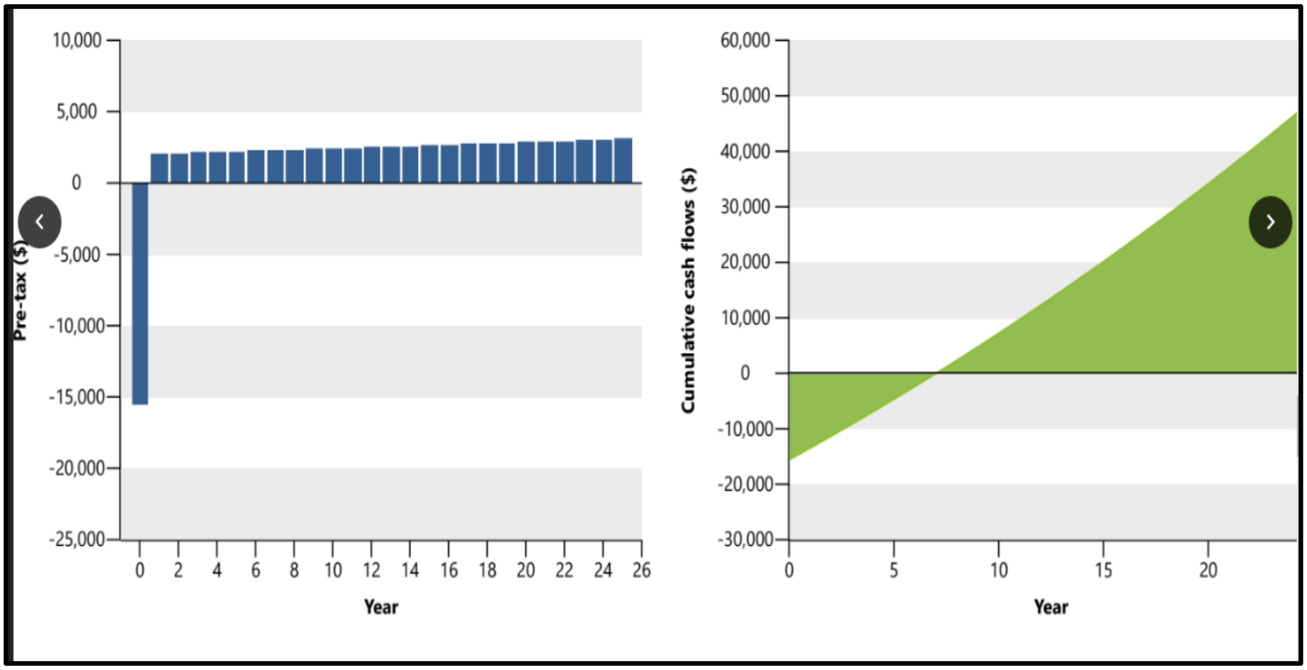
Yearly cash flows

Year	Pre-tax	Cumulative
#	$	$
0	-15,500	-15,500
1	2,109	-13,390
2	2,147	-11,244
3	2,184	-9,060
4	2,222	-6,837
5	2,261	-4,576
6	2,300	-2,276
7	2,340	63.92
8	2,380	2,444
9	2,420	4,864
10	2,461	7,326
11	2,503	9,829
12	2,545	12,373
13	2,587	14,961
14	2,630	17,591
15	2,673	20,264
16	2,717	22,980
17	2,761	25,741
18	2,805	28,546
19	2,849	31,395
20	2,894	34,289
21	2,940	37,229
22	2,985	40,214
23	3,031	43,245
24	3,077	46,322
25	3,123	49,445

Source: Reproduced from RETScreen.

The feasibility analysis carried out for the pilot project focused in determine the financial viability of the project based on widely-used metrics. RETScreen allowed us to simulate certain financial indicators such as the Net Present Value (NPV) and Simple Payback Period over the life of the project. Based on the financial analysis, the project is deemed to be profitable (attractive) and has a simple payback period of 7.5 years. The Internal Rate of Return (IRR) on Equity is 14.6 per cent. The project lifetime is 25 years. In most projects, a lesser payback period, a higher IRR and a positive NPV value are desired, however, using a shorter payback would pose a strong misrepresentation of what is happening with the project. See Figure 18 and 19. The cash flows (see figure 18) show a $15,000 in debt on the first zero year of the project (pre-tax). In year one of the project, there are positive cash inflows which increase through to year 25. On the cumulative side, the simple payback period falls on the 7th year of the project. See figure 19.

