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RENEWABLE ENERGY DIFFUSION IN GHANA: INVESTMENT DECISION MAKING STRATEGIES UNDER UNCERTAINTY

CHARLES GYAMFI OFORI
(ID: 10283050)

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DECLARATION

I declare that this thesis is the result of my original work, and all referenced materials have been duly cited. It has not been sent to any institution where for an academic award. All criticisms regarding any imperfection of this thesis should be attributed to me and me alone.

.... 06/01/2023 ....
Charles Gyamfi Ofori
(Candidate)
Date

.... 6/01/2023 ....
Prof Godfred A. Bokpin
(Supervisor)
Date

.... Jan 6, 2023 ....
Prof Anthony Q. Q. Aboagye
(Supervisor)
Date

.... 06/01/2023 ....
Prof Anthony Afful-Dadzie
(Supervisor)
Date

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DEDICATION

To Josephine Araba Duncan Ofori. Best of wives and best of women.

Without wax!

To Lian Afram Ofori. I know you will blow us all away, someday!

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LIST OF ABBREVIATIONS

ACEP	Africa Centre for Energy Policy
BoG	Bank of Ghana
BS	Black-Scholes
CAPM	Capital Asset Pricing Model
CBOD	Chamber of Bulk Oil Distributors
CCS	Carbon Capture and Storage
CSP	Concentrated Solar Power
DCF	Discounted Cash Flow
ECG	Electricity Company of Ghana
EIA	Energy Information Administration
ESG	Environmental, Social and Governance
FIT	Feed-In Tariffs
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Fund
GEP	Generation Expansion Plan
GHS	New Ghanaian Cedi
GPRS	Ghana Poverty Reduction Strategy
GSE	Ghana Stock Exchange
GSE-GAX	Ghana Alternative Market
GSGDA	Ghana Shared Growth and Development Agenda
GSS	Ghana Statistical Service
IEA	International Energy Agency
INDC	Intended Nationally Determined Contributions
IPSMP	Integrated Power System Master Plan
IRENA	International Renewable Energy Agency
IRR	Internal Rate of Return
LCOE	Levelised Cost of Energy
LNG	Liquified Natural Gas
LSMC	Least Squares Monte Carlo
NEDCO	Northern Energy Distribution Company
NPV	Net Present Value
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OVX	Crude Oil Volatility Index
PURC	Public Utilities Regulatory Commission
PV	Present Value
RE	Renewable Energy
REMP	Renewable Energy Master Plan

SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SGN	Sankofa Gye Nyame
SME	Small and Medium Scale Enterprise
Solar PV	Solar Photovoltaic
SRT	Social Representations Theory
TEN	Tweneboa Enyerra Ntomme
UN	United Nations
VAR model	Vector Autoregressive Model
WACC	Weighted Average Cost of Capital
WAGP	West Africa Gas Pipeline

ABSTRACT

Climate change and energy sustainability concerns have spurred renewed interest in the transitioning from fossil fuels to cleaner sources of energy generation, of which renewable energy generation plays an important role. However, the conversation surrounding renewable energy integration goes beyond environmental considerations to include other factors, such as ensuring profitability and increased investment. Renewable energy integration requires substantial buy-in from governments, investors, and businesses, particularly Small and Medium Scale Enterprises. However, securing the buy-in from these stakeholders, especially investors and businesses, requires that a business case be made for them in an environment riddled with uncertainties. Also, creating value within the uncertain environment requires investment decisions regarding the context-specific issues that could aid or offset profitability and the potential for renewable energy integration.

This thesis seeks to provide decision-making strategies for large-scale and small-scale renewable energy investments in uncertain environments. Three independent studies are carried out with specific objectives that seek to achieve the overall aim of the study. The first study analyses the value of delaying utility-scale renewable energy investments. The second study analyses the cost-saving potential for SMEs to switch to renewable energy technologies. Lastly, the third study presents a cost minimisation model for renewable energy investments while providing approaches towards financing same.

Using real options models and linear programming models, the study outlines several findings that have implications for research, policy and investment decisions. The studies have varying implications for businesses in providing investment strategies for utility-scale and small-scale renewable energy investment. It also contributes largely to the pool of literature on renewable energy and investments using rigorous methodological approaches that consider inherent uncertainties in the business environment.

First, there is value in delaying utility-scale renewable energy investments until the uncertainties are relaxed. However, delaying investments have opportunity costs and must be matched with the gains in delays to create an optimal investment timing point that maximises the option value for investors. Other factors that affect the option value for renewable energy investments include the

volatility resulting from the upside potential of the investments. Also, governments are required to create an environment that increases the demand for renewable energy technologies.

Second, SMEs obtain significant value when they replace, either wholly or partially, conventional energy supply sources with renewable energy technologies. This replacement allows for renewable energy technologies to be counted as part of the primary energy sources for the SME. However, SMEs do not obtain significant investment value when renewable energy technologies are used only for backup energy supply. SMEs are also required to consider the capacity factor of renewable energy technologies, tariffs for conventional power supply, system reliability of conventional systems and the investment costs for renewable energy generation as essential factors for renewable energy investments.

Third, SMEs can finance their capacity expansion and renewable energy integration plans through debt financing amortised using savings they obtain when they use renewable energy technologies. However, considering the investment options, the study results show that in situations where savings from conventional tariffs are not enough to meet required loan repayments, delayed investments could yield substantial value for SMEs. The results further show that investment pooling can prove helpful to SMEs as unionised groups can drive trust from financial institutions. This approach is beneficial for SMEs that work within an industrial enclave.

CHAPTER ONE

INTRODUCTION

1.1 Background

With rapid population growth, urbanisation and globalisation, the demand for electricity has witnessed a steady increase. Between 2014 and 2020, global electricity consumption increased by about 11%, i.e., from 22,400Twh to approximately 24,900Twh. Within the same period, renewable energy consumption increased by over 40%, from about 5000Twh to about 7200Twh (International Energy Agency, IEA, 2021). The IEA further predicts that renewable energy technologies are expected to account for about 36% of global electricity generation by 2026. Thus, renewable energy technologies are becoming significant contributors to increased global power consumption towards meeting current and future energy demands.

The wide recognition gained by renewable energy is attributed to two key factors. First, renewable energy can serve as an alternative source to conventional energy, thus improving the reliability of supply. Secondly, the discourse around climate action has exemplified renewable energy as a means for climate change mitigation, particularly in reducing greenhouse gas emissions. These factors have contributed toward investment generation into renewable energy technologies. Between 2004 and 2018, over $2 trillion was invested in renewable energy worldwide (International Renewable Energy Agency (IRENA), 2018).

Globally, about 2.8 Terawatts (TW) of renewable energy have been installed as of the end of 2020. This capacity represents a growth rate of about 128% since 2010, with an average annual growth rate of about 9% (IRENA, 2020; IRENA, 2021). Asia recorded the highest level of growth in renewable energy generation capacity. Renewable energy capacity in Asia grew by about 232%

between 2010 and 2020, with an average annual growth rate of 13%. Africa has seen steady growth in its renewable energy generation capacity, increasing from about 26 gigawatts (GW) in 2010 to about 53GW in 2020 representing a cumulative growth rate of 104% or an average annual growth rate of 7% (IRENA, 2020; IRENA, 2021).

Ghana has shown interest in mitigating climate change and its harmful effects. The country is a signatory to various international protocols that seek to contribute to reducing global carbon emissions. For instance, Ghana has signed The Paris Agreement, which has the general objective of maintaining global temperatures at 1.5 degrees. Renewable energy penetration forms an integral part of the policy actions that will be implemented to meet the intended goal of the country. Ghana plans to scale up renewable energy penetration by 10% as it seeks to generate over 1,000MW of power from renewable energy sources by 2030 (Energy Commission, 2019). The government of Ghana acknowledges that achieving this target requires substantial capital investment. Thus, its financing plan seeks to rely on state funds, donor funding and private capital. Therefore, to attract the needed private capital, the government must provide an incentive for private investments. These incentives include feed-in tariffs, i.e., pricing policies designed to promote renewable energy investments, and net metering mechanisms that allow self-generators of electricity to export surplus energy to the grid to be used when the self-generator needs the electricity.

Renewable energy penetration in Ghana is beneficial for Ghana to advance its climate change mitigation agenda and offer a pathway to meet its national electrification targets. Ghana missed the 2020 target for achieving 100% electrification with an electrification rate of about 85.3% as of the end of 2020 (Energy Commission, 2021). This notwithstanding, renewable energy technologies can provide options to catalyse the country's national electrification agenda through off-grid or stand-alone technologies, which can provide access to communities where the grid connection is difficult.

Businesses and households also utilise self-generation options either to offset increasing conventional tariffs or as a backup source of energy supply. Renewable energy investments by businesses and households can serve as an option for self-generation for primary or secondary electricity supply. These technologies can be used as an additional generation capacity to augment supply from conventional sources from the national grid and save power consumption costs. The foregoing show that there is value for renewable energy adoption by governments, businesses and households. A business case must therefore be made to encourage these stakeholders on decision making strategies towards renewable energy adoption and investment.

1.2 Overview of renewable energy technologies

Renewable energy is generated from natural processes which are replenished continuously, hence its name. Renewable energy includes solar, biomass, wind, and geothermal energy. On the other hand, conventional energy resources include fossil fuels (e.g., coal, crude oil and natural gas) and are not easily replenished. These resources are either not renewable, or have slower replenishment rates relative to the rate at which those resources are extracted. For instance, the decay of fossil fuels into crude oil takes over a million years, meaning that the current resources were deposited millions of years ago. On the other hand, renewable energy sources such as sun and wind are available at an instant, though there might be some intermittency in their availability. While there are different renewable energy technologies, this section presents an overview of three commonly used renewable energy sources: solar energy, wind energy, and biofuels.

1.2.1 Solar energy

Solar energy is one of the main global sources for renewable energy technologies for the provision of heat and electricity. It is a form of clean, renewable energy that is created from sunlight. Energy from the sun is known to be the largest carbon-neutral source of energy. Harvesting energy from the sun requires research into the relevant technologies. Solar energy technologies consist of two main types: Solar Photovoltaics (Solar PV) and Concentrated Solar Power (CSP).

Solar PV cells convert sunlight energy directly into electricity. Solar PV cells are combined to form a solar module which is mounted in an array in the form of a flat photovoltaic (PV) plate. The PV plate is mounted in such a way that it can capture the sun's energy over the day. PV cells are primarily used in households for electricity generation. A larger interconnection of PV cells is required to generate electricity for industrial utilisations. Thus, hundreds to thousands of interconnected arrays can be used depending on the amount of energy needed.

On the other hand, Concentrated Solar Power (CSP) technologies utilise solar concentrators to convert solar energy into thermal energy. The solar concentrators receive solar radiation and focus them at a single focal point, generating heat energy (Joardder, Halder, Rahim & Masud, 2017). Typically, a CSP plant would consist of thermal collection, thermal generation and thermal storage. Thermal generation could be used to power engines or drive turbines to generate electricity. Further, the CSPs can be applied in various industrial operations. These operations include food and mineral processing, chemical production and desalination.

One significant advantage of solar energy is its ability to provide a clean source of energy. Solar PV technologies are sustainable and environmentally friendly (Peng, Lu and Yang, 2013). Solar energy does not emit any direct greenhouse gasses since the electricity is produced directly from the sunlight and does not involve the combustion of fuels. The greenhouse gas emission potential of solar PVs using a Life Cycle Assessment (LCA) ranges from 61g CO_2 eq/kwh to about 16061g CO_2 eq/kwh, depending on the type of solar cell (Baharwani *et al.,* 2014). Comparatively, combined cycle gas plants have a gas emission potential is approximately 400g CO_2 eq/kwh and does not compare to that of solar PVs even if carbon capture and storage technologies are used in gas plants (Modahl *et al.,* 2011).

Unlike conventional energy technologies such as thermal plants, solar PVs do not require fuel to generate electricity. Also, routine maintenance practices such as cleaning of solar panels and regular servicing of inverters, generally have a lower comparative cost than other conventional power plants (IRENA, 2017). These relative low O&M costs ensure a long-run economic potential for solar PVs. While there have been drastic reductions in the cost of photovoltaic equipment, there has been a steady increase in its production capacity (Bhatia, 2014). The international renewable energy agency (IRENA, 2014) records that in Europe, the price for photovoltaic systems has reduced by over 80% over the past decade. The durability of solar panels helps reduce repair costs since quality solar panels can last up to 30 years.

As already noted, solar energy requires substantial capital investments, making an investment into such systems difficult. In addition, solar power requires a large area of installation, sometimes known as solar farms, to meet higher energy demands (Sampaio & Gonzalez, 2017). Higher volumes of solar power can be generated in tropical areas where sunlight is in abundance. On the other hand, there is a low likelihood of generating enormous solar power in more temperate regions. However, technological advancements are making it possible for solar technologies to store enough power for unavailable solar energy. The storage costs depend largely on the kind of technology and the capacity of storage equipment (Shioshansi *et al.,* 2021).

Solar energy provides a means of achieving the national electrification agenda for many developing countries, especially those within the tropical regions where sunlight is readily available. In addition, it offers the opportunity to ensure easy access to electricity, especially in remote areas where the grid connection is difficult to reach.

1.2.2 Wind power

Wind power has been utilised for mechanical purposes for the past centuries (Ackermann & Soder, 2002). In the late 20th century, the focus of wind energy was shifted from the generation of mechanical energy into electrical energy. A simple wind turbine has three main parts: the rotor blades, the shaft and the generator. The wind forces the energy to move, creating mechanical energy in the form of rotational energy. The propellers or the blades turn around a rotor that is connected to the main shaft (Ramkumar & Rajesh, 2021). Thus, energy is transferred from the rotor blades to the main shaft, which spins the generator to produce electricity. The generator turns the mechanical energy into wind energy. Wind turbines can be installed for use in households for domestic electricity generation. It can also be connected to the grid as an additional source of power generation.

There are two primary forms of wind power generation, and they differ in terms of the location of installed turbines. Onshore wind turbines are installed on land, while offshore wind turbines are installed on the open seas or large water bodies. Unlike solar energy, which may not be readily available in temperate regions, wind power is available worldwide, irrespective of whether the area is tropical or temperate, as long as there is adequate wind generation (Kyriakopoulos, 2021).

Therefore, wind energy investments are made in areas where wind speed and energy generation potentials are higher. For example, in the USA wind investments in electricity generation has surpassed hydro as the most used renewable energy generation resource in 2019, as it exceeded the latter's generation potential by about 26 million MWh (U.S Energy Information Administration, 2020)

In remote areas where grid connections may not reach, wind power provides a valuable energy alternative. In areas where high rise buildings are not common, the wind energy is efficiently distributed as they are free from artificial windbreaks. Since wind energy is a clean energy source, wind turbines do not harm environments, nor do they pose any harm to crops. For this reason, wind farms can be in local farmlands. Farmers can therefore lease part of their lands to wind energy generating companies to obtain an extra source of income.

Like solar energy, wind energy comes with high capital costs, out of which the turbines constitute 76% of the total cost (Morthorst, 2009). Operating and maintenance costs also account for about 20 to 25% of the total levelized cost for a new turbine. In addition, wind energy is not reliable in areas where the speed of wind is low. Finally, although wind energy helps reduce pollution caused by fossil fuels, noise pollution is caused by the sound of the turbines within a wind electricity generating area (Kaplan, 2015). Despite these shortfalls, the merits of wind-generated electricity outweigh its demerits, making it a suitable source of energy generation.

1.2.3 Biofuels

Biofuels are produced from biological processes such as anaerobic digestion. Therefore, it is different from fossil fuels which are made from geological processes of prehistoric biological matter. The rate of decay and formation of biofuel is consequently faster than that of fossil fuel sources. For our transportation needs, biomass is converted into liquid fuels, and these are used as fuel substitutes or fuel additives (Awudu & Zhang, 2012). The most familiar biofuel types are biodiesel and ethanol (Hasan & Kalam, 2013).

Awudu & Zhang (2012) group biofuels into four generations: the first-generation biofuel refers to those obtained from food crops such as corn, starch or sugar beets. An examination of these sources shows their renewable and biodegradable nature, which do not produce toxic chemicals. The second and third generations of biofuels are obtained from crop and forest residues and waste from industries. They provide an avenue for the proper industrial waste recycling process to reduce solid and liquid waste to the environment. Finally, the fourth generation of biofuel consists of biochemical, thermal, and other processes other than the first, second and third-generation biofuels. Research and development into the fourth-generation biofuels have not generated much attention compared to the first, second and third-generation biofuels.

Biofuel is readily available and does not go through stringent processes of production. Therefore, biofuel can be an excellent fuel source for sustainable rural development, especially in areas where fossil fuel transportation may not reach (Huang, Zhou & Lin, 2011). However, biofuel has some disadvantages, it has a corrosive nature, and its presence corrodes brass and copper metals, causing excessive wear in engines. However, advancements in research and development have led to new biofuels that do not pose risks of corroding metals while catalysing the rate of wear and tear.