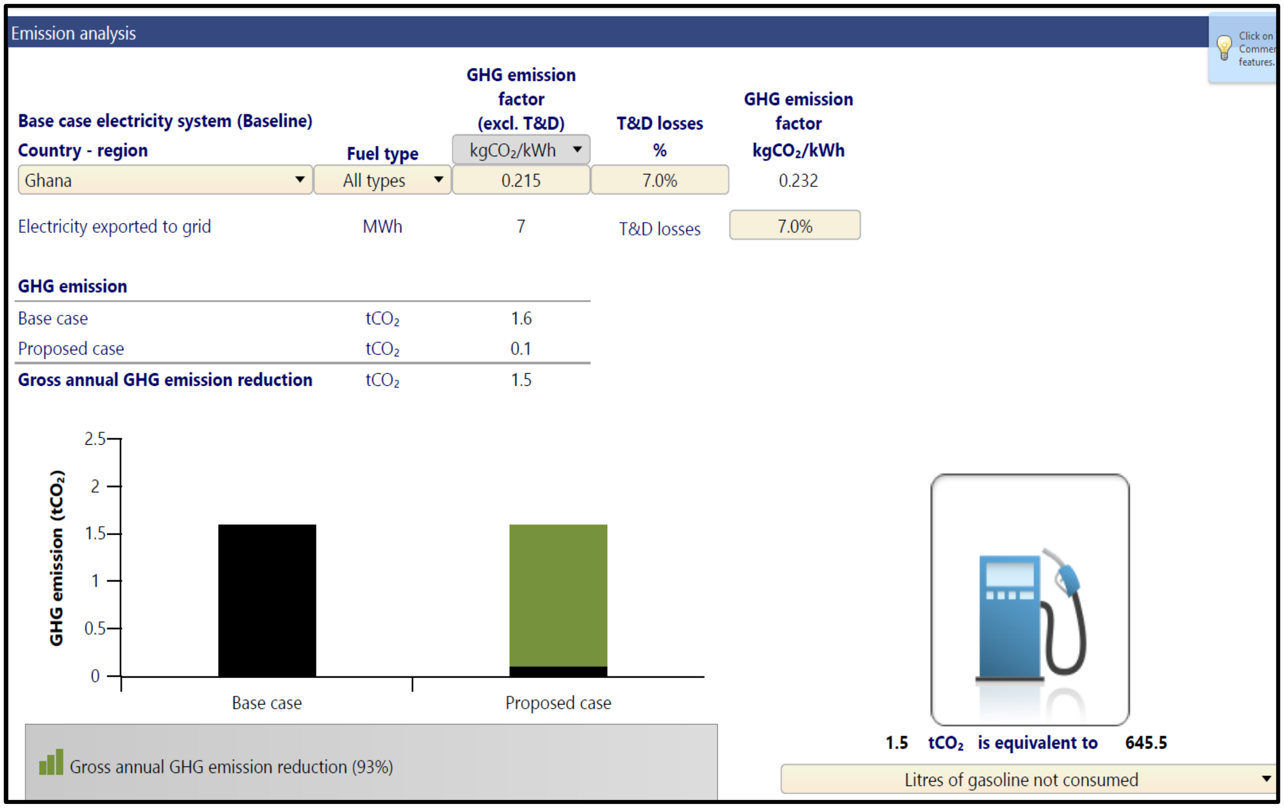
Figure 19: Shows the Cash Flows of the Project



Source: RETScreen calculation.

The emission analysis page shows a reduction in Green House Gas (GHG) emissions. The project is anticipated to save 645.5 litres of gasoline that will not be consumed by any of the police stations. Overall, we expect a 93 per cent baseline reduction in GHG (See figure 20 below).

Figure 20: Anticipated GHG Emissions Reduction



Source: RETScreen.

The sensitivity analysis (see figure 21) shows the impact of variations of key project parameters on the payback period. The payback period is expected to be 7.5 years with all parameters constant i.e. no changes in export rate and upfront capital cost. A 25 per cent increase in export rate and a 25 per cent reduction in capital cost is the best-case scenario, with a very attractive payback period of 4.2 years. However, the project could face a very critical setback if the capital cost increases drastically with a simultaneous decrease in the export rate. This is expected to be the worst-case scenario generating a payback of 11.5 years if the increase in capital cost and a decrease in export rate is 25 per cent. A similar analysis can be done with Operation and Maintenance (O&M) cost to examine its impact on payback period. Overall, it is important to note these scenarios and plan for unforeseen contingencies that could change the parameters.

Figure 21: The Sensitivity Analysis of the Project

Sensitivity analysis

Click on Tools, Comment to a features.

Perform analysis on	Equity payback	
Sensitivity range	25%	
Threshold	7	yr

- Remove analysis

Electricity export rate		Initial costs				$
		11,625	13,562	15,500	17,437	19,375
$/MWh		-25.0%	-12.5%	0.0%	12.5%	25.0%
240.00	-25.0%	7.2	8.3	9.4	10.5	11.5
280.00	-12.5%	6.1	7.1	8.0	8.9	9.8
320.00	0.0%	5.3	6.1	**7.0**	7.8	8.6
360.00	12.5%	4.7	5.4	6.2	6.9	7.6
400.00	25.0%	4.2	4.9	5.6	6.2	6.9

- Remove analysis

O&M		Initial costs				$
		11,625	13,562	15,500	17,437	19,375
$		-25.0%	-12.5%	0.0%	12.5%	25.0%
119	-25.0%	5.2	6.0	6.8	7.6	8.4
139	-12.5%	5.3	6.1	6.9	7.7	8.5
159	0.0%	5.3	6.1	**7.0**	7.8	8.6
179	12.5%	5.4	6.2	7.0	7.9	8.7
199	25.0%	5.4	6.3	7.1	8.0	8.8

Source: RETScreen.

Chapter 5 – Findings & Conclusions

Discussion

The key findings of the case study include:

- The load estimate provided by Neopower Consulting, shows that over a year, the load will be a bit over 8 MWh.
- The PV output will be just under 7 MWh per year.
- The battery is very small— only capable of providing for a small load over a short period. It will not be able to store much PV power, hence in the case of power outages it will produce power to some extent and blackouts will rollover.
- The Ghana Police Stations will need to replace the battery every 5 years which might cost the Police Stations in the long-run.
- Solar energy intermittency as production of power depends on the sun.
- Implementation of policies to drive the growth of RE in Ghana.
- Above all, this is a viable project.

Ghana’s faces many obstacles in electrifying its remote and dispersed rural communities where economic activities cannot justify huge investments in grid extension. In addition, the country has not been able to provide reliable electricity services to its customers in the major urban centres and adjacent communities. In these circumstances, the success of the pilot project indicates great opportunities for similar projects in remote rural communities where grid extension and connectivity is not financially feasible due to substantial up-front costs. It is also beneficial to public and private enterprises and domestic consumers who are eager to of reduce their overall energy costs whilst ensuring greater reliability of service.

Statistics show that over 22 countries in the world are meeting more than 1 per cent of their electric power requirements from solar PV. Italy, Greece and Germany are among the world leaders in solar PV. Solar PV accounts for 7.8 per cent, 6.5 per cent and 6.4 per cent of their annual power generation respectively (Asif, 2016, p. 1; Sahu, 2015). As the big three solar PV global leaders, their success could be a roadmap for implementation of these systems in Sub-Saharan West Africa. Asif (2016) notes that small-scale and building-integrated applications such as the one analyzed in the case study account for the greatest share of global solar PV capacity. Germany's solar PV installed capacity for example, is largely based on small-scale systems. This reality bodes well for countries like Ghana that has the resources but do not have dedicated funding sources for larger-scale renewable energy projects. Since introducing the feed-in tariff (FIT) concept in the early 1990s, Germany has managed to establish a large base of small-scale PV power producers, geared towards meeting the energy needs of the residential sector (Asif, 2016; Barker, 2011; Curry, 2013; Sahu, 2015). Germany's successful utilization of FIT policies has been replicated elsewhere in the world with varying degrees of success. Ghana like many other countries following Germany's example has adopted its own FIT programme, however, it has been plagued with many issues notably, the duration of contracts (Kenning, 2016). Despite the above, the latest statistics available shows that Ghana had 23.22 MW of grid connected solar PV installed capacity as of the end of the first half of 2016 (Bellini, 2017). This installed capacity is mainly due to the existence of the 2MW grid-connected solar PV farm constructed at Navorongo by the VRA and the 20MW PV plant completed by the independent power producer BXC Ghana Ltd. Additional capacity is anticipated when the Nzema 155MW Solar Power Station is completed. These developments are promising yet still require stronger government policies and a more aggressive mandate to expand solar PV systems and other forms of renewable energy technologies across the country, especially in remote communities. Such steps would help Ghana meet its energy requirements, diversify its energy base away from fossil fuels, improve the energy and environmental footprint of public and institution, restore public faith in the energy sector, and most importantly, improve energy security for the future.