1.3 Overview of Ghana's power sector

As of the end of 2020, the power sector of Ghana had an installed capacity of about 5,134MW made up mainly of thermal and hydro sources. Ghana's thermal plants make up about 69% of the total installed capacity, hydro sources are about 29.9%, while renewable energy accounts for about

1.1% of total installed capacity (Energy Commission 2021). Hydroelectric power used to be the main source of power generation for the country up to the late nineties. However, reductions in water levels resulted in severe energy crises in the late nineties and the early parts of the 21st century. The long spell of severe power outages which gave rise to the term *"dumsor"* in Ghana between 2012 and 2016 led to drastic measures to be undertaken by the government during these periods. The government entered into various power purchase agreements that provided liabilities to pay for capital recovery charges by power generators which were not fully utilised. This decision to enter into the various power purchase agreements was to ensure the security of supply to meet the growing energy demand, culminating in the increased generation capacity for the country. Ghana's peak load on the transmission grid for 2020 amounted to 3090MW showing a difference of over 2000MW of unutilised capacity.

Other challenges in power supply include increasing levels of transmission and distribution losses, non-payment of debts owed to distribution companies by consumers and the over-dependence on hydro and thermal sources of power generation (Kumi, 2017). Transmission losses has increased from 3.7% to 4.5% between 2010 and 2020. Additionally, distribution losses reduced from 29% to 23% between 2010 and 2013. However, it has witnessed a steady increase from 23% in 2013 to about 26% as of the end of 2020. The distribution sector is mainly responsible for revenue generation along the power sector value chain. However, increasing losses and other factors affect sector's ability to generate substantial revenues. Consequently, this has resulted in a pile of debts across the power value chain for the country.

Realising the importance of natural gas as a cost-effective and environmentally friendly option for powering thermal plants than liquid fuels, the government of Ghana has mapped out a gas master plan which seeks to optimise gas utilisation by creating demand at both power and industrial sectors of the economy. Currently, over 90% of the country's thermal plants is fuelled with natural gas. Ghana sources gas from its domestic fields; the Jubilee Field, the Tweneboa Enyerra Ntomme (TEN) Field and the Sankofa Gye Nyame (SGN) field. It also imports some of its gas requirement from Nigeria through the West Africa Gas Pipeline (WAGP). Gas has reduced the reliance on more expensive liquid fuels for power generation.

Ghana's power demand is estimated to grow by 10% annually. It is also estimated that the country will require an additional 200MW of power every year to meet this demand (Energy Commission, 2019b). This requirement has necessitated several policy actions, such as increasing gas availability with imports of liquified natural gas (LNG) and the use of renewable energy as additional options for power generation. In addition, Ghana has signed on to several regional and international protocols that seek to reduce CO2 emissions and ensure environmental sustainability. These protocols have renewable energy promotion as a sure way to meet the set environmental and climate change mitigation targets.

Consequently, the renewable energy master plan was mapped out to ensure a substantial penetration of renewable energy in Ghana's energy generation mix. The plan has targeted a total installed renewable energy capacity of about 1300MW by 2030, requiring an investment estimated at $5.6 billion. The master plan estimates about 80% to be sought from the private sector. Thus, government policies must realise the need to seek private investment by creating the appropriate environments for such investments to thrive amidst competition with conventional energy sources. The need for government to effectively time its investments to generate maximum benefits is therefore opportune.

1.4 Problem Statement

The preceding sections have highlighted some benefits for renewable energy integration. Ghana has several policy documents that speak to increasing the share of renewable energy technologies in its energy mix. The country had a target of ensuring that at least 10% of its total energy mix would consist of renewable energy technologies outside the current hydro capacity by 2020. However, as of the end of 2020, the country had less than 1.5% share of renewable energy in its energy mix (Energy Commission, 2021). Thus, Ghana was unable to meet its target of renewable energy generation and has consequently shifted the target to 2030. Ghana must accelerate its pace of renewable energy integration if it wants to achieve its target by 2030.

Achieving this target requires substantial investments and this is recognised in the country's Renewable Energy Master Plan (REMP). The investment requirement under the REMP demonstrates the essence of private investors in the country's agenda for renewable energy penetration. However, irrespective of the renewable energy investments being environmentally friendly, investments in the technology must generate value to the investor. Again, the investor must not be exposed to excessive risks which could be detrimental to ensuring investment value. Zhang, Zhou & Zhou (2016) indicate that renewable energy investments are irreversible, cost intensive and are prone to various risks. Further, Michelez *et al*. (2011) outline various types of risks faced in the renewable energy sphere, namely political risks, economic risks and climatic risks which impacts negatively on investment returns. These risks must be considered and managed renewable energy investment decisions.

For instance, the challenge of excess power generation capacity has been a significant factor that affects the government's power investment and power sector regulatory decisions in one way or another. As of the end of 2020, the country's excess generation capacity was about 1,400MW

(Energy Commission, 2021). As part of measures to curtail the problem of excess capacities, the government of Ghana has placed a moratorium on renewable energy power purchase agreements. It has also extended this suspension for embedded generation, with impacts on renewable energy investments in the country. Thus, the government's decision on the renewable purchase agreements can affect investment decisions within the environment since government is a key purchaser for power generated by utility or large-scale renewable energy technologies.

Beyond the large-scale grid connections, small scale investments are available for business owners and households that could offer gains through substantial cost savings. However, many of these intended beneficiaries, particularly Small and Medium Scale Enterprises (SMEs), cannot take advantage of self-generation through renewable energy integration. This is fuelled by limited knowledge of the economic potential of renewable energy penetration, the perceived high cost of investment and a narrow focus on environmental sustainability (Africa Centre for Energy Policy (ACEP), 2021). Thus, to secure their buy-in, it is essential to make a business case for SMEs. Making a business case for SMEs will involve analysing the economic benefits and approaches to finance SMEs' investment in renewable energy technologies. This notwithstanding, renewable energy penetration remains a possibility when the necessary investment environment is created for SMEs.

Generally, studies on renewable energy in Ghana have focused on the policy dimensions of the technology. For example, Gboney (2011) focused on the policy and regulatory framework of renewable energy in Ghana and concluded that international support is required to advance the course of renewable energy penetration in the country. Asante *et al.* (2014) also revealed that political and regulatory challenges affected renewable energy investments in Ghana. Lastly, Aboagye *et al.* (2021) undertook a comprehensive review of the state of renewable energy penetration in Ghana and found that Ghana can take advantage of its resources to advance the course of renewable energy penetration. At the small-scale level, research on the viability of renewable energy penetration is generally scant. ACEP identified some knowledge and financial barriers to renewable energy deployment among SMEs (ACEP, 2021).

These studies provide enough justification for further studies to be conducted on the need to make a business case for both large-scale and small-scale renewable energy investments. Again, the regulatory challenges highlighted in the findings of previous studies elicit questions as to how investors could navigate such challenges in their investment decision making strategies. Particularly for businesses, the conversation of renewable energy must move beyond the environmental perspective towards a more incentivised approach where SMEs and households could see the economic benefits of renewable energy integration.

Therefore, this thesis seeks to provide decision-making strategies on renewable energy investments for government, private investors, and businesses while considering the risks inherent in the environment. The study applies various aspects of real options theory and optimisation techniques to make investment decisions concerning timing of renewable energy installation, capacity and the profitable areas for renewable energy investment.

1.5 Objectives of the study

The main objective for the study is to explore decisions for renewable energy investments by governments, private investors and business owners. It applies, real options analysis and optimisation techniques to help achieve the objective. Also, three studies are carried out, with each study outlined to achieve a specific objective:

1. **Objective one:** The first objective examines the risks inherent in utility-scale renewable energy investment and provides an outlook regarding the optimal time that creates maximum value for such investments. The study utilises the binomial lattice approach to real options analysis for the valuation using the first cycle of Ghana's Renewable Energy Master Plan as a case.
2. **Objective two:** The second objective undertakes a cost-benefit analysis that determines the benefits for SMEs in transitioning from conventional sources to renewable energy technologies. The study focuses on providing cost-saving options for SMEs in integrating renewable energy technologies through the application of real options techniques.
3. **Objective three:** The third objective applies optimisation techniques to provide an investment outlook that minimises the long-run cost of power supply. The model also offers practical approaches towards financing capital intensive renewable energy investments.

1.6 Significance of the thesis

Investment in renewable energy technologies requires decisions that balance trade-offs between meeting renewable energy targets and growing energy demand. Further, there is the need to ensure that government also create conducive environment for renewable energy investments to thrive. The study is relevant for policymakers in finding a sustainable means to address Ghana's energy challenges. It highlights solutions that generate maximum investment value to governments and investors in utility-scale renewable energy resources. Aspects of the study shall provide a sensitivity analysis that identifies factors that will impact investment value in utility-scale renewable energy technologies.

The study makes a business case for SMEs to integrate renewable energy technologies into their energy supply mix. The study also outlines investment approaches for SMEs to finance these investments in a way that does not entirely limit their ability to fund their everyday business operations. Lastly, SMEs are introduced to renewable energy integration options that will further minimise their long-run cost of energy consumption.

This thesis adds to the increasing knowledge on investment valuation and optimisation by providing novel approaches towards valuing investments that consider uncertainties. Lastly, the methodological rigour offers a means to extend academic research to practical policy-making situations.

1.7 Chapter organisation

The thesis is arranged into six main chapters. The first chapter provides a background to the study. This chapter describes the problem and outlines the objective of the studies. A review of the various risks in renewable energy investments is provided in the second chapter. The third, fourth and fifth chapters respectively present the three studies that meet the objectives of the thesis. The sixth summarises the findings of the studies and provide the necessary conclusions and recommendations relevant to meeting the study objectives

CHAPTER TWO

RISKS AND DECISION-MAKING STRATEGIES IN RENEWABLE ENERGY INVESTMENTS

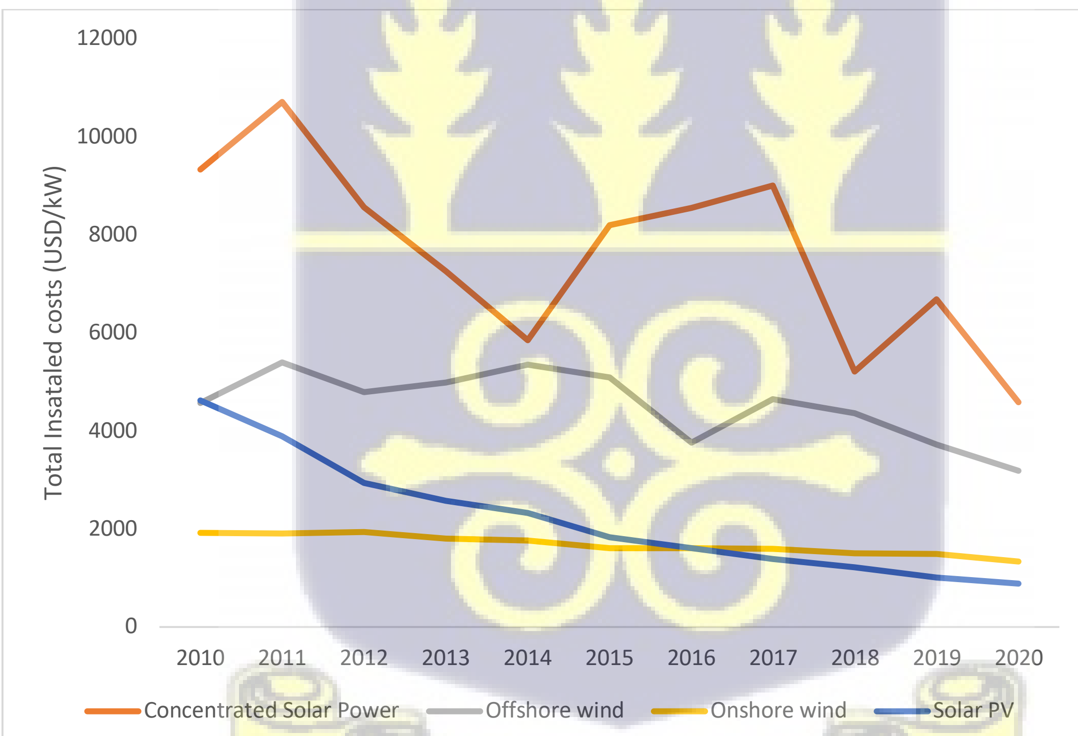
2.1 Introduction

Conditions in renewable energy technologies vary significantly from fossil fuel plants, albeit there are some similarities. Johansson (2013) presents several characteristics of renewable energy systems which differ from one fossil fuel generating source to another. First, renewable energy depends on the flow of energy rather than the availability of an exhaustible stock of dead material such as fossils. In addition, its location is widespread rather than concentrated, as in the case of fossil fuels. Lastly, renewable energy systems have close interactions between themselves and other biological systems, particularly in biomass. These conditions suggest that a plethora of factors are antecedent to the success of renewable energy investments. This chapter presents a review of such factors outlined in the literature as contributory to the benefits or risks of renewable energy systems. The chapter also outlines various approaches to making investment decisions within context riddled with uncertainties.

2.2 Renewable energy costs and financing investments

There are three main levels of the power value chain: generation, transmission, and distribution. At each level of the chain, associated costs can be classified into capital and operation and maintenance costs (Stram, 2016). Globally, reducing the costs of renewable energy systems has contributed to an increase in investments in the resource (REN 21, 2019). These investments have improved the manufacturing technologies, and consequently, unit costs of solar photovoltaic and onshore wind power systems have seen rapid declines. Figure 2.1 shows the trend in cost declines of various renewable energy generation sources. Between 2010 to 2020, average global installed costs for Concentrated Solar Power (CSP) had reduced by about 51%. Solar Photovoltaics (PV) have witnessed the highest reduction rate, with cost reductions of about 81% between 2010 to 2018. Offshore wind and onshore wind energy sources have reduced by about 30%. Significant reductions in renewable energy costs are mainly due to increased efficiency fuelled by advanced manufacturing technologies, reductions in importation tariffs, tax holidays and subsidy provisions. These incentives and subsidies are given to generate and sustain investor interest in renewable energy systems.

Figure 2. 1: Capital (investment) costs per kw of renewable energy systems from 2010 to 2020



Source: International Renewable Energy Agency (IRENA)

Notwithstanding the significant reductions in installed costs of renewable energy, it remains an essential factor in the scheme of renewable energy diffusion. The upfront investments required for their construction can be challenging (Steckel and Jakob, 2018). The average capital investment necessary for conventional power generation is still competitive with that of renewable energy generation. Data from the US Energy Information Administration indicate that the capital cost for single and combine cycle range from $730 to $200 per kW as of the year 2020.

In countries with continuous currency depreciation, additional costs are incurred with importing RE technologies at high foreign exchange rates to local currencies. For example, the capital costs for solar PVs witnessed an annual reduction at a rate of 15% between 2010 and 2020. However, the cedi equivalent of similar technologies witnesses an average reduction of approximately 2% within the same period. The impact of currency depreciation is further exacerbated by importation charges and other taxes which increase the capital costs of installation in Ghana.

High capital costs in renewable energies generally limit the benefits accrued through feed-in tariffs and other subsidies. It also provides an additional concern for governments to increase adoption and investment into renewable energy systems by increasing subsidies, placing extra costs on the government. A strong perception of the high capital costs of renewable energy systems limits its penetrability, especially at the firm and household levels in developing countries (Rout, Sahoo & Thomas, 2018).

The energy generation capacity in fossil fuel-powered plants is determined by the power plant's capacity and fuel availability. However, location plays a significant role in the effectiveness of renewable energy's generation capacity. For instance, a more substantial amount of solar and wind energy can be generated in abundant sunlight and higher wind speed respectively. The location of these resources may require additional investments that connects energy generated to the national grid for onward transmission and distribution, especially in utility-scale renewable energy systems. In addition, the high installation cost of solar plants can also be due to the special equipment needed to convert direct current to alternating current (Stram, 2016). The combination of these high costs shifts attention towards investment in fossil fuel generation systems.

Increasing the level of RE penetration requires private capital in addition to efforts made by governments and donor agencies. For example, Ghana in its Intended Nationally Determined Contributions (INDCs), in response to meeting targets under the Paris Agreement, has targeted a 10% in the country's energy mix by 2030. This target has culminated in the drafting of the Renewable Energy Master Plan (Energy Commission, 2019). These require substantial investments, which necessitates the inclusion of private investors. However, the perceptions of risks tied with creating investment value can affect investment decisions in renewable energy systems.

The limited access to capital further exacerbates the high capital costs of renewable energy generation. In assessing investment decisions in the renewable energy sector, Masini and Menichetti (2012) highlighted the difficulties in mobilising capital for investment in renewable energy systems. Such challenges arise in the form of high costs of capital and the unwillingness of financial intermediaries to provide capital for investments in large scale renewable energies due to their perceived risks.

In Ghana, there are limited specialised financing packages for green-focused investments. Thus utility-scale or small-scale investors of renewable energy would access funding at similar interest rates as other non-green focused investments. The financing cost may even be higher if the bank perceives the investment as a risky venture, especially, when business has not made a good case for financing, save the environmental friendliness of renewable energy technologies. Banks on the other hand limited in their ability to secure funds from big-ticket green funds such as the Green Climate Fund (GCF) and the Global Environment Fund (GEF). As of the end of 2020, Ecobank Ghana was the only Ghanaian private financial company that is accredited to receive funds from the GCF. Many of the financial companies do not have the requisite documentation to enable access to funding from GCF and GEF, particularly related to the Environmental, Social and Governance (ESG) principles. The Bank of Ghana, however, has introduced the sustainable banking principles which aimed at ensuring that the financial sector employs ESG principles in their decisions for funds disbursement (Bank of Ghana, 2019).