The lessons learned from the case study are therefore both positive and negative and should be built into future solar PV projects. On the positive side, the project proved that solar PV technology clearly works and can provide a lower cost electrification solution to grid connection. On the other hand, the issues of ownership, maintenance, cost-recovery, and financing need to be clearly defined as these can hinder longer-term development of the technology, as was the case with the Renewable Energy Services Project (RESPRO) operated in Ghana from 1999 to 2003 (Dadzie, 2015).

Recommendations

The role of renewable energy in meeting energy needs in countries with lower electrification rates is becoming ever more important. Availability of resources, environmentally friendly technologies and declining start-up and maintenance cost have all contributed to the rapid growth of RE across the globe. Solar photovoltaics (PV) are one of the most prominent renewable technologies in use today (Asif, 2016).This is made possible because of favourable institutional environments where renewable energy policies set the stage for its expansion. Policies include having renewable energy targets, providing tax incentives, using regulatory tools such as feed-in-tariffs, net-metering, and other associated instruments. If Ghana intends to reap the benefits of renewable energy technologies, diversify its energy mix and reduce its dependence on expensive and imported fuel, it must heed the following:

1) Set and work towards meeting realistic renewables targets in combination with feed-in tariffs and other policy measures;
2) Create an enabling environment that favours capital flows in the form of sustained investment in renewable technologies;
3) Take advantage of declining clean energy equipment costs, technological transfer and best practices by the forerunners in renewable energy adoption;
4) Amend existing national policy frameworks and regulations that favour investment in traditional fossil fuel-based power supplies;
5) Strengthen existing environmental and energy policies that favour the deployment of renewable energy technologies by removing bureaucratic red tape and unnecessary obstacles to local entrepreneurial participation;
6) Support cost-effective distributed energy systems;
7) Invest in the requisite infrastructure that allows for grid connectivity and electricity transmission from renewable energy sources;

8) Boost energy access by holding tenders in which off-grid developers and distributors compete for the right to provide electricity(Bloomberg New Energy Finance, 2017); and
9) Embark of campaign to educate the public about renewable energy options, the financial costs and benefits that can be accrued and its overall impact of the local environment. Such public awareness campaigns have the added benefit of changing energy consumptions habits.
10) Consider desalination of sea water into fresh water with renewable energy to pump water into the hydro dam reservoir to address the issue of load shedding.

Conclusion

RE technologies offers a clean, renewable source, and are essential components of sustainable energy future. RE technologies such as solar are renewable from the sun, a strategy to address Ghanaian climate change, environmentally friendly and the sole panacea to address the power outages situation the country is facing. During the design and evaluation of solar for the Ghana Police Service, information on solar irradiation and its components at a given location is needed. In addition, reliable solar radiation and accurate databases are of huge importance to the development of the case study. Data provided by the RETScreen was more reliable since it has a significant ground – data component, which makes its output quite close to the reference ground – measured data from GMA.

From the case study, replication of the pilot project at other police stations, polyclinics and community health centres, as well as, public schools could improve service delivery in each sector. Additionally, it would provide these institutions some degree of security in electricity supply that is not based on the government’s ability to pay debts to the various utility companies. The case study would also create room for the government to embark on off–grid electrification for those rural communities that lack access to electrical grid extension. Due to the changing weather pattern, proper energy storage must be used to prolong the amount of power to be consumed.

However, the efficiency of the power supplied by the renewable energy sources can be maximized when paired with an energy storage system.

Another advantage of solar energy is that, the solar panels will provide shades for buildings as well as reducing the cost of energy in Ghana. This could be achieved by incentivising the private sector to participate in the energy industries. This will go a long way to boost the energy performance of the country, address the country’s GHG emissions since most Ghanaians will switch from the gensets powered by dirty diesel, and make electricity affordable for the masses.

References

Acheampong, T., & Ankrah, F. (2014). *Pricing and deregulation of the energy sector in Ghana: challenges and prospects*. Retrieved from http://www.imanighana.com/wordpress/wp-content/uploads/2014/01/Ghana_Energy_Report_2014-Imani-Report.pdf.

African Development Bank Group. (2013, February 18). The High Cost of Electricity Generation in Africa. Retrieved July 15, 2018, from https://www.afdb.org/en/blogs/afdb-championing-inclusive-growth-across-africa/post/the-high-cost-of-electricity-generation-in-africa-11496/

Armah, B. (2003). *Economic Analysis of Ghana' Energy Sector*. Accra: Ghana Energy Commission.

Arndt, C., Asante, F., & Thurlow, J. (2015). Implications of climate change for Ghana's economy. *Sustainability*, *7*(6), 7214–7231.

Asif, M. (2016). Urban Scale Application of Solar PV to Improve Sustainability in the Building and the Energy Sectors of KSA. *Sustainability*, *8*(11), 1–11. https://doi.org/10.3390/su8111127

Barker, G. (2011, March 21). UK can learn from Germany's feed-in tariff lessons. *The Guardian*. Retrieved from https://www.theguardian.com/environment/2011/mar/21/germany-feed-in-tariff

Bellini, E. (2017, December 18). Ghana to launch rooftop solar program in 2018. Retrieved July 15, 2018, from https://www.pv-magazine.com/2017/12/18/ghana-to-launch-rooftop-solar-program-in-2018/

Blackshear, B., Crocker, T., Drucker, E., Filoon, J., Knelman, J., & Skiles, M. (2011). Hydropower vulnerability and climate change. In *A Framework for Modeling the Future of Global Hydroelectric Resources, Middlebury College Environmental Studies Senior Seminar, Fall*.

Boadi, S. A. (2015). *The Influence of Climate Variability and Change on the Attainment of Energy Security in Ghana: A Study of the Akosombo Hydroelectric Power Project* (Thesis). University of Ghana, Ghana.

Boadi, S. A., & Owusu, K. (2017). Impact of climate change and variability on hydropower in Ghana. *African Geographical Review*, *0*(0), 1–15. https://doi.org/10.1080/19376812.2017.1284598

Bryan Cave Leighton Paisner LLP. (2017, January 25). Power to Africa volume 2: Ghana (part 2) | Power Sector Expert Insights. Retrieved July 15, 2018, from http://www.blplaw.com/expert-legal-insights/articles/power-to-africa-volume-2-ghana-part-2

Central Intelligence Agency (CIA). (n.d.). The World Factbook — Ghana [Government]. Retrieved June 16, 2018, from https://www.cia.gov/library/publications/the-world-factbook/geos/gh.html

Chizoba, I. (2017, March 22). Ghana Natural Resources: List of Natural Resources Found in Ghana. Retrieved July 15, 2018, from https://www.nigerianinfopedia.com/ghana-natural-resources-found-in-ghana/

Curry, A. (2013, April 1). Germany's solar-power success: Too much of a good thing? Retrieved July 15, 2018, from https://grist.org/business-technology/germanys-solar-power-success-too-much-of-a-good-thing/

Dadzie, F. Y. (2015). Lessons Learned In Implementing Off-Grid Electrification Projects in Africa- Ghana's Example. *2015 Africa Energy Yearbook*, 97–100.

Duku, M. H., Gu, S., & Hagan, E. B. (2011). A Comprehensive Review of Biomass Resources and Biofuels potential in Ghana. *Renewable and Sustainable Energy Reviews*, *15*(1), 404–415.

ECOWAS. (2015). *ECOWAS Renewable Energy Polcy*. Cape Verde: Centre for Renewable Energy and Energy Efficiency (ECREEE). Retrieved from http://www.ecreee.org/sites/default/files/documents/ecowas_renewable_energy_policy.pdf

ECOWAS Observatory for Renewable Energy and Energy Efficiency. (n.d.). Energy Efficiency for Households in Ghana. Retrieved July 2, 2018, from http://www.ecowrex.org/news/energy-efficiency-households-ghana

Energy Commission, Ghana. (2016). *2016 Energy (Supply and Demand) Outlook for Ghana - Final* (p. 72). Accra, Ghana: Energy Commission of Ghana.