Lenders tend to mitigate risks of loan defaults by increasing interest rates on loans. Interest rates largely depend on the credit risk profile of the investor as well as the level of risk of the investment. The credit rating of the borrower mostly determines the provision of capital for investments. Aktan et al. (2019) found evidence of credit ratings being antecedents to an organisation's capital structure. Companies tend to have less debt than equity after a downgrade in credit ratings. This situation can be attributed to the increased cost of capital resulting from perceived risks of default to lenders. Credit ratings for most developing countries are low, which further worsen their ability to seek capital (Arnold & Yildiz, 2015). These issues culminate in credit facilities not being readily available for renewable energy investment, particularly in developing countries. With the prevalence of high capital costs, investment potential in renewable energy sources continues to be reckoned by the forces of conventional power sources.

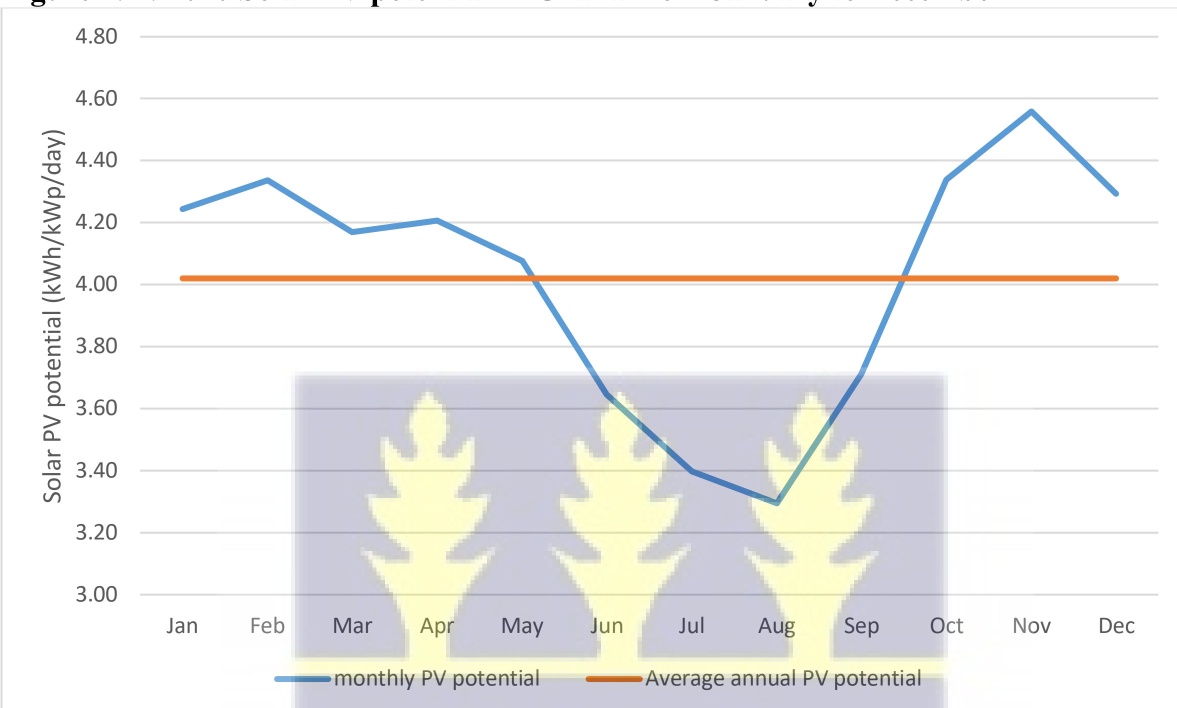
2.3 Weather risks

Weather or climatic factors generally impact the demand and supply of energy. On the demand side, the increasing temperature may increase the demand for electricity for cooling, especially in tropical regions. In temperate areas, reduction in atmospheric temperature results in increasing demand for electricity for heating (Ling *et al*., 2014). In addition to providing power for industrial and manufacturing needs, electricity is generally used to provide heating and lighting in residential facilities. Davies (1958) identified five meteorological elements that affect electricity demand. He classified them under heating-affect factors and lighting-affect factors. Heating factors include temperature and wind speed, whereas lighting factors include visibility, cloud formation, and precipitation. Beyond heating and lighting, energy is required for other uses, especially in the industrial sector. In Ghana, the industrial sector has the highest share of grid electricity consumption of 46% (Energy Commission, 2019). Therefore, the widening industrial sector has increased demand for energy, which must be met with an adequate supply level.

On the supply side, renewable energy technologies rely mainly on the climate for power generation. Solar energy relies directly on sunlight's availability, which means that solar energy is unavailable at night and periods when clouds cover the sun's energy. Onshore and offshore wind energy generation also relies on the availability of wind. Therefore, the increased dependency of renewable energy on the weather can lead to an unstable energy supply (Komendantova et al., 2011).

Ghana has a fairly distributed solar radiation across the months of the year, as shown in Figure 2.2. The highest PV potential occurred in November, recording an average of 4.29 kWh/kWp/day compared to the least potential of 3.29 kWh/kWp/day which occurred in August. Ghana has two main climatic seasons; the dry season which occurs from November to March and the rainy season which lasts from April to October. Thus, the lower PV potentials occurred in the rainy seasons. However, the deviation of the PV potential in the rainy season from the average annual potential is not substantially high, and the least values are adequate for solar power generation.

Figure 2. 2: 2020 Solar PV potential in Ghana from January to December



Source: Solar GIS

The reliance of renewable energy on climatic factors provides variations in load when there are changes in weather patterns and seasons, limiting the performance or capacity factor of renewable energy systems. The factors that contribute to capacity factors include resource quality, tracking capabilities and the size of the inverter (Energy Information Administration, 2019). For example, the capacity factor for solar PVs and wind power generators are averaged at about 19.5% and 16.5%, respectively (IRENA, 2018). To mitigate the impact of predictable and unpredictable variations in weather patterns and the lower capacity factors of utility-scale renewable energy systems, reserve capacities for power storage to be used during low generation periods of renewable energy are required. Investment in storage technologies includes batteries and capacitors that can store power in periods of limited energy generation from renewable energy systems, increasing the costs for power generation. Johansson (2013) argues that integrating both renewable and non-renewable power systems can reduce variability in the supply of energy.

2.4 Political and policy risks

The main objective of government policies on energy is to ensure the security and sustainability of energy supply (Aslani *et al*., 2013) and to provide increased access to electricity. Aslani *et al.* (2013) further distinguish energy security into direct and indirect measures. The direct measure involves surveillance and guarding the country's power investments against theft, arson and other power attacks. Indirect energy security measures involve the government's ability to quickly respond to problems, preventing power outages.

In countries where governments are the sole owners of power generation, transmission and distribution systems, grid management is reserved for these governments. Also, at each level of the power sector value chain, government agencies regulate the activities of both private and government players in the power sector. Therefore, government's regulations and policies affect investments in each aspect of the power sector value chain. It has been identified that the costs of renewable energy sources are high, and the competitive nature of conventional sources remain a barrier to investment in RE systems. A stable environment will therefore cause renewable energy investments to thrive. The provision of incentive packages for investors can increase the returns on investment or reduce the various risks and enhance the willingness of investors to spend in RE systems (Gross et al., 2010, Naicker & Thopil, 2019). Aquila *et al* (2017) highlight some incentive packages for renewable energy investments that can provide value and create a good business case for the investor. These include feed-in-tariffs, renewable energy commercialisation and net metering schemes.

Government policies such as tax rebates, reduction of import duties and increasing feed-in tariffs for renewable energy systems provide the requisite environment for renewable energy investment to thrive (Masini & Menichetti, 2012; Ajayi, 2013; Ahmad *et al*., 2016). However, in an environment where electricity prices are highly dependent on market factors, the stability of electricity prices cannot be guaranteed. Feed-in-Tariffs (FITs) are electricity generation prices provided by a government that guarantees the price for renewable energy produced by setting the price in advance for the renewable energy generation company. This advanced price setting is advantageous to the investor in two main ways; first, the investor can plan operations with lower volatilities. Second, the FITs are generally higher than conventional energy generation sources' average electricity generation prices.

On the demand side, net metering systems provide self-generators of electricity with the opportunity to make most of their investments in renewable energy by providing excess generation onto the grid at a reasonable price (Poudineh, Sen & Fattouh, 2018). With time, consumers can recoup renewable energy installation costs from cost savings through massive reductions in tariffs and gains in feeding excess power generation onto the national grid. The Renewable Energy Act (Act 832) in Ghana makes provision for some incentives in renewable energy investments. These include the provision of feed-in-tariffs, power purchase obligations and net metering schemes.

On the other hand, government policies that do not support renewable energy resources also pose challenges to renewable energy investment. The lack of the political will to promulgate and implement favourable legislation on renewable energy systems in a country stifle investor interest in renewable energy. Investors face regulatory risks when the political and legal framework of a country remains unstable. Changes in regulations or policies impact investment costs, feed-in tariffs and the ease of doing business in the country (Gross et al., 2010; Arnold and Yildiz, 2015). In a highly politically polarised country, government transitions can negatively impact investment in renewable energy technologies. This decision to invest or not could be borne from several reasons. For instance, a new government may decide not to continue with projects sanctioned by the old government under the guise of cost auditing. Secondly, new governments may have energy policy ideologies that are different from enhancing the growth of renewable energy in the country.

The lack of a political will could also result from an increased affinity for fossil fuel resources. For instance, natural gas provides a cheaper and more environmentally friendly fuel source for thermal plants than liquid fuels. Although natural gas can be used for several industrial purposes, it is primarily used in thermal power plants for power generation. Therefore, countries with rich gas deposits tend to maximise gas revenues by ensuring the utilisation of gas for power, reducing fuel and other operating costs. The preferences for gas and its perceived advantage provide a disincentive for promoting renewable energy technologies in some countries. Ghana's thermal power supply is mainly powered by natural gas sourced from domestic gas fields and imports through the West Africa Gas Pipeline. One of the key objectives of government is to maximise the gas supply from domestic sources to reduce their exposure to paying for unutilised gas. These objectives and other concerns of excess generation capacity has impacts on large- and small-scale renewable energy generation.

2.5 Technological factors

Solar photovoltaic and wind technologies have higher technology maturities and are more advanced in technology advancement than other renewable energy sources. This notwithstanding, renewable energy technologies are still considered emerging technologies as their level of technology maturity is relatively lower than fossil fuel resources. The low level of technology maturity generally provides fossil fuel power generating systems with a stronger market position than renewable energy systems (Naicker & Thopil, 2019).

Technology maturity affects the decisions to invest in renewable technologies (Masini & Menichetti, 2012). Preference is given to technologies almost at par with fossil fuel systems in terms of technology maturity. Technologies such as geothermal and hydro-electric plants are mature are economically advantageous. These technologies have been in existence for a comparatively longer period and are at parity with fossil fuelled power generation sources. Solar and wind technologies are currently being deployed and are not as mature as hydro and geothermal plants. They require more R&D to improve their maturity and competitiveness.

Investors assume lower risks with RE technologies that are highly matured. Immature technologies face the risk of replacement and eventual obsolescence, which have cost implications. The cost implications limit investments in new technologies, which could have been a technological breakthrough, requiring higher capital costs. Increased volatilities in cost estimates also pose higher technical risks for renewable energy investments (Allan et al., 2011).

Esmaieli and Ahmadian (2018) indicate that technology research and development efforts provide a better pathway to ensure technology maturity in renewable energy generation systems. However, the lower capacities of R&D and the slow progressiveness of RE technologies heighten the risk of technology maturity (Liu & Zeng, 2017). Therefore, the drivers of technological innovation include the resource capacity for invention, the capacity for commercialisation, capacities for adoption, and success or failure rates, which depend highly on the availability of funds for technological innovation.

Besides technology maturity, Naicker and Thopil (2019) indicate that the main technical factors in adopting renewable energy technologies include the availability of local champions to support the renewable energy technology after its implementation and the ease of transfer of knowledge and skill and the ease of maintenance. The increased level of technology maturity among solar PVs and wind generation systems stems from their ease in implementing technology and knowledge transfer policies. In addition, the scarcity of materials for systems utilising renewable energy can be a challenge in its technological advancement. For example, Johansson (2013) highlighted that the growing demand for RE had increased the scarcity of materials used in RE systems. Materials such as lithium and indium for solar energy systems are concentrated in fewer countries with fewer substitutes, which requires significant investments in substitutes. Fortunately, Ghana has discovered deposits of materials such as lithium required for some renewable energy technologies. Further, aluminium from the country's bauxite deposits can be used to produce some parts of solar PVs.

One of the main reasons for adopting renewable energy technologies is the mitigation of carbon dioxide emissions from fossil fuel sources, which has implications for environmental sustainability. However, decarbonisation efforts among countries involved in exploration and production activities such as Carbon Capture and Storage (CCS) technologies have heightened. CCS technologies can capture a more significant proportion of carbon dioxide emissions that will be produced. In addition, these technologies prevent the release of CO2 into the atmosphere.

Globally, Norway leads in the utilisation of CCS technologies. Other countries such as the United Kingdom, Canada, Japan, the USA and China are also found within the top hierarchies of CCS technology utilisation. South Africa is the only Sub-Saharan African country recognised to have a substantial penetration of CCS technologies (Global CCS Institute, 2018). CCS technologies are beneficial to countries that produce or consume large quantities of fossil fuels. Although these technologies are currently immature, they have the potential to dominate the fossil fuel market. The widespread utilisation of CCS technologies will reduce climate change threats posed by fossil fuel technologies. However, this technological breakthrough can have detrimental impacts on renewable energy generation as its main advantage of reducing climate change impacts is offset by the presence of CCS technologies.

2.6 Demand factors

Generally, ensuring the availability of supply of power has been a major approach to ensure energy security. Several development policies, especially in developing countries such as Ghana, have ensured the security of the power supply. The objective of the Ghana Poverty Reduction Strategies' (GPRS I and II) included the development of reliable and affordable energy systems supporting economic activities, particularly in rural communities. The Ghana Shared Growth and Development Agenda (GSGDA I), which ran from 2010 to 2013, aimed to increase access to reliable electricity supply to households and industry (National Development Planning Commission, 2010). In addition, UN member states were urged to develop plans to increase awareness of sustainable energy as the year 2012 was declared a Year of Sustainable Energy for All. The key objectives were to ensure universal access to modern energy services, double efficiency rates, and double the share of renewable energy in the global energy mix among UN member states. Ghana also has the Renewable Energy Master Plan, which seeks to improve the penetration of renewable energy and subsequently increase generation capacity between 2019 and 2030.

Extant research in energy security has also focused on the sustainability of the energy supply required to meet increasing energy demand (Ajayi, 2013; Viebahn, Lechon & Trieb, 2011).

However, whereas ensuring security in terms of supply is suitable, generating demand for the increased capacity generation is equally important. One of the necessary market factors that spur the success of any investment is the ability for demand to be created for the utilisation of the investment outcome. The benefits of power generation are reduced when there is little demand for the power that is generated. For the energy supplier, obtaining demand is essential in generating maximum returns on investment (Johansson, 2013). In a free market, the security of energy demand is influenced by the ability of an investor to protect his market share or absorb market share from competitors.

Several factors impact power demand, both directly and indirectly, due to the complexities of electricity-generating systems (Saavedra, Christiano & Francisco, 2018). First, supply capacities can limit energy demand (Mutingi, Mbohwa & Kommula, 2017). However, in an environment with increased supply capacity, the energy demand depends on other factors beyond the supply capacity. Factors that drive demand in the power market include population growth, electrification rate, industrialisation rate and the willingness to pay for electricity (Ahmad et al.; Arnold & Yildiz, 2015). Second, power demand can be increased through massive industrialisation, which relies on government policies and creates an environment that supports foreign direct investors in a country (Mutingi et al., 2017).

Energy demand is also affected negatively by increasing prices. Households that are unable to pay for electricity can reduce electricity consumption. Also, industries reduce production levels to match the budget for electricity consumption. However, there is a silver lining for stand-alone systems. Increasing prices on grid-connected electricity present opportunities for industries to self-generate rather than rely on the grid. This potential for self-generation is advantageous for off-grid-connected systems such as rooftop solar PVs as long as such systems can provide power generation at lower costs. Thus, although utility-scale or grid-connected utilities may obtain a stable price arising from feed-in tariffs, their profitability can be offset by increasing prices from grid distributors to consumers, which may cause reductions in power demand.

2.7 Oil price and renewable energy dependencies

Several authors have argued that specific dependencies exist between the movement of crude oil prices and that of renewable energy technologies. As a substitute for fossil fuels, an understanding of the dynamics of oil prices can prove helpful in making investment decisions in renewable energy resources (Reboredo, 2015). This section reviews studies that have examined the relationships between oil prices and renewable energy prices.

Kumar, Managi and Matsuda (2012) found that movements in oil prices influenced variations in the value of renewable energy stocks on the stock exchange. Again, Sadorsky (2012) also showed that company sales growth and oil price changes were the two key factors that impact the systematic risk of renewable energy companies. Increases in oil prices generally increase the cost of doing business for non-oil-related companies. While oil prices may be market-related and not directly under the control of governments and corporations, increases in sales can offset the exposure to systematic risks posed by increasing oil prices. Thus, pull policies attract more adoption and investment into renewable energy technologies, and cushion exposure to the inherent risks.