Energy Commission of Ghana. (2016). *National Energy Statistics - 2007 -2016* (Energy Statistics). Accra, Ghana: Energy Commission of Ghana. Retrieved from http://energycom.gov.gh/files/National%20 Energy%20Statistics_2016.pdf

Energy Commission of Ghana. (2017). *National Energy Statistics (2016-2017)* (National Energy Statistics). Ghana: Energy Commission of Ghana. Retrieved from http://energycom.gov.gh/files/ENERGY_STATISTICS_2017.pdf

Energy Foundation. (n.d.). Energy Efficiency for Households/SMES. Retrieved July 2, 2018, from https://www.efghana.org/project/energy-efficiency-for-householdssmes/

Gboney, W. (2009). Policy and Regulatory Framework for Renewable Energy and Energy Efficiency Development in Ghana. *Climate Policy*, *9*(5), 508–516. https://doi.org/10.3763/cpol.2009.0636

Government of Ghana. (2018). Bui and the Tale of Three Hydro Dams. Retrieved July 15, 2018, from http://www.ghana.gov.gh/index.php/media-center/features/805-bui-and-the-tale-of-three-hydro-dams

Guéniat, M., Harjono, M., Missbach, A., & Viredaz, G. V. (2016). *Dirty Diesel. How Swiss Traders Flood Africa with Toxic Fuels*. Lausanne: Public Eye.

Guéniat, Marc, Harjono, M., Andreas Missbach, & Viredaz, G.-V. (2016). *Dirty Diesel: How Swiss Traders Flood Africa with Toxic Fuels*. Retrieved from https://goo.gl/wXhLCq

Gyamfi, S., Modjinou, M., & Djordjevic, S. (2015). Improving electricity supply security in Ghana—The potential of renewable energy. *Renewable and Sustainable Energy Reviews*, *43*, 1035–1045.

Hagan, B. E. (2015). The Renewable Energy Policy Review, Identification of Gaps and Solutions in Ghana, United Nation Development Programme (UNDP), New York City, Ny USA.

Harrison, H., Birks, M., Franklin, R., & Mills, J. (2017). Case Study Research: Foundations and Methodological Orientations. *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *18*(1), 1–17.

International Energy Agency. (2012, July). National Electrification Scheme - Ghana. Retrieved June 23, 2018, from http://www.iea.org/policiesandmeasures/pams/ghana/name-24778-en.php

IRENA. (2013). *Africa's Renewable Future: The Path to Sustainable Growth* (32). United Arab Emirates: International Renewable Energy Agency. Retrieved from http://www.irena.org/DocumentDownloads/Publications/Africa_renewable_future.pdf

IRENA. (2016). *Solar PV in Africa: Costs and Markets* (p. 84). United Arab Emirates: International Renewable Energy Agency.

Jeong, M. (2017). *National Renewable Energy Policy in a Global World* (PhD). University of Maryland, College Park, Maryland. Retrieved from http://search.proquest.com/openview/4bb01caeb48ffd7639f4424e743310cc/1?pq-origsite=gscholar&cbl=18750&diss=y

Kemausuor, F., Obeng, G. Y., Brew-Hammond, A., & Duker, A. (2011). A review of trends, policies and plans for increasing energy access in Ghana. *Renewable and Sustainable Energy Reviews*, *15*(9), 5143–5154.

Kenning, T. (2016, April 20). Ghana to update feed-in tariffs to last 20 years. Retrieved July 15, 2018, from https://www.pv-tech.org/news/ghana-to-update-feed-in-tariffs-to-last-20-years

Kofi-Opata, E. (2013). *Alternative energy and the developmental state in Ghana* (Masters). University of Toledo, Ohio. Retrieved from http://rave.ohiolink.edu/etdc/view?acc_num=toledo1368117768

Kumi, E. N. (2017). *The Electricity Situation in Ghana: Challenges and Opportunities* (Policy Paper No. CGD Policy Paper 109). Washington, D.C.: Center for Global Development. Retrieved from https://www.cgdev.org/ publication/electricity-situation-ghana-challenges-and-opportunities

Lucien, G., Mark, M., & Martyn, P. (n.d.). The global green economy: a review of concepts, definitions, measurement methodologies and their interactions. *Geo: Geography and Environment*, *4*(1), e00036. https://doi.org/10.1002/geo2.36

Mensah, J. T., Marbuah, G., & Amoah, A. (2016). Energy demand in Ghana: A disaggregated analysis. *Renewable and Sustainable Energy Reviews*, *53*, 924–935.