Using Copulas, Roboredo (2015) investigated co-movement between oil prices and renewable energy stocks. Copulas are measures of association that are used in examining the dependence structure between two or more random variables (Alexander, 2008). The results of the study show an asymmetric tail dependence between oil markets and renewable energy markets. Thus, low oil prices provide insufficient inducements for the development of the renewable energy market. Dutta

(2017) also assessed the impact of oil price uncertainty on renewable energy stock returns using the Crude Oil Volatility Index (OVX). The study reveals that high OVX values greatly influence the stock market return of clean energy sources. Thus, increases in oil volatility can increase the volatility of renewable energy stocks.

The results of Reboredo (2015) and Dutta (2017) have implications for policymakers and investors. First, policymakers should support the profitability of renewable energy companies during periods of lower oil prices, especially when thermal generation costs seem to be lower than that of renewable energy generation. Second, governments must enact policies to attract more investors in the period of lower oil prices. These policies can help generate the affinity towards cleaner substitutes for crude oil. Third, the guidelines can be relaxed during periods of high oil prices. This form of relaxation is possible because the high costs of fossil fuels have become a push factor for investors and buyers to gravitate towards renewable energy technologies. For investors, extreme movements of oil prices significantly increase the Value at Risk (VaR) of renewable energy stocks whose losses can put RE investors out of business. Thus, investors in renewable energy technologies must make sure they protect their investments against oil price shocks.

Different data sources, methods of analyses and variables have pointed out the relationships between oil prices and the prices of cleaner energy sources. The studies have noted that movements in renewable energy stocks and their investment are either aided by the rise in oil prices or offset by falls in oil prices. At the same time, others have also concluded that volatilities in oil prices also result in the eventual increase in volatilities of renewable energy stocks.

2.8 Decision making approaches in renewable energy projects

The renewable energy value chain involves various decisions made at each value chain level, including strategic, tactical, or operational level decisions. Multiple choices are also made by each stakeholder in the renewable energy sector to create value along the chain. For example, renewable energy companies make strategic decisions in the form of production technologies to use, tactical-level decisions such as production scheduling and operational-level decisions which include daily or weekly management of inventory (Awudu & Zhang, 2012).

Policymakers, including governments, make decisions regarding which policies to enact within a particular time. Also, governments' decisions on taxes and subsidies are made continuously to meet renewable energy targets in their various jurisdictions. Investors are also interested in managing their portfolios, including renewable energy assets, in creating profits and driving higher returns on their investments. As far as each of these decisions are concerned, they risk facing uncertainties that may hamper the desired objectives. Decision-making is further offset by fluctuations in exchange rates, loan interest rates and inflation (Kim, Park & Kim, 2017). Thus, decisions must therefore be made to ensure that the objective of achieving value is met for each stakeholder. This section reviews methods of evaluating renewable energy investments to reduce risks of shortfalls and creating overall value.

2.8.1 Real options modelling

Although investment appraisal using discounted cash flow models such as static NPV present a straightforward, time value of money based and a relatively simple approach to the analysis of investment options, it provides a go- or no-go response to investment decisions. On the other hand, real options modelling considers the ability of investors to delay, expand or abandon their investment to acquire more knowledge concerning the risky nature of their investments (Zhang et al., 2016). Thus, while static NPV provides decision alternatives as to the choice of investing or not investing, real options modelling provides additional decision-making alternatives such as deferral and the reversibility of investments (Sporleder & Balley, 2001). Also, discounted cash flow analysis works better within a deterministic environment where all cash flows, costs and prices are known with certainty. The renewable energy environment, however, does not always possess deterministic characteristics. It is mainly characterised by a rise and fall in demand and volatility in prices and costs. As observed in Section 2.7 of this text, fluctuations in oil prices affect the returns on renewable energy investments. Hence renewable energy prices are not stable, judging from the instability in oil prices. Therefore, stochastic modelling of investment decisions characterised by scenarios and flexibility of decisions is reasonable in this regard.

Zhang et al. (2016) proposed a real options model in evaluating renewable energy investments in China. In their model, they included factors such as CO_2 price, non-renewable energy cost, the cost of investment into renewable energy and the price elasticity of renewable energy products. The study results reveal that notwithstanding the gains in renewable energy diffusion in China, the current investment climate in the country is not positive enough to attract more investments into their renewable energy sectors. Secondly, the study shows that carbon emissions trading, which provide economic benefits for reducing CO_2 and other greenhouse gas emissions, presents more incentive for carbon-emitting firms to plan for more sustainable energy use. In the presence of carbon emissions trading, the value of the investment in renewable energy markets increases substantially. Lastly, the study finds that the optimal timing in achieving an optimal investment value may be delayed because of electricity and CO_2 price volatilities. Therefore, there must be deliberate regulations on carbon dioxide and fossil fuel usage to drive investments in renewable energy technologies.

Real options analysis also helps to obtain an optimal investment timing for renewable energy projects. Boomsma, Meade & Fleten (2012) applied real options modelling in analysing and selecting an optimal investment timing for renewable energy projects based on differing support schemes. The study finds that feed-in tariffs encourage investment into renewable energy projects. Also, uncertainties impact the timing of renewable energy investments.

Real options valuation involves a series of steps of variable identification, valuation and sensitivity analysis. Kim et al. (2017) proposed a real options framework for evaluating renewable energy investments outlining four main steps. The first step is made of the development or the design of an investment scenario. This step involves the different phases of planning, design, construction, and operation. In the second phase, the cash flow for the investment is predicted, considering tariffs, energy production capacities, the price of renewable energy, and costs of operation and maintenance. The third phase involves a three-point estimation of the volatility of the project using optimistic, pessimistic, and most likely outcomes. Next, a compound option model is developed, and the value of the option is determined. Based on this value, the fourth step involves a sensitivity analysis of the variables after an investment decision. This approach is set to include possible scenarios and volatilities not included in the traditional NPV approach.

Compared to static discounted cash flow analysis, real options modelling is a relatively new but widely used approach for investment appraisal and decision making while considering uncertainties. For example, MacDougall (2015) applied real options modelling in valuing tidal wave conversion devices. Büyüközkan & Güleryüz (2016) also used real options modelling in investigating donor investors' decisions to finance wind and solar facilities. In addition, the authors analysed investment for solar power generation under market uncertainties.

Zhang, Zhou and Zhou (2014) also used a real options model to evaluate a renewable energy policy model for investors and governments. The model considered non-renewable energy costs, carbon prices, renewable energy costs and renewable energy prices as sources of uncertainties. A review by Liu, Zhang & Zhao (2019) show the application of real options in several renewable energy investment scenarios. These studies reveal that real options modelling has been applied with success to renewable energy investments. The model's flexibility also allows for the inclusion of several variables that are reflective of the context within which the assessment is being conducted.

2.8.2 Optimisation methods in renewable energy risk modelling

As already stated in the preceding sections, renewable energy sources have their advantages and disadvantages. Drawbacks to renewable energy generation include their complexity in design and their reliance on climate. Renewable energy systems are also seen to have a lesser energy capacity than the other conventional energy sources, particularly thermal generation (Baños et al., 2011). Thus, achieving universal coverage or meeting total energy requirements requires an optimal mix of renewable and non-renewable resources so that economic, social, and environmental targets are all met. One crucial fact to consider is the decisions made by governments, firms, and households regarding the best energy source or combination of sources under different operational circumstances (Baños et al., 2011; Gordon & Barry, 2009; Kanase-Patil, Saini, & Sharma, 2009). Energy resource indicators are very complex. It is in this sense that optimisation models are essential in solving these complex problems.

Optimisation is a branch of mathematics that deals with finding the values of inputs of functions that maximise the value of the function subject to certain constraints. In this way, the capacity for both renewable and non-renewable energy can be planned to maximise energy generation whilst making sure that some requirements (e.g., sustainability issues and socio-economic issues) are still met.

Linear programming models consists of meeting a set of objectives while working under some constraints or limitations. Stochastic linear programming models provide an added advantage of solutions due to uncertainties to the model. For example, Cai *et al.* (2009) applied a mixed-integer linear programming model to plan renewable systems management under uncertainty. The objective of the model was to minimise costs associated with primary energy supply, fixed and variable costs of energy generation, and capital costs for energy capacity expansion. The model was subject to constraints such as energy resource availability, electricity demand, capacity limits and technical constraints. Thus, the authors designed capacity expansion systems for renewable energy facilities in a multi-period and multi-option context. The model considers uncertainties associated with demand, capacity limits and resource availabilities and determines the optimal mix of conventional power and renewable energy systems at a minimised cost.

Nie *et al*. (2016) also presented an interval fuzzy functional programming model for adding renewable energy to existing power systems. They incorporated modelling issues of electricity utilisation, energy supply security and the mitigation of greenhouse gas emissions. The model provided various decision alternatives that can be made, bearing in mind the uncertainties that surround electricity demand and price.

Optimisation models has largely been used to determine the optimal means of deploying hybrid renewable energy technologies, thus a combination of several renewable energy technologies to meet constraints of costs and capacity requirements. For example, Kusakana, Vermaak and Numbi (2012) designed a linear programming model that determined the optimal size and cost for a hybrid renewable energy technology consisting of solar, wind and hydro for a remote area in South Africa.

The model considered load and costs in renewable energy generation as the main constraints. Vaccari *et al.* (2019) designed a sequential linear optimisation model for a hybrid renewable energy system which considered solar PV, wind generator and a thermal configuration. Afful-Dadzie *et al.* (2017) also presented a stochastic optimisation model for long term power generation in developing countries. The model considered mainly budget and energy demand constraints to determine an optimal energy mix and financing requirements that would provide cost savings for developing countries.

Optimisation techniques for decision making can be categorised into two main groups based on the number of objective functions – the single objective and the multiple objective problems. Single objective issues meet only one purpose (i.e., cost minimisation, profit maximisation, emissions reduction, etc.). Therefore, these models are relatively easier to model and evaluate. However, most business problems that require optimisation techniques have multiple objectives that need to be optimised simultaneously. For instance, the triple bottom line concept presents three focus areas for businesses or governments (social, economic, and environmental considerations). In addition, the concept broadens the firm's objective of profitability by including social and ecological concerns. Meeting these objectives are conflicting. Hence it is difficult to reach a single solution that provides an optimal value for all the three objectives concurrently (Devika, Jafarian & Nourbakhsh, 2014). Bearing this in mind, Kamjoo et al. (2016) developed an algorithm to solve such multiple objective problems within a hybrid renewable energy system design. The algorithm also considered the levels of uncertainties within the renewable energy resources, with decision variables being the required areas for wind turbine rotor and PV panel and the number of batteries to be used. The conflicting objectives that were considered included minimising total cost and maximising system reliability.

2.9 Behavioural factors for renewable energy risks

So far, the issues discussed under this review concern renewable energy risks obtained from uncertainties and volatilities in oil price and other demand uncertainties. In most situations, energy demand and cost uncertainties are modelled with random walks or Brownian motion (Gendreau, Michel & Potvin, 2010; Lin & Wesseh, 2013; Kitzing, 2014; Zhang et al., 2016). While these models are essential, they cannot capture the exact behaviour towards the adoption and the investment in renewable energy sources. Traditional finance theories, on the one hand, make several normative assumptions concerning human behaviour. On the other hand, human behaviour suggests that different people have varying degrees of risk and react differently to a given level of risk.

It is argued that the acceptance of renewable energy technologies drives the demand for such technologies. Therefore, if the level of acceptance and willingness to adopt renewable systems is low, the need for renewable energy shall be low and vice versa. Hujits, Molin & Steg (2012) presented a comprehensive framework for renewable energy acceptance. The authors argue that one's attitude towards the acceptance of renewable energy technologies is based on the individual's perception of risks, costs, benefits, and positive and negative feelings about the technology. They further add that other social factors such as values, worldviews, sociodemographic characteristics, and media attention can affect the acceptance of renewable energy technology.

Following Huijts et al. (2012), Hall, Ashworth & Devine-Wright (2013) studied the factors that can affect the acceptance of wind farms in Australia. Based on qualitative interviews with representatives of wind farm companies, local government, community members and hosts of wind turbines, the results show a strong affinity towards wind-generated energy systems, owing to the renewable and clean energy targets. However, the societal acceptance of wind power in the study area hinges on four key themes. First is trust, which fosters the relationship among all the stakeholders involved, especially between turbine hosts and wind development companies. The second issue was based on distributional justice, which ensures a just distribution of costs and sharing of benefits. The third issue was procedural justice, which ensured open, transparent, and participatory decision-making among all stakeholders of wind farm generation. The last item relates to place attachment which was explained as a sense of emotional attachment to lands that have been leased to wind farm companies.

The Social Representations Theory (SRT), developed by Moscovici (1961), focuses on the linkage between human behaviour and current societal and cultural trends. The theory predicts what facilitates a social change process, such as attitudes, beliefs and practices. Renewable energy technologies represent a social change process as it involves to a large extent technological innovation. Batel & Devine-Wright (2014) proposed that the social representations theory can analyse patterns of human beliefs and attitudes towards the acceptance of renewable energy technologies.

The theory of planned behaviour extends the theory of reasoned action by Ajzen (1991). The theory was propounded to predict a behavioural intent. It links the behavioural intentions of individuals to their efforts. The theory explains that the behavioural intent of an individual depends on the individual's attitude, subjective norms, and perceived control over the performance of the behaviour. Attitudes reflect the individual's beliefs concerning the behaviour. It measures the individual's evaluation of how favourable or unfavourable the behaviour of interest may be. Using the theory of planned behaviour, Yun & Lee (2015) examined the impacts of technical and social factors on the attitude towards renewable energy systems and their perceived behavioural control of renewable energy systems. The results show that technical factors such as system quality and facilitating technical conditions and social factors such as trust, and social support are antecedents of the attitude towards adopting renewable energy systems and their perceived behavioural control of renewable energy systems. These attitudes and behavioural control impact the individual's intention to utilise renewable energy systems.

The review of behavioural theories towards renewable adoption stresses that in addition to price volatilities and system uncertainties, human behaviour towards renewable energy adoption can pose a high risk towards its investment. Therefore, risk managers for renewable energy projects must also be concerned with the societal demand and the societal climate as essential points to consider in the distribution of renewable energy technologies. Furthermore, emerging issues such as trust, and the direction of media reportage can determine the societal adoption of renewable technologies. Thus, behavioural theories tend to augment the deterministic and stochastic models for managing renewable energy risks.

2.10 Conceptual framework for the study

The study objectives require a framework that integrates all the input requirements, the model assumptions, and the expected outputs. Therefore, the study provides a simplified concept that seeks to achieve the stated objectives, as shown in Figure 2.2. The framework is categorised into three broad groups – inputs and decisions, model, and outputs.

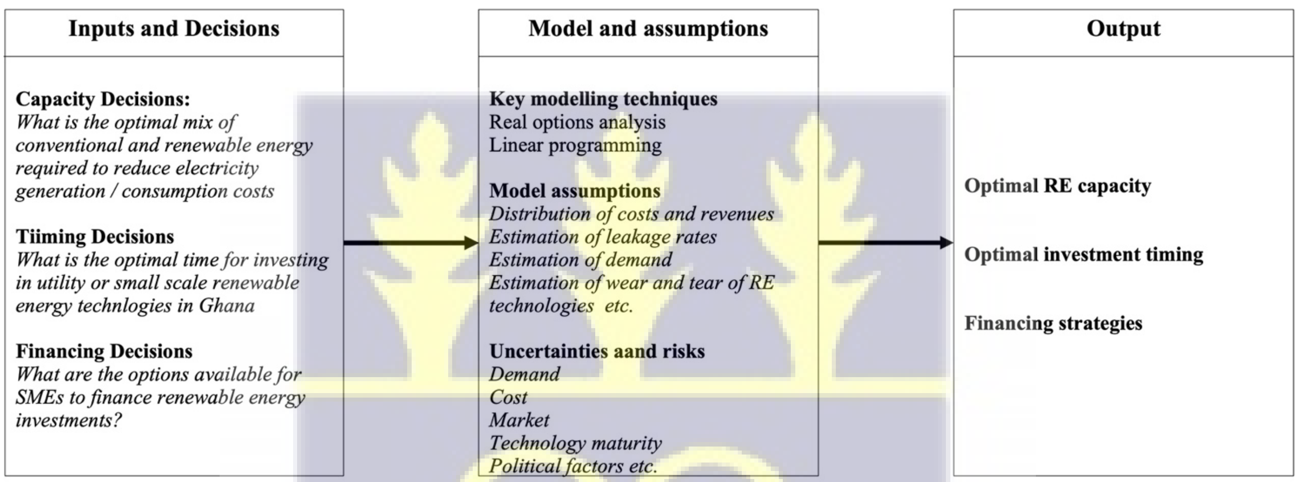
The first group describes the inputs or resources required to make the decisions by defining the broad decisions that the investor must make. For this study, three critical decisions must be considered: the capacity decisions, the timing decisions and the financing decisions. The capacity decisions outline the mix of renewable and conventional energy required to reduce the cost of power generation or maximise the gains in renewable energy integration and must justify the necessary investments. Other capacity decisions include the form of operation of the renewable energy, i.e., whether it must be used as a primary or backup power source. This decision is crucial for SMEs whose objective would be to reduce power generation costs and make substantial savings from conventional tariffs.