Ministry of Energy. (2010). *Energy Sector Strategic and Development Plan*. Ghana: Ministry of Energy.

Ministry of Energy, & World Bank. (2004). *Ghana Poverty and Social Impact Analysis Electricity Tariffs: Phase I*. Ghana: Government of Ghana and World Bank. Retrieved from http://webcache.googleusercontent.com/search?q=cache:r4I7XHIxhb8J:siteresources.worldbank.org/INTPSIA/Resources/490023-

1120841262639/psia_ghana_electricity.pdf+&cd=2&hl=en&ct=clnk&gl=ca&client=firefox-b-ab

Mohammed, Y. S., Mokhtar, A. S., Bashir, N., & Saidur, R. (2013). An overview of agricultural biomass for decentralized rural energy in Ghana. *Renewable and Sustainable Energy Reviews*, *20*, 15–25.

Moujaled, J. K. (2014). *A comparative assessment of solar resource databases, simulations and ground observations for Kumasi* (BSc). Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. Retrieved from http://dspace.knust.edu.gh/handle/123456789/6508

Natural Resources Canada. (2018, January 25). RETScreen [Government]. Retrieved July 2, 2018, from http://www.nrcan.gc.ca/energy/software-tools/7465

Neopower Engineering Consulting, http://www.neopower.com.gh/

Oyoh Tolumo Desmond (2016):Desalination in water treatment

Retrieved from

https://www.theseus.fi/bitstream/handle/10024/124763/desalination.pdf?sequence=1

HAMK (P.5)

REN21. (2017). *Renewables 2017 Global Status Report* (Renewables Global Status Report No. ISBN 978-3-9818107-6-9). Paris: REN21 Secretariat.

Rickerson, W. (2012). *Feed-in tariffs as a policy instrument for promoting renewable energies and green economies in developing countries*. New York: United Nations Environmental Programme.

Sahu, B. K. (2015). A study on global solar PV energy developments and policies with special focus on the top ten solar PV power producing countries. *Renewable and Sustainable Energy Reviews*, *43*, 621–634.

Schaeffer, R., Szklo, A. S., de Lucena, A. F. P., Borba, B. S. M. C., Nogueira, L. P. P., Fleming, F. P., … Boulahya, M. S. (2012). Energy sector vulnerability to climate change: a review. *Energy*, *38*(1), 1–12.

Schillings, C., Meyer, R., & Trieb, F. (2004). *Solar and Wind Energy Resource Assessment (SWERA): Final Report* (Solar and Wind Energy Resource Assessment (SWERA)) (p. 56). Germany: UNEP/GEF.

Shillito, J. (2016, October 17). Ghana domestic gas production casts more doubt on FSRU [ICIS]. Retrieved June 26, 2018, from https://www.icis.com/

Silicon Solar: http://www.siliconsolar.com/grid-tie-solar-systems-with-battery-backup.html

Statista. (2018). Brent crude oil price annually 1976-2018 | Statistic. Retrieved June 26, 2018, from https://www.statista.com/statistics/262860/uk-brent-crude-oil-price-changes-since-1976/

Stewart, R. (2017, April 28). Africa rejects Europe's "dirty diesel." Retrieved June 26, 2018, from ttp://p.dw.com/p/2c4l8

UN Dept of Economic and Social Affairs. (2017). *Sustainable Development Goal 7: Ensure access to affordable, reliable, sustainable and modern energy for all* (Progress towards the Sustainable Development Goals No. E/2107/66). Retrieved from https://sustainabledevelopment.un.org/sdg7

United Nations. (1987). *Report of the World Commission on Environment and Development: Our Common Future* (No. A/42/427). United Nations Environmental Programme. Retrieved from http://www.un-documents.net/wced-ocf.htm

World Energy Resources, 2016. https://www.worldenergy.org/publications/2016/world-energy-resources-2016/. Retrieved on the 26th of July,2018 at 12:55pm

Yin, R. K. (2009). *Case study research: Design and methods (applied social research methods)* (2nd ed.). Thousand Oaks, Calif: International Educational and Professional Publisher.