The timing decisions refer to the optimal time that maximises value for the investor. Decisions must be made on whether immediate or delayed investments justify the costs and opportunities inherent in the renewable energy investment space. The financing decisions include the form of raising the required finance for investment. These are important, especially when there is no ready cash to undertake investments. Therefore, the investor must decide whether to consider sources such as equity or debt financing as the most appropriate source of funding, as well as the assessment of the optimal capital structure if there is going to be a blend of equity and debt financing.

The second group describes the various models that must be considered to meet the objectives or to achieve the decisions. This study finds real options and linear programming models appropriate for meeting the study objectives. Given these models, it is essential to consider the various underlying assumptions. These include the distribution of costs and potential revenues or savings, the estimation of drifts and volatility rates and the sources of uncertainties. The model must also consider the constraints within the investor's context. Real options and linear programming models have various variants, and assessing the most appropriate variant must be used to make the relevant decisions is essential. For example, justification must be made on the suitable model towards solving problems involving American Options where closed-form solutions are not readily available. Again, decisions must be made on whether the programming technique must be static or dynamic, deterministic or stochastic, or if it contains integer-based variables.

The outputs present the result of the model based on the input parameters and the estimation techniques. It provides the optimal decisions that would justify the investment, such as the ideal capacities and the optimal timing, which the investor must consider. Within the outputs, sensitivity analysis would also be made to examine the flow of decisions, given that key input parameters change to reflect contextual realities. These sensitivity analyses would impact the capacity, timing and financing decisions.

Figure 2. 3: Simplified conceptual framework for the study



CHAPTER THREE

STUDY ONE: A REAL OPTIONS APPROACH TO INVESTMENT TIMING DECISIONS IN UTILITY-SCALE RENEWABLE ENERGY IN GHANA[1]

Abstract

Private capital is required to urgently complement government efforts to meet initial capital outlay in renewable energy investments. However, minimising the downside risks for a given return in such a venture presents valuation challenges, including the timing of such investments. Investment timing is therefore relevant to consider when making investments in utility-scale renewable energy technologies which require high initial capital.

This study assesses the value of investment delay in renewable energy projects using the real options analysis. A model that combines binomial trees and Monte Carlo simulations is used to evaluate the optimal investment timing of the first cycle of Ghana's Renewable Energy Master Plan. The model incorporates multiple dimensions of uncertainties related to market, economic and technological factors to determine the value of delaying utility-scale renewable energy investments.

The results show that there is value in delaying investments until uncertainties are reduced and maximum benefit is obtained. Also, high system capacities and favourable renewable energy policies that border on attractive feed-in tariffs are required to drive private investment in utility-scale renewable energy.

Keywords: Renewable Energy, Real Options Analysis, Investment Timing

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3.1 Introduction

Ghana showed renewed interest in renewable energy as it passed a legal framework (Renewable Energy Act (Act 832)) that seeks to boost renewable energy penetration in the country. In addition to the Act, the government has drafted other policies that ensure a smooth deployment of renewable energy technologies. An example of such a policy document is the Nationally Determined Contributions (NDCs) which is in response to the Paris Agreement. The NDCs specify mitigation and adaptation measures towards reducing GHG emissions and ensuring the country's resilience to climate change. Renewable energy integration plays a substantial role in the country's NDCs.

Ghana missed its target of increasing the share of renewable capacity the national energy to 10% by 2020. However, it has revised the target and plans to achieve it by the end of 2030. In furtherance of meeting the target, the ministry responsible for energy has drafted a renewable energy master plan that serves as a guide to achieving the set targets for renewable energy penetration. The plan estimates an investment of about $5.6 billion, out of which at least 80% must be sourced from private investors. The investment requirement also suggest that the plan seeks to have massive investments from private investors towards utility scale renewable energy technologies. Thus, the business and regulatory environment must promote growth in the sector to gain investor confidence.

The primary objective of investors, in general, is to maximise the payoff of their investment (Komendantova, Patt & Williges, 2011). Beyond maximising these payoffs, investors seek to minimise their exposure to downside risks that can occur with such investments. In renewable energy investments, these risks cannot be downplayed. As explained in the previous chapter, the risks associated with the renewable energy market are generally in the form of conflicting government policies (Gross *et al.,* 2010, Naicker & Thopil, 2019), market factors (Mutingi, Mbohwa & Kommula, 2017), economic factors (Rout, Sahoo & Thomas, 2018), technological factors (Kim, Park & Kim, 2017) and climatic factors (Mosquera-López, Uribe & Manotas-Duque, 2018).

In the face of uncertainties, it is essential for investors to consider decisions that reduce their exposure to downside risks. One of such investment decisions is the timing of investments which could impact on the investment value. Thus, it may be of more excellent value to delay investments in renewable energy systems. Investment delays may help gather more information, significantly curtail uncertainties or provide strategic flexibilities for the investor (Barrero & Bloom, 2020). Further, it reduces potential losses that may arise with immediate investments that are carried out without adequate knowledge of the market's level of uncertainties. While the option to delay investments may provide additional value to the investor, it is essential to note that delays in investment pose risks such as competitor's entry into the market and forgone cash inflows. Therefore, obtaining the optimal time for investment is important in an environment riddled with uncertainties (Macdougal, 2015).

The choice of an optimal time for investment depends on a thorough valuation or appraisal of the investment. Thus, renewable energy investors must also value their investments by thoroughly considering factors such as the price of electricity, the favourability of policies, the availability of materials to produce renewable energy technologies, and the availability of resources for research and development. A thorough valuation is essential for optimal decisions that reflect the contextual realities of the investor.

Traditional means of valuation, primarily Discounted Cash Flow (DCF) models such as the net present value (NPV), is widely used to value capital investments. Advanced DCF methods account for strategic flexibility using scenarios and other decision tree alternatives. However, these methods do not accurately account for the valuation of flexibility inherent in the investment. Real options provide the holder with the right to decide to invest in a real asset. It provides an approach to include flexibilities in the valuation and planning of investments in real assets such as renewable energy technologies (Kozlova, 2017). Real options approach to investment valuation has been noted to accurately estimate the intrinsic value of an investment. There has been an appreciable amount of research that has applied various variations of real options techniques towards energy investments. However, studies that have used real options analysis in valuing investment timing are generally scant, especially within the context of a developing country. Section 3.2.1 of this text provides a review of some works on real options in the renewable energy space which demonstrate that investment timing has not been considered to a large extent. Further, the section also discusses gaps that relate to incorporating some measures of uncertainties in the real options evaluation process.

The focus of this chapter is two-fold. First, the chapter seeks to determine the value of delaying renewable energy investments in an uncertain environment. Second, the chapter aims to provide an optimal time that creates maximum value for large-scale renewable energy investment projects, using the Ghana's Renewable Energy Master Plan as a case. This chapter contributes to the literature on the option to delay. It also presents an approach for determining the cost of delaying investments with unequal cashflows. The chapter is made up of five sections. The second section introduces the theory that underpins the chapter and provides further clarity on the concept of real options valuation, while the third section presents the real options model that assesses the option to delay. The fourth section presents the results, while the last section presents the conclusions made in the chapter.

3.2 Theory of investment decisions and real options valuation

Investors prefer options that provide the maximum value. Value creation can vary in different forms, ranging from increased cash flows, cost savings, environmental sustainability, and goodwill. The income approach to investment valuation examines the discounted cash flow stream of investments at a discount rate that is adjusted for risk (Mun, 2006). The uncertain future could provide a positive or a negative outlook to the investor. Capital intensive projects are mostly complex with varying interdependencies, and as such, the estimation of cash flows is less predictable (Mun, 2006). In capital budgeting, the determination of a worthwhile investment is dependent largely on projected future cashflows of the investment, and an appropriate estimation of the weighted average cost of capital (Guerard & Schwartz, 2007). These are mainly in the form of traditional Discounted Cash Flow (DCF) models such as the net present value (NPV) and the internal rate of return (IRR). An investment is desirable when the present value of the projected cash flows, discounted at an appropriate cost of capital is greater than the cost of the project. Also, the investment is worthwhile if its internal rate of return is greater than its cost of capital.

Advanced discounted cash flow methods can account for uncertainties and variations in future cash flows. When future cashflows are not known with certainty, expected future cash flows are determined under various scenarios, with their respective probabilities of occurrence. These scenarios and probabilities enable the determination of an estimated present value of cash flows that account.

In an investment environment riddled with uncertainties, the uncertain future could either provide a positive or a negative outlook to the investor. Capital intensive projects are mostly complex with varying interdependencies, and as such, the estimation of cash flows is less predictable (Mun, 2006). In addition to tangible cash flows, investments have intrinsic values, resulting in advantageous strategic positions. The value of such positions must be accounted for in investment appraisals. Therefore, investment decisions must be made with the utmost level of strategic flexibility in such an uncertain environment.

Although advanced DCF models account for strategic flexibility to some extent, they fail to accurately account for strategic flexibility in the valuation process. DCF approaches apply the same discount rate in the valuation of projects without accounting for reductions in systematic risks arising from flexible projects (Feinstein & Lander, 2002; Pless *et al.,* 2016). Further, DCF models are not suitable for the valuation of long-term investments where the determination of future cash flows occurs with higher uncertainties. DCF analysis generally does not account for the qualitative benefits that characterise strategic investments, thereby undervaluing the investment's potential (Mun, 2006; Pless *et al.,* 2016; Pivorienė, 2017).

Generally, options in the purchase or sale of a financial asset, or a commodity provide the right but not the obligation to buy or sell the asset. In a capital investment project, the option provides the holder the right but not the obligation to invest in a real valued asset. Real options analysis provides an approach to include flexibilities in the valuation and planning of renewable energy investments (Kozlova, 2017). Real options models and DCF models are not mutually exclusive as the latter has the DCF as its basis.

The value of an investment can be broken down into two parts; the tangible value that is created from the assets in place, and the intangible value that arises from the flexibilities inherent to take advantage of future opportunities. Real options analysis introduces further options that present additional flexibility to the investor in addition to its ability to estimate the true intrinsic value of an investment. Thus, does not completely play down the importance of DCF methods but builds on it.

There are several options that are inherent in investment decisions which include expansion, abandonment, and deferment options. First, the option to expand or grow a business provide an opportunity for the investor to take advantage of earlier investments for future expansion through research and development (Chance & Peterson, 2002). The option to abandon provides the investor the option to sell assets to recover the projects' salvage value. This option can be likened to an insurance guarantee which is drawn upon when projects do not generate the required value after investment.

The option to defer the execution of a project in real options analysis, which is the focus of this chapter, provides the investor with the option to delay investments until the project is more profitable. An investment with a negative expected NPV, considered unprofitable, may hold value when future business and economic conditions are favourable. Thus, the delay option allows the investor to better understand the uncertainties inherent in the generation of future cash flows through the acquisition of new information.

3.2.1 Options valuation in renewable energy investments

Over the past decade, extant studies have been conducted using real options analysis as an analytical tool in meeting various research objectives in renewable energy investments. Kumbaroglu, Madlener & Demirel (2008) analysed the impact of uncertainty and technical change of renewable energy technologies. The study outlined the impact of uncertainty and changes in technologies on renewable energy diffusion in Turkey using a real options approach to dynamic programming. Their primary sources of uncertainty included electricity prices and demand uncertainty. Lee & Shih (2010) presented a model that integrates cost efficiency on renewable energy power generation by evaluating the value provided by renewable energy technologies in the face of uncertainties in fossil fuel prices. Using a binomial lattice structure, the authors presented an optimal policy framework for RE development.

Heinrich et al. (2012) analysed investment decisions of electricity producers to invest in renewable and non-renewable energy markets under price uncertainty in Germany. Using real options analysis, the study found that uncertainties in environmental conditions affect the load profiles of renewable energy technologies, which increases the inertia of investors to invest in RE technologies. Kim *et al.* (2017) developed a real options framework to assess investments in a hydropower project in Indonesia. Project volatility was identified using a three-case scenario model that reflected uncertainties in tariffs, energy production costs, carbon emissions trading costs and operation and maintenance costs.

In the Philippines, Agaton & Karl (2018) evaluated the attractiveness of renewable energy investment. In addition, the study considered the environmental consequences of using fossil fuel sources as substitutes for renewable energy investment generation. The study results show that investment value exists in renewable energy, especially under uncertainties in oil prices. Li *et al.* (2019) also utilised real options and a stochastic dynamic programming model to identify an optimal feed-in tariff for wind power investments in China by considering uncertainties in the intermittency of renewable energy technologies.

Other studies have also involved the use of real options to identify the value of delaying investments. For instance, Martínez-Ceseña & Mutale (2011) proposed a methodology for renewable energy generation projects using a combination of mathematical programming and real options analysis. The objective was to determine the investment timing and design that can maximise the profits of such renewable energy projects by considering uncertainties in electricity prices and environmental policies.

MacDougall (2015) analysed the value of delaying investments in a 10MW array of in-stream tidal energy conversion devices by considering uncertainties in electricity prices. The research highlighted three main factors that impact the option value of renewable energy investments: the inherent volatility, the opportunity cost of waiting, and the time to expiry of the option. The authors further concluded that government policies related to renewable energy development are essential for reducing uncertainties related to its development. Finally, Nunes, de Lima, Davison, and Leite (2021) assessed the value of switching and delaying renewable energy investments in Brazil. The research considered uncertainties in solar and wind power irradiation and electricity prices.

Most of these studies proxied their uncertainties by considering uncertainties in electricity prices and fossil fuel prices. However, these measures of uncertainties do not cover the various dimensions of uncertainties as described in sections 2.2 to 2.6. Thus, beyond uncertainties in tariffs, and fossil fuel prices there are other sources that affect the general appraisal of renewable energy investments. Therefore, this study examines investment timing while considering other sources of uncertainty. These sources include demand, exchange rate volatilities, adjustments in renewable energy purchase obligations, and capacity factors of renewable energy. In this case, the study examines investment decisions under market, technical, regulatory, and economic uncertainties.

3.3 Real options modelling: Assessing the option to delay

The option to wait or delay investments for a specific time is essential because of the volatility of cash flows. There is the possibility that investments with negative net present values can yield positive net present values when the investment is delayed. Consider a project that has a lifetime T and is initiated at time t. The value of the project (V_t) is determined by calculating the difference between the present value of the cash inflows (Π_t) and the present value of the investment cost at time t (I_t), as explained in Equation 1:

$$V_t = \Pi_t - I_t \quad (1)$$

The decision to invest or not to invest depends on the sign of V_t, implying that the firm obtains a negative payoff for $\Pi_t < I_t$ and a positive cash flow for $\Pi_t > I_t$. For any period the investor does not invest in the project, there is no cost of investment incurred. This creates an implicit call option with the project as the underlying asset, a strike price of I_t and the value of asset Π_t. The value of such an option with investment costs and revenues is provided in Equation 2:

$$V_t = Max(\Pi_t - I_t, 0) \quad (2)$$

The value of a plain vanilla European call option which is exercised only at maturity, can be determined using the Black and Scholes (BS) formula. The BS formula provides a closed-form solution for the value of the option. However, real options are similar to American options since they can be exercised any time it is in the money. This study, therefore, relies on the use of numerical methods in the determination of option value.

Several numerical methods exist for the valuation of American options, including the finite difference approaches (both explicit and implicit), binomial lattice approach, the trinomial lattice approach and the quadratic approximation methods. In evaluating these numerical methods, Zhao (2018) concluded that the binomial is the best approach for option evaluation in efficiency and accuracy. Therefore, this study applies the binomial lattice approach to the valuation of the implicit call option.

The option value using the binomial option pricing model is determined by evaluating the upward (u) and downward (d) movements of the value of the project at any point in time, the risk-neutral probability (q) of an upward movement in the value of the project, volatility (σ) and the period of expiry of the option (t). Equation (3a) presents the expression for determining the value of an option which is determined by calculating the expected payoff of the option, discounted at the risk-free rate r_0.

$$V = e^{-r_0 t}(qV_u + (1-q)V_d) \tag{3a}$$

The upward and downward movements represent the change in the value of the project after Δt period. The expression for the movements depends on the volatility (determined by σ). If σ is zero, the upward and downward movements are equal, and the binomial lattice becomes a straight line. The risk-neutral probability (q) also depends on the risk-free rate and the value of upward and downward movements. Equations (3b) and (3c) and (3d) give expressions on the upward and downward movements and the risk-neutral probability, respectively.

$$u = e^{\sigma\sqrt{\Delta t}} \tag{3b}$$

$$d = e^{-\sigma\sqrt{\Delta t}} \tag{3c}$$

$$q = \frac{e^{rt} - d}{u - d} \tag{3d}$$

Source: Mun (2006)

3.4 Case Study – the Ghana Renewable Energy Master Plan

The Renewable Energy Master Plan (REMP) is a 12-year master plan with the objective of *"providing investment focused framework for the promotion and development of the country's rich renewable energy resources for sustainable growth, contribute to improved social life and reduce adverse climate change effects*" (Energy Commission, 2019b). The government of Ghana has thus identified renewable energy as a double-edged strategy to reduce harmful CO_2 emissions while meeting global environmental targets and increasing the overall energy supply mix in Ghana. The overall target of the plan is to increase the portion of renewable energy to 1363MW by 2030. The 12-year plan is estimated to cost about $5.6 billion, with at least 80% of the investment cost to be borne by private investors. This highlights the need for an enabling environment for profit generation to boost investor confidence. Table 3.1 provides details of renewable energy development projects under the master plan.

This study focuses on analysing the first of three cycles of the project, which aims to expand utility-scale renewable energy generation by 130MW by the end of 2020. The geographical location of Ghana provides good exposure to solar radiations, which is ideal for solar power generation. The country receives average solar irradiation of about 4 to 6kwh/m^2/day with an annual sunshine duration between 1800 – 3000 hours.

Table 3. 1: REMP implementation plan

Renewable Energy Technologies	Reference 2015		Cycle I (2019-2020)		Cycle II (2021-2025)		Cycle III (2026-2030)		Cumulative in 2030	
	No. of units	MWp	No. of units	MWp	No. of units	MWp	No. of units	MWp	No. of units	MWp
Solar Energy										
Solar Utility Scale	-	22.5	-	130	-	195	-	100	-	447.5
Distributed Solar PV		2		18		80		100		200
Standalone Solar PV	-	2	-	8	-	5	-	5	-	20
Solar Street/Community lighting	-	3	-	4	-	4	-	14	-	25
Solar Traffic signals (% of total traffic signals installed in the country	14	3	11	-	15	-	20	-	60	-
Solar Lanterns	72000	-	128000	-	300000	-	500000	-	100000 0	-
Solar Irrigation	150	2.8	6000	6	20000	20	20000	20	46150	48.8
Solar Crop Dryers	70	-	80	-	250	-	300	-	700	-
Solar Water Heaters	4700	-	15300	-	50000	-	65000	-	135000	-
Wind Energy										
Wind Utility Scale	-	-	-	-	-	275	-	50	-	325
Standalone Wind Systems	-	0.01	-	0.1	-	0.9	-	1	-	2
Wind Irrigation/ Water Pumping	10	-	25	-	30	-	35	-	100	-
Biomass/ Waste-to-Energy										
Biomass Utility-Scale	-	-	-	-	-	72	-	-	-	72
Waste-to-Energy Utility Scale	-	0.1	-	-	-	30	-	20	-	50.1
Biogas (Agricultural/ Industrial Organic Waste)	10	-	20	-	70	-	100	-	200	-
Biogas (Institutional)	100	-	80	-	140	-	180	-	500	-
Biogas (Domestic)	50	-	30	-	50	-	70	-	200	-
Woodlot Cultivation (ha)	190000	-	60000	-	100000	-	78000	-	428000	-

Renewable Energy Technologies	**Reference 2015**		**Cycle I (2019-2020)**		**Cycle II (2021-2025)**		**Cycle III (2026-2030)**		**Cumulative in 2030**	
	No. of units	**MWp**	**No. of units**	**MWp**	**No. of units**	**MWp**	**No. of units**	**MWp**	**No. of units**	**MWp**
Charcoal (Local Demand)	1551282	-	94017	-	93947	-	100877	-	1840123	-
Charcoal (Export)	190450	-	59550	-	100000	-	78000	-	428000	-
Briquetting/ Pelleting	19700	-	20300	-	25000	-	35000	-	100000	-
Biofuel (tonnes)	-	-	100	-	4900	-	15000	-	20000	-
Hydro/ Wave Power										
Small/ Medium Hydro Plants	-	-	-	0.03	-	80	-	70	-	150.03
Wave Power	-	-	-	5	-	-	-	45	-	50
Hybrid Mini-Grids										
Mini/ Micro-grids	13	-	73	-	114	-	100	-	300	12
End User Technologies										
Improved Biomass Cookstove (Domestic)	800000	-	50000	-	500000	-	1200000	-	3000000	-
Improved Biomass Cookstove (Institutional/ Commercial)	1800	-	1200	-	7000	-	8000	-	18000	-
Total Installed RE Electricity Capacity										1,353.63

Source: Energy Commission (2019)

In 2019, Ghana's peak energy demand on the transmission grid was about 2,800MW, with an installed capacity of about 4,900MW. The major source of the country's installed capacity is thermal energy generation. An additional utility-scale solar energy capacity may thus pose a threat to increasing the excess unutilised generating capacity. However, this can be advantageous for the country, as renewable energy sources can reduce the costs of fuel and replace liquid fuel-powered thermal plants. Ghana also has the potential to export power to other neighbouring countries. Albeit this requires other factors such as the competitiveness of power and the extent of demand for power from the different countries.

Essentially, the appropriate investments and timing of investment can yield the best possible returns for the country. This study examines the value of delaying investments in the first cycle of Ghana's REMP and provides an optional timing that maximises profits in a utility-scale renewable energy project. The following subsections provide details of the variables used in the option valuation model and the case study.

3.4.1 Inputs for valuation

The value of the underlying asset

The valuation of options is based on the price of an underlying asset. For most financial options, the underlying asset is the value of a stock at any point in time t. In this study, the underlying asset is the utility-scale renewable energy project with a capacity of 130MW. Generally, solar PVs have a useful life between 25 to 40 years (Tierney & Bird, 2020). Therefore, the value of the underlying asset is the present value of the future cash flows with an assumed lifespan of 25 years. the lower bound of the lifespan was used to avoid overestimation of option values which could occur with larger cash flows. Equation 4 expresses the present value of the total cash inflows from the project after T years. The yearly cash flows (PV_t) is discounted at a continuously compounded rate of r.

$$\Pi = \sum_{t=1}^{T} PV_t e^{-rt} \quad (4)$$

At every point in time, the cash inflow comprises cash inflows from power generation determined by the feed-in tariffs and the quantity of energy generated, as outlined in equations (5) and (6). The quantity of energy generated in a year is a function of the total installed capacity (130MW) of the solar PV and the capacity factor of the solar PV technology (τ) and the number of hours in the year.

$$PV_t = QE_t . FIT_t \quad (5)$$

$$QE_t = 130MW \times \tau \times 8760\ hours \quad (6)$$

Exercise value

The exercise value is the cost of making the initial investment. The exercise value, also known as the strike price, is the present value of the total costs. The total cost is expressed as the sum of the investment cost (I_t) and the present value of the yearly operation and maintenance costs (O_t), also discounted at a continuously compounded rate r.

$$TC = I_t + \sum_{t=1}^{T} O_t e^{-rt} \quad (7)$$

Cost of delay

Notwithstanding the potential value in delaying investments, some costs can be incurred for every period an investment is delayed, which is described as the leakage rate (MacDougal, 2015). First, there is a cost to hold the option, which is determined by the value of the premium. Second, every time an investment is delayed, there is a corresponding loss in potential cash inflow if the option was exercised on time. In addition, the entry of competitors can reduce the value of delay, especially in a competitive environment, where a company has no special advantage over its competitors. The leakage rate is expressed as a discount rate. MacDougal (2015) determined the leakage rate for unequal cash flows as $\frac{1}{t}$ percent per year, where t is the lifespan of the project. However, this approach does not consider the potential cash flows generated by the project for each period the investment is delayed. Therefore, this study presents another method for determining the leakage rate for unequal project cash flows.

A delay of the project for N years indicates forgone cashflows for the period of delay. For each period the investment is delayed, the investor forgoes an amount C_n. Thus, for n years, the present value of forgone cash inflows (K) is expressed as the present value of the yearly forgone cashflows expressed in Equation 8. To obtain an annualised cash flow forgone for the investor, the equivalent annual annuity (A) is calculated from the present value of the forgone cashflows as expressed in Equation 9.

$$\mathrm{K} = \sum_{n=1}^{N} C_n e^{-rn} \qquad 8$$

$$A = \frac{rK}{1-(1+r)^{-N}} \qquad 9$$

The leakage is represented as the ratio of the equivalent annual annuity to the present value of cash flows, given that investment was not delayed over the project's lifetime as given in equation (10).

$$\partial = \frac{A}{\Pi} \qquad 10$$

Scenario analysis of project costs and revenues

The first cycle of the renewable energy master plan seeks to increase the total installed capacity of renewable energy by 130MW by installing utility-scale solar systems. Determining the present values of costs is based on two key factors: investment cost and operation & maintenance costs. Operation and maintenance costs involve costs for preventive maintenance, repairs of solar panels, plant control and other expenses for the commercial management of the solar plant (Steffen et al., 2020). These cost components are affected either directly or indirectly by fluctuations in exchange rates and inflation rates. Therefore, the scenario analysis for the cost components is mainly based on changes in the exchange rate values between the Ghanaian Cedi (GHS) and the US dollar.

According to the Renewable Energy Master Plan, the 130MW project requires a capital cost of $169 million, equivalent to about GHS 912.6 million in 2019. However, the International Renewable Energy Agency (IRENA, 2019) statistics indicate that average capital costs for utility-scale solar PVs in the African market are likely to be about $1.2 to $2 (GHS 6.48 7 – GHS 10.6) per Watt of installed capacity. These costs culminate in total capital costs between GHS 842.4 million ($156 million) to GHS 1.406 billion ($260.37 million), with an average of GHS 1.123 billion ($227.7 million). This study uses these different investment costs as scenarios.

Operation and Maintenance (O&M) costs are estimated to be about $30 (GHS 162) per kW (IRENA, 2019). O&M costs have witnessed declines globally due to increased economies of scale, technology maturity, rising learning curves, and lower capital costs (Steffen *et al.*, 2020). However, given that parts of the O&M costs include administrative costs and the need to import peripherals, they are affected by changes in inflation and exchange rates. Therefore, this study offsets the decline in global O&M costs for solar PVs with the changes in inflation and exchange rates.

From October 2018 to November 2019, Ghana's central bank recorded a continuous depreciation of its currency against the dollar with a maximum depreciation of about 10% and a minimum depreciation of about 5.18% (Bank of Ghana, 2019). Ghana's current inflation rate is approximately 9%. Within the past decade, the Ghana Statistical Service (GSS) reports inflation rates to range between a minimum of 7% and a maximum of 17.4%. A three-case scenario for each of these rates, which identifies the base case, best-case and worst-case scenarios for the inflation and exchange rates, were generated. Table 3.2 presents the summary of the scenarios for the estimation of the costs.

Table 3. 2: Cost scenarios for Ghana's RE project

Cost component	Cases			
	African Minimum	**African Maximum**	**African Average**	**Ghana Average**
Installation costs (GHS million)	842.4	1,406	1,123	912.6
	Best Case	**Base case**	**Worst case**	
Inflation rates (%)	5	9.2	17.4	
Exchange depreciation rate (%)	0	5	10	

Source: Author's Construct (2021)

Feed-in tariffs (FITs) form the main component of revenues generated from renewable energy. According to the Renewable Energy Act 2011 (Act 832), FITs are guaranteed for ten years and subsequently subject to review every two years. The last review of FITs by the industry regulator saw FITs for solar PVs increase to GHS 0.5978 (11 US cents) per kWh of energy produced (PURC, 2016). The upward or downward adjustment of the FIT depends on the price differential between the electricity from renewable sources and that generated from other non-renewable sources. Scenarios for FITs in this study are based on the ten-year review of the tariffs. Beyond the value of the FIT, this study highlights two important factors that can impact total revenue: the solar plant's capacity factor and the purchase obligations of the solar plant. In the best case, the capacity factor of 30% is given, and in the worst case, a capacity factor of 16.5% was used to determine project revenue. The summary of cases is presented in Table 3.2.

The Renewable Energy Act 2011 (Act 832) for Ghana ensures that power distribution companies and bulk suppliers purchase a specified percentage of the total purchase of electricity from renewable energy sources. A governance environment that provides favourable conditions for renewable energy to thrive can increase purchase obligations such that the maximum capacity of power generated from renewable sources will be utilised. However, as highlighted in the previous chapter, other political factors can reduce the level of purchase obligations, which can minimise the amount of power produced. Therefore, this chapter expresses the purchase obligation as a percentage of the total quantity of energy produced. In Table 3.3, a three-case scenario is also presented, which describe possible purchase obligations by the government of Ghana. The best-case scenario presents the situation where the government of Ghana allows a 100% purchase obligation. The second scenario (base case) allows a purchase obligation of 80%, while the worst-case scenario allows for a purchase obligation of 60%.

Table 3. 3: Revenue scenarios for Ghana's RE project

Revenue component	**Cases**			
	Best case	**Base case 1**	**Base case 2**	**Worst case**
FIT adjustments (%)	20	10		0
Purchase obligation (%)	100	80		60
Capacity factor (%)	30	25	20	15

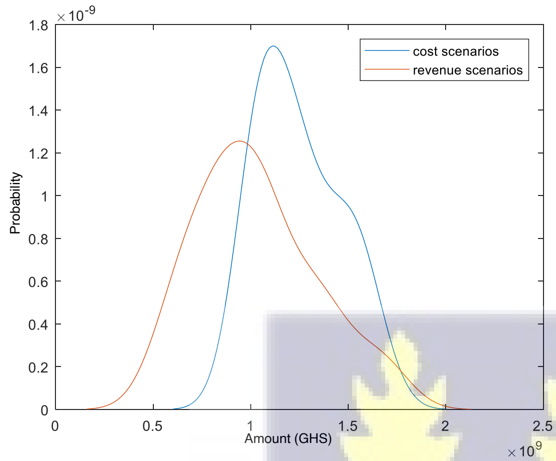
Source: Author's Construct (2021)

Determination of project volatility

An assessment of the scenarios under projected costs and revenues yielded 36 scenarios each for projected costs and revenues, based on the possible combinations of each scenario for the various costs and revenue components. Under these scenarios, the net present values of the project were calculated for costs and revenues, with an assumed lifespan of 25 years (IRENA, 2018). The distribution of these values under costs and revenues were fairly normally distributed, as shown in Figure 3.1. In determining the volatilities in project costs and revenues, a Monte Carlo simulation of 1000 samples of revenues and costs according to the normal distribution was done for both costs and revenues. The overall project volatility was expressed in terms of the volatilities in revenues (σ_R^2) and volatilities in costs (σ_C^2). Given that the revenues and costs are dependent on the quantities of energy generated, it is assumed that these two variables are dependent, with a non-zero correlation coefficient. Therefore, the variance of the profits is expressed in terms of the variance in costs (σ_C^2), revenues (σ_R^2) and the covarance between the costs and revenues (Cov_{RC}). (See Equation 11)

$$\sigma = \sqrt{\sigma_R^2 + \sigma_C^2 - 2Cov_{RC}} \qquad 11$$

Figure 3. 1: Probability distribution of costs and revenues



Source: Author's Construct (2021)

3.4.2 Results

Option valuation of the base model

Analysis of static present values for project costs and revenues show that the total present value for the cost is about GHS 1.246 billion ($230.7 million), and that of revenues is about GHS 1.03 billion ($190.7 million), resulting in a negative net present value for the project. This shows that the main driver of revenues, which is the feed-in tariff, may not be substantial enough to cause investors to break even. However, given the negative net present value and the project volatilities, there is an opportunity to analyse the value of waiting or delaying investments. Table 3.4 presents the input parameters for the real options valuation. The average annual cost of delay, expressed as a percentage, was estimated to be 12.7%. The risk-free discount rate was expressed as 12%, and the overall project volatility was estimated to be about 47%. The subsequent analyses present the analysis of the delay option using the static NPV calculated as a baseline.

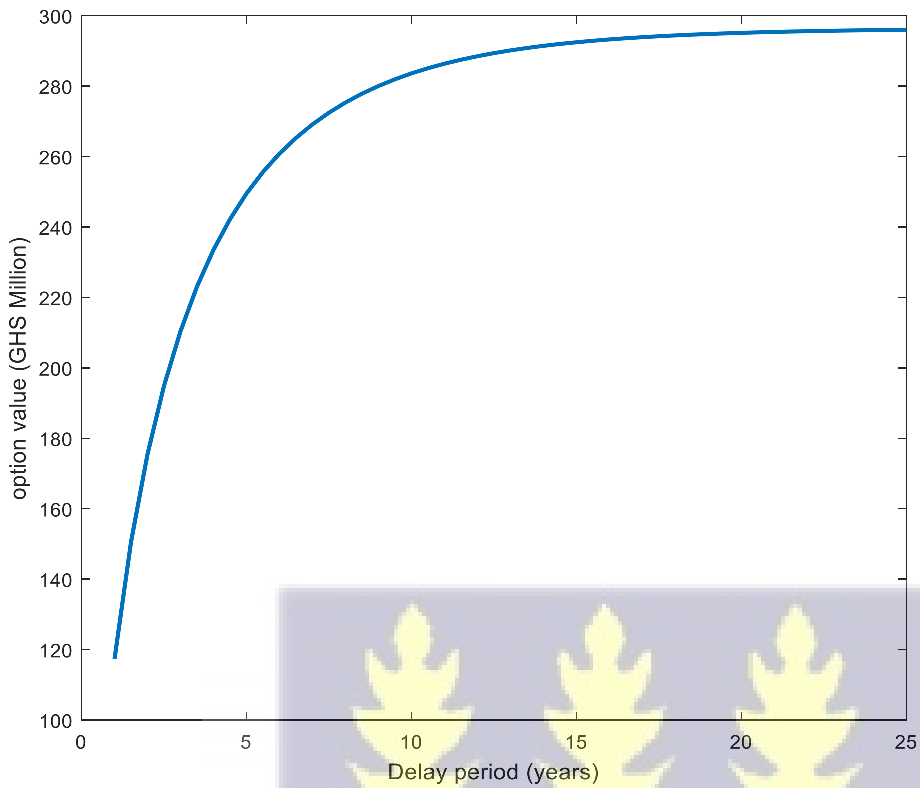
Table 3. 4: Input parameters for real option valuation

Variable	Base Case
Costs and revenues	
PV of Costs	GHS 1,246 million ($230.7 million)
Standard deviation of cost	GHS 207 million ($38.33 million)
Average PV of revenues	GHS 1,029 million ($190.7 million),
Standard deviation of revenues	GHS 302 million ($55.93 million)
Rates	
Average annual cost of delay	12.7%
Risk-free interest rate	12%
Volatility estimates	47.3%

Source: Author's Construct (2021)

Using the binomial lattice option valuation model with 300-time steps, the real option was evaluated to examine the value of investment delay. Option values for 50 different values of t ranging between 0 and 25 with a half year time interval were generated. For each of the values of t, the option value was determined. Figure 3.2 presents the results of using the parameters in Table 3.4 above to determine the option value. Figure 3.2 shows that the value of the option increases for increasing values of t. The behaviour of the option indicates a diminishing marginal utility property as the rate of increase reduces for increasing values of t.

Figure 3. 2: Option values for different values of t



Source: Author's Construct (2021)

Thus, although there is an incentive for the project to be delayed, it is not advisable to delay investment over its lifetime. The stopping criterion for the solution to this model is described by examining the rate of increase in the option value for each half-year the project is delayed. Graphically the stopping value of t can be determined from the elbow of the graph shown in Figure 3.3. The stopping criteria determines a value ε, such that the rate of change of the option value from period t to period $t+1$ is less than ε. Mathematically, the stopping criteria for successive values of the option follow the ratio shown in equation (12).

$$\ln\left(\frac{V_{(t+1)}}{V_{(t)}}\right) \times 100\% < \varepsilon \qquad 12$$

Table 3.4 provides optimal investment trigger periods for varying degrees of ε of 5%, 2% and 1%. For each value of ε, the trigger period and the average option value are determined from the binomial lattice model. Investment trigger points range between four to eight and a half years, given the different values of ε (See Table 3.5). Delaying the investment provide a better outlook for the investor and where some levels of uncertainties are clarified. One of the key drivers of the viability of investment delay is the potential increase in the renewable energy prices which the off-taker would be required to pay to the consumer.

Table 3. 5: Investment trigger points and average option values

Value of ε	5%	2%	1%
Option value (million)	GHS 233.55 ($43.3)	GHS 265.31($49.1)	GHS 277.87 ($51.5)
an investment trigger point (years)	4.0	6.5	8.5

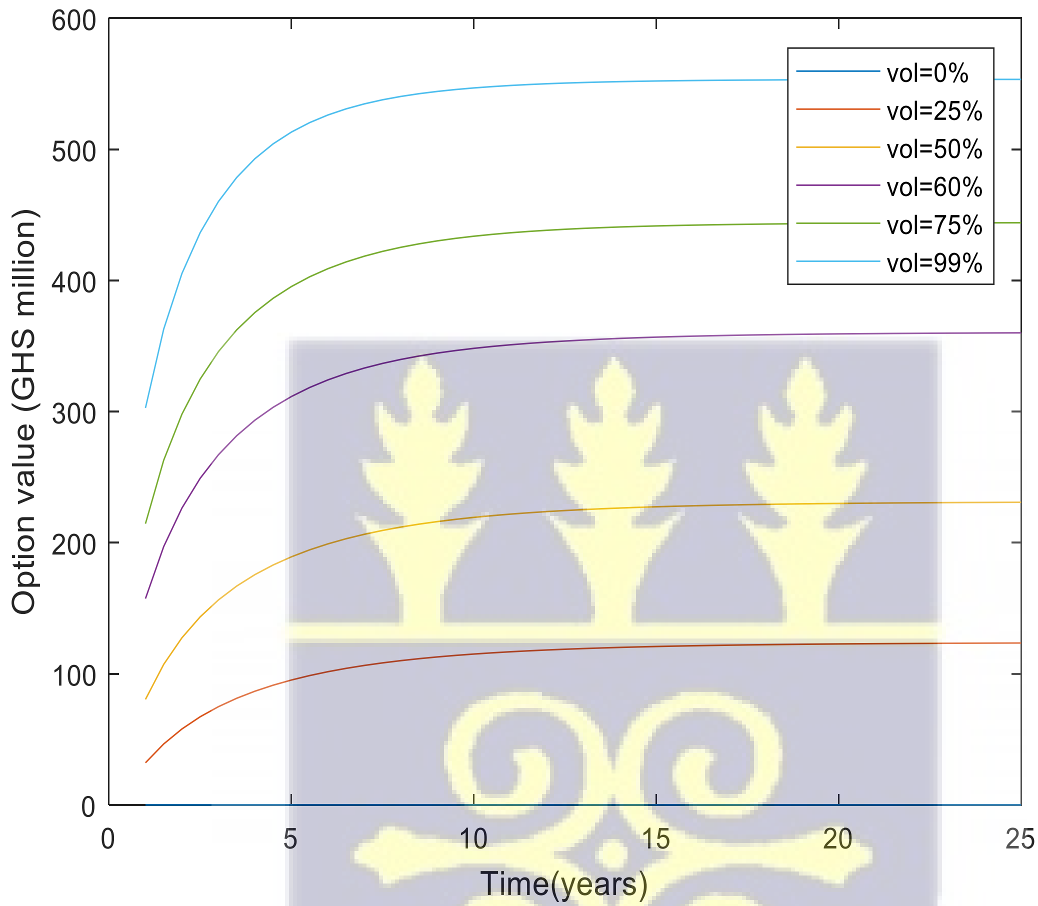
Source: Author's Construct (2021)

Sensitivity analysis

The option valuation model consists of three main parameters – the volatility, the risk-free rate and the leakage rate. The sensitivity analysis is done to examine changes in option value and investment trigger points given changes in the parameters of the sensitivity model. For each of the parameters, the sensitivity analysis was carried out based on six main scenarios: (1) when the value of the parameter is zero, (2) when there is a 50% reduction in the base value, (3) when there is a 20% reduction in the base value, (4) when there is a 20% increment in the base value, (5) when there is a 50% increment in the base value, and (6) when there is 100% increment in the base value.

Increasing volatility increases the option value. In the analysis of project costs and revenues, volatilities in revenues outweighed that of costs. This shows the upside potential of the project, which results from increasing FITs, increases in capacity factors and increases in purchase obligations. There is no change in costs and revenues at zero volatility throughout the time steps, resulting in the same negative NPV across the lattice. Given the options available, the optimal decision is to forgo investment entirely, resulting in a zero value. As the volatility increases, the optimal investment time increases from four and a half years to six years (See Figure 3.3).

Figure 3. 3: Sensitivity analysis for changes in volatility

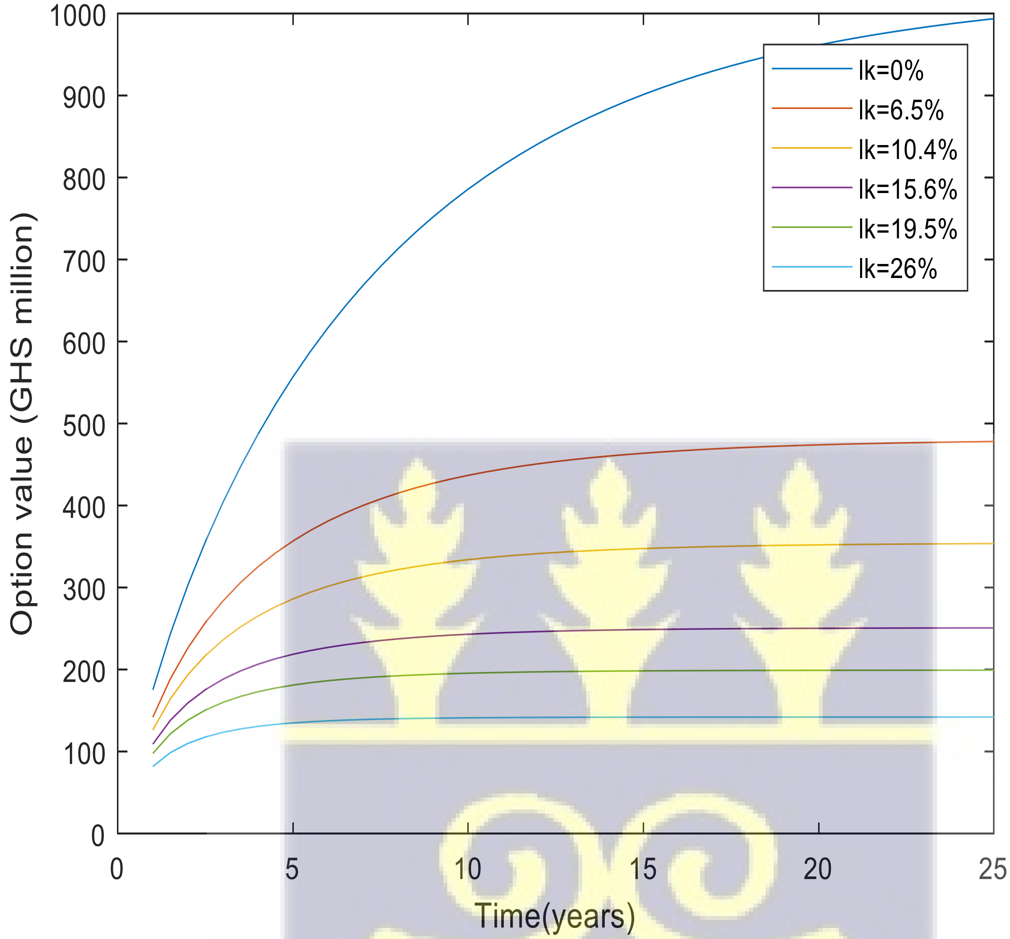


Source: Author's Construct (2021)

In the second case, increasing leakage rates reduces the option value. The option value is highest at a zero leakage rate, even compared to the other sensitivity values. Thus, where there is little or no 'punishment' to delaying investments, the investor is allowed to postpone investment for a more extended period. At a zero-leakage rate, the project's intrinsic value is estimated to be about GHS 770 million ($142.6 million), with an optimal trigger period of about eight and a half years. A 100% increase in the base value of the leakage rate lowers the average option value to about GHS

137 million ($25.37 million), for which the optimal trigger period is about four years (See Figure 3.4).

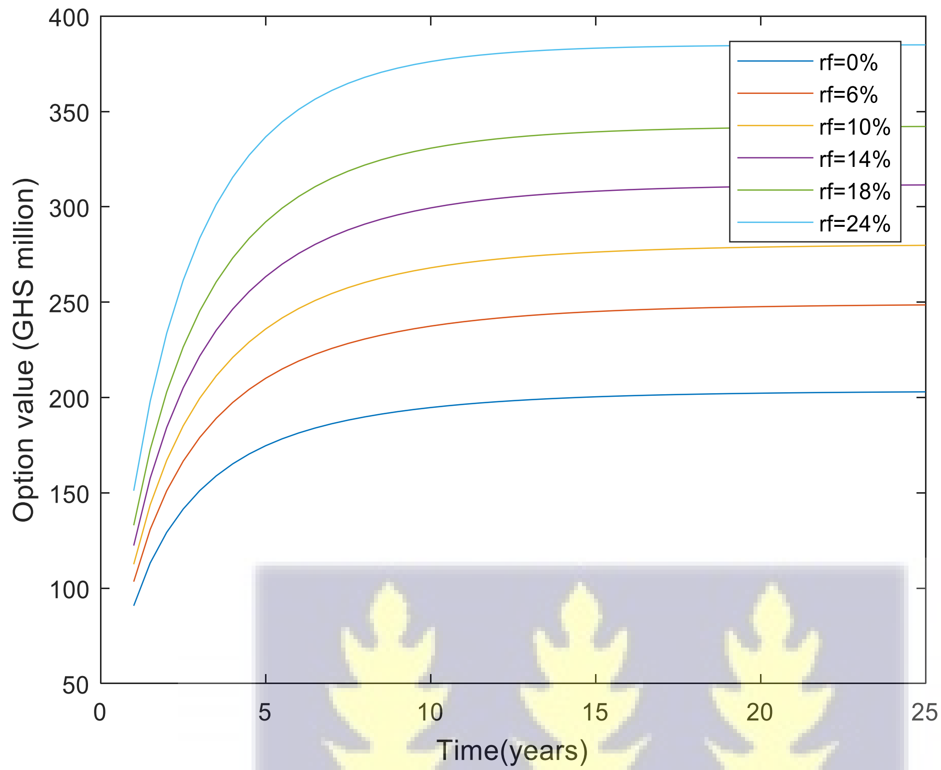
Figure 3. 4: Sensitivity analysis for changes in leakage rate



Source: Author's Construct (2021)

The third case presents changes in the discount rate. Increasing values of the discount rate cause a corresponding increase in the option value. Option values range between GHS 187 million ($34.6 million) to GHS 358 million ($66.3 million), given various scenarios corresponding to changes in the discount rate. Investment trigger periods for these values lie in the range between five to five and a half years (See Figure 3.5).

Figure 3. 5: Sensitivity analysis for changes in the discount rate



Source: Author's Construct (2021)

Table 3. 6: Results of sensitivity analysis

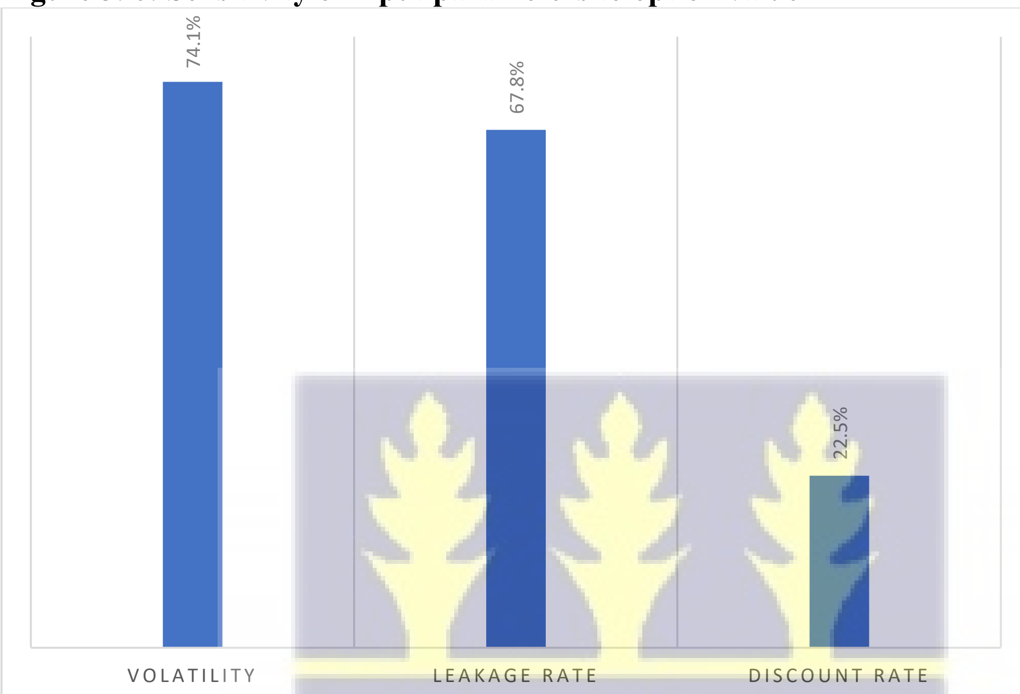
	Volatility		Leakage rate		Discount rate	
Sensitivity value	**Option value[1]**	**Investment trigger[1]**	**Option value**	**Investment trigger**	**Option value**	**Investment trigger**
100% reduction	0.00	Do not invest	779.48	8.50	187.79	5.00
50% reduction	109.31	4.50	418.73	6.50	228.30	5.00
20% reduction	209.42	4.5	319.54	5.50	256.86	5.00
20% increment	334.06	5.00	233.32	5.00	286.31	5.50
50 % increment	417.11	5.5	188.47	4.50	315.58	5.50
100% increment	528.40	6.0	137.01	4.00	358.12	5.00

Source: Author's Construct (2021)

[1]Optimal values are measured in GHS millions, and the investment trigger period is measured in years

The sensitivity of the option value to input parameters is assessed by examining the coefficient of variation for each of the input parameters (MacDougal, 2015). An input parameter with a higher coefficient of variation shows a higher sensitivity parameter to option values. As shown in Figure 3.6, volatility and leakage rates are most sensitive to option values. It is seen that changes in these figures impact largely on the option values.

Figure 3. 6: Sensitivity of input parameters to option value



Source: Author's Construct (2021)

3.5 Discussions and conclusions

This study aimed at determining the value of delay for utility-scale renewable energy investments using real options analysis. The relevance of real options approaches is essential to determine the value of investments. In this chapter, the real options approach was applied to assess the value of utility-scale renewable energy investments. Real options approaches have the advantage of capturing the flexibilities and uncertainties that are inherent in investment decisions. The results of the study show the importance of delays for utility-scale renewable energy investment. Delaying investments in an uncertain environment provides intrinsic managerial flexibilities through the real option valuation, which would be non-existent if the investment is carried out at time zero. By delaying, investors obtain new and valuable information that can help minimise uncertainties in the project (Zhang, 2016; Gross et al., 2010). In addition, investment delays can help to improve levels of technology maturity, which provide reductions in technology risks (Gross et al., 2010). In the case of Ghana, the importance of delay in triggering investment is highlighted in all scenarios within the sensitivity analysis, with delay times ranging between 4 and 8 years.

The negative net present value for the investment is driven by lower Feed in Tariffs, capacity factors of renewable energy systems and purchase obligations that are set by governments. These are factors which governments and investors can control. To drive investor confidence, the attractiveness of FITs must be ensured in addition to ensuring that demand is created for the utilisation of the solar energy generated. The results show that the current feed-in tariffs are not sufficient to build investor interest in renewable energy generation in the country, considering the costs that are involved. Policies that are favourable for renewable energy investment are needed to drive early investment in utility scale renewable energy. Lenders also expect that project cashflow is enough to cover investment costs and its associated interests that will be generated, with reduced payback periods for investments. While a fixed feed in tariff may be advantageous in controlling for falling electricity prices, the locked in price may not reflect the true value of capital costs required to for investment in renewable energy systems. High capital costs are however offset by lower operation and maintenance costs required for power generation which provides extra incentive for renewable energy investment.

Whereas costs are charged on installed capacities of plants, revenues are obtained on the generation capacities of electricity plants. This means that investors can also ensure that investment in new technologies that increase the capacities of solar plants are done to ensure reliability and constant supply of power. Higher capacity factors will therefore have the guarantee enhanced generation capacities to increase revenues.

In consonance with MacDougal (2015), the study shows that volatility and leakage rates are the dominant drivers in the investment timing decisions to be made by investors in renewable energy markets. Although increased volatility in project revenues drive option values, the increase in value is offset by further delay, for which national targets for renewable energy generation may be missed. The study highlights that policy support is required for renewable energy investments to thrive and to fairly compete with conventional fossil fuel-based energy resources. Inadequate political will and the lack of policy support are major sources of risk to the investor. The antecedents to such policy risks which affect revenues include industry regulation, tariff policies and tax policies on renewable energy materials, among others (Liu & Zeng, 2017).

Renewable energy has witnessed significant reductions in installation costs, reducing global capital costs over the past decades. However, the benefits of cost reductions are seen in the developed world compared to the developing nations. For developing countries, giant steps towards renewable energy penetration require private sector investors whose objective is profitability, besides ensuring environmental sustainability. Moreover, the risks inherent in utility-scale renewable energy investments in such an environment require decision-making that considers risk reduction through optimal investment timing.

Utility-scale renewable energy projects in Africa and, for that matter, Ghana are scant, and as a result, there is limited data on costs, revenues, capacity factors and purchase obligations. Therefore, the limitation of this study is the utilisation of estimated values for the parameters of this study. As the technologies become more mature in Africa, data will be available in real-time, depicting the actual scenarios for such projects. However, in the absence of real data on costs and other variables, simulations represent the reality of the appraisal of renewable energy projects.

Further studies can investigate how governments can make decisions to drive investor interest in renewable energy. This includes levels of subsidies and FITs that are attractive for investors as they can be further researched. In addition, trade-offs between renewable energy generation increased FITs, and end-user tariffs can be further investigated to generate an optimal tariff scheme beneficial for industries, power generators and residential consumers.

CHAPTER FOUR

STUDY TWO: A REAL OPTIONS APPROACH TO ASSESSING THE COST SAVINGS POTENTIAL OF RENEWABLE ENERGY ADOPTION AMONG SMES

Abstract

Small and Medium Scale Enterprises (SMEs) are integral to the development of economies. This notwithstanding, they face significant challenges within their operations of which access to affordable power supply is profound. Self-generation options have the potential to curtail these challenges to an extent, however, it is essential for SMEs to choose options that provides them with significant cost savings. This study proposes a real options model to evaluate the cost savings potential for SMEs in switching from conventional power generating sources to renewable energy based on three main scenarios: using renewable energy as backup, a full transition to renewable energy generation and a partial transition to renewable energy sources.

The results show that using renewable energy as backup sources do not provide significant cost savings to the SME. However, a complete or a partial transition from conventional to renewable energy resources provide substantial cost savings for the SME over the life of the renewable energy technology. SMEs need to consider capacity factor of renewable energy technologies, tariffs for conventional power supply, system reliability of conventional systems and the investment costs for renewable energy generation as important factors for renewable energy investments.

4.1 Introduction

Small and Medium Scale Enterprises (SMEs) are significant contributors to the growth of most economies globally. Generally, they account for a substantial proportion of businesses in many countries (Yacob, Wong & Khor, 2019). In Ghana, SMEs are integral to economic development as they form about 90% of businesses (Abor & Quartey, 2010; Avevor, 2016). They are vital agents of employment and job creation in the country, contributing about 85% of jobs in the manufacturing sector (Amoah & Amoah, 2018).

However, SMEs face various challenges, including but not limited to access to finance, markets and technical capacities. In addition to these challenges is the costly and intermittency of power supply in the country. These power sector intermittences result in reduced productivity (Hardy & McCasland, 2019). The long spell of power outages in Ghana between 2012 and 2015, christened as *dumsor* impacted SMEs in several ways including high production and maintenance costs, increased redundancies and damage to equipment (Boakye, Twenefour & McArthur-Floyd, 2016). These challenges culminate in loss of productivity among SMEs. Agyapong, Mmieh & Mordi (2018) also indicate that the erratic power supply caused some SMEs to relocate in other neighbouring countries. Abebrese, Ackah & Asuming (2021) estimated that an extra day of power outages in Ghana resulted in a 1% reduction in labour and total factor productivity. These have impacts on domestic revenue mobilisation as the country is loses potential taxes due to the relocation of businesses.

In Ghana, SMEs broadly fall into the category of non-residential or commercial power consumers with electricity tariffs higher than that of residential consumers. The average tariff for commercial consumers per kWh of power consumed, as of December 2020, was about GHp 69 (12.1 US cents) for residential consumers and GHp 94 (16.6 US cents) for non-residential consumers (Public Utilities Regulatory Commission (PURC), 2021). Thus, SMEs which form a large portion of the productive bear the burden of residential consumers, thereby increasing their operation costs. Ghana's Energy Sector Recovery Program (ESRP) acknowledges that the cost of power in Ghana is expensive when compared to other developing countries in Sub Saharan Africa. For example, as of 2019, the average tariff by non-residential consumers was about $0.23/kwh compared to countries like South Africa ($0.08-$0.1/kWh) and Ivory Coast ($0.15/kWh) (Ministry of Energy, 2019; Acheampong, Menyeh & Agbevivi, 2021).

Financial and technical challenges in the transmission and distribution aspects of Ghana's energy value chain contribute to the intermittency in power supply. The System Average Interruption Duration and the System Average Interruption Frequency indices (SAIDI and SAIFI) measuring electricity utilities' reliability fall below the standard threshold. For instance, in 2017, Ghana's power distribution company for the Southern Sector (Electricity Company of Ghana (ECG)) recorded an average SAIFI of about 64 outages, above the maximum regulatory benchmark of 6 outages. The company also recorded an average SAIDI of 115 hours for its urban customers, against a maximum regulatory benchmark of 72 hours (Energy Commission, 2018).

Like many other developing countries, Ghana has a centralised electricity generation, transmission and distribution system (Energy Commission, 2018; Gregory & Sovacool, 2019). End-users of electricity, particularly SMEs, generally interface with the distribution end of the power sector value chain, which two major companies manage in the country's northern (Northern Energy Distribution Company (NEDCO)) and southern (ECG) sectors of the country. The Public Utilities Regulatory Commission (PURC) determines electricity tariffs by considering factors such as the price of gas, power generation costs, exchange rates and margins from generation, transmission and distribution sectors.

Centralised generation systems have the advantage of ensuring economies of scale; however, this is offset by increased costs that occur because of transmission and distribution losses (Martin, 2009). In Ghana, about 26% of revenues for the energy transmission company is used to recover transmission losses, while about 47% of revenues for distribution companies is used to recover distribution losses (PURC, 2020). The end-user faces two challenges; intermittency of power supply resulting from increasing transmission and distribution losses, and the high tariffs from costs transfer for recovering transmission and distribution losses.

Given the challenges and the costs in the centralised power systems, SMEs need to obtain alternative energy sources or backup systems that are affordable, reliable, and less harmful to the environment. Access to such technologies has the potential of meeting Goal 7 of the United Nation's Sustainable Development Goals (Verboven & Vanherck, 2016) while providing economic benefits. The flexibility in switching to alternative energy generation sources can provide avenues for reducing risks that businesses face due to unmet power demand (Lund *et al*., 2015). This flexibility drives competition among utility companies as well as power producers, and can ensure efficiency along the power value chain. Renewable energy integration has the potential to achieve this desired flexibility (Javed *et al.,* 2021).

Increased interest in renewable energy technologies as alternative power generation sources for SMEs increases the investment potential in the resource. It also allows private investors, who hitherto did not obtain value in investing in utility-scale renewable energy projects due to lower feed-in tariffs and regulatory bottlenecks, to invest in alternative renewable resources with promising returns.

Despite the global support for the switch to renewable energy, SMEs' rate of renewable energy adoption is low (ACEP, 2021). Factors that account for this situation include high investment costs for renewable energy integration. While there are the touted benefits of renewable energy as an environmentally friendly option for providing stable power (Hanna et al., 2017), there is the need to make a business case for SMEs to invest in renewable energy technologies. SMEs are primarily focused on production and profitability. However, the lack of information, funding, and technical expertise conceal the benefits of energy efficiency and renewable energy adoption as cost reduction measures (Suciu et al., 2017). Generally, SMEs do not have the time and laxity to manage their energy systems. However, thorough consideration and analysis of their energy systems and the forms of energy to use can prove cost-effective for them in the long run (Cosgrove et al., 2017). Thus, renewable energy suppliers and investors must justify the incentive for SMEs to switch to renewable energy technologies.

This chapter examines the economic benefits of decentralised solar Photovoltaics (solar PV) utilised by SMEs in Ghana. It contributes to existing literature in the following ways; first, this chapter presents a real options model that seeks to investigate the inherent value of renewable energy integration from the SMEs' perspective; second, it outlines some technical considerations for SMEs to maximise their gains from renewable energy integration; third, the chapter contributes to existing literature by focusing on three main scenarios; using renewable energy as a backup source of power generation, completely switching to renewable energy and a partial switch to renewable energy.

The chapter is organised into five sections. The second section presents a review of the literature and the theory that underpins the research. The third section presents the real options model to be used for the assessment. Findings from the broader study and the case studies are presented in the fourth sections. A discussion of the implications of the study is presented in the fifth section.

4.2 Literature review

4.2.1 Characteristics and challenges of SMEs

The definition of SMEs in one context may refer to another class of business in another context. As a result, there is no universally accepted definition of the term. However, various definitions of SMEs have been provided in terms of employee size and the value of assets. The European Union classifies small businesses as those with a maximum employee size of 250 and an annual turnover of €250 million (Altman, Sabato & Wilson, 2008). Generally, developing countries classify firms with less than five workers as micro-scale businesses and small-scale businesses with an employee size between five to 19. Firms with employee size between 20 to 99 are further classified as medium scale, while those with an employee size of 100 or more are classified as large scale (Abor & Quartey, 2010).

In Ghana, the Ghana Statistical Service defines the concept based on the number of employees. Firms with less than ten employees are considered small-scale enterprises, while those with more than ten employees are regarded as either medium-scale or large-scale enterprises (Abor & Quartey, 2010). Further, the National Board of Small-Scale Industries (NBSSI, now Ghana Enterprises Agency) defines SMEs based on the value of assets and the number of employees. It describes small enterprises as businesses that employ between 5–29 workers with fixed assets not exceeding US$100,000 (excluding land and building). It further classifies medium-scale enterprises as employing between 30–99 workers (Oppong et al., 2014). Other authors describe SMEs as firms with between 6 and 99 employees and plant and machinery assets not exceeding US$100,000 (Asante et al., 2021; Zotorvie, 2017). This study employs the definition by Asante et al. (2021) and Zotorvie (2017).

The structure and form of SMEs' operations are distinct from large-scale businesses or multinational companies. While the latter seems to have a more organised corporate governance system with boards, management members performing different functions, the management and control of SMEs is usually centred on the owner or founder of the business (Abor & Quartey 2010). The owner is essentially the source of innovation and knowledge management, which largely influences the firm's success or failure. Major decisions, including operational and financial decisions, rest with the owner, who mostly doubles as the manager (Wee & Chua, 2013; Rasheed & Siddiqui, 2019).

SMEs have a more simplified internal structure and minimal levels of bureaucracy. The simplified governance practice presents an advantage for SMEs. For instance, there is the speed in the extent of decision making, which minimises the level of delays inherent in large scale companies (Paul, Parthasarathy & Gupta, 2017). Generally, the behaviour of SMEs is not the same as compared to the conduct of large-scale businesses. These differences enhance SMEs' uniqueness and further limits the ability to clearly explain their behaviours with various capital structure theories (Rasheed, Siddiqui & Rahman, 2018). This is because the personal and behavioural characteristics of the owner influence most of the financing decisions for the business. They also possess a higher level of risk aversion compared to large scale companies with organised corporate governance structures. Rasheed *et al.* (2018) observed that the SMEs in emerging economies prefer informal sources of funding, such as self-financing and loans from families and friends. In terms of marketing, SMEs have a lower market and brand orientation. Hence, they do not invest much into branding and advertising as these activities are often considered as additional costs of operations (Wong & Merrilees, 2005).

Notwithstanding the importance of SMEs to the economic development of countries, they are faced with various challenges that hamper their growth, and for that matter, their contribution to national economic development. Some of these challenges arise because of their distinctiveness compared to large scale companies. The lack of, or inadequacy in obtaining financial resources is one major challenge that hampers the survival of SMEs. These include inadequate financing options for SMEs and the high costs of capital (Muriithi, 2017). This results mainly from high lending rates offered by financial institutions, which inhibits SMEs from sourcing capital for expansion and other business-related activities. Access to finance is further worsened by banks' inability to accurately determine the creditworthiness of the SME, which make it difficult to issue loans to SMEs. SMEs, therefore, resort to other approaches such as self-financing, funding from close relations or microfinance institutions financing, which results in either raising lower-than-expected capital or assessing options with higher costs of funding.

The inadequacy of financial resources forms the bedrock of the numerous challenges that are faced by SMEs in many instances. Technological advancement, as well as employment of skilled labour in carrying out efficient work operations, are curtailed among SMEs because of the challenges with accessing finance (Ezeagba, 2017). Inadequate skilled labour reduces the extent to which innovative capability and strategic goals are applied as an administration instrument within the SME. The entire cooperate governance framework for the SME is mainly informal, and the desire to take on skilled labour is low because it is perceived to be another layer of cost for the business (Murithi, 2017). Other managerial challenges include the inability of the SME in managing its financial records and other bookkeeping practices. Donkor *et al.* (2018) observed that the limited utilisation of innovation and strategic goals is a result of the disregard of their application by the managers of SMEs, contributing to the gradual decline in most SMEs.

Further, globalisation and competition have reduced the competitiveness of SMEs compared to large scale companies. While large scale companies have the advantage of scale, which reduce their respective unit cost of operation, SMEs lower scale production leads to relatively higher unit costs of production (Ocloo, Akaba, & Worwui-Brown, 2014). SMEs face difficulties in assessing reliable distributors, limited negotiating power and understanding of the market in which they operate. SMEs could have taken advantage of globalisation. However, these challenges prevent them from operating up to their expectation

Mitigating the challenges faced by SMEs provide avenues for their growth and development, which enhance their contribution to economic growth (Delalić & Oruč 2014). This includes providing an enabling environment for SMEs to assess the needed financial options for improved business operations. SMEs are further encouraged to build the necessary managerial and innovative competencies within their operation.

4.2.2 Security of energy supply for SMEs

While the aforementioned challenges have been well documented, the adequate supply of electricity is another critical component that needs to be addressed. Electricity is an essential commodity for every business. It serves as a catalyst for the conversion of raw materials into finished products for manufacturing and other industrial operations. In service operations, electricity is essential in facilitating document processing, communication and other business operations. Power generation is an integral component of the entire operational value chain of a business, whether small scale or large scale. The World Bank's Enterprise Survey reveals that about 22% of business managers note that unstable electricity supply is a key constraint that impedes the survival of the business. Access to reliable and affordable electricity can prove to be a critical component of cost reduction for businesses. It is therefore vital to address issues that confront reliability and access to electricity as critical for the survival of SMEs. The ability of SMEs to switch from manual labour to automated labour entirely relies on power availability. This switch is hampered if such adequate power is not available (Asare, Gopolang, Mogotlhwane, 2012)

One of the critical components of energy security is the security of supply or availability of power. The concept of security of supply is not only applicable at the macro level where nations plan towards ensuring access and reliable supply of energy, but also at the micro-level where firm-level decisions are undertaken to provide same. This is because it is critical for businesses to have an uninterrupted supply of power to enhance their sustainability. Bekhrad, Aslani & Mazzuca-Sobczuk (2019) identified five dimensions of energy security, namely the availability of fuel, its affordability, sustainability, technology development and efficient regulation of the sector.

In addition to the availability of demand, Azzuni & Breyer (2017) describe that the security of supply is dependent on the availability of energy resources to transform these resources into energy services. The natural resources required to provide fuel in firing coal and liquid fuel power plants are globally available in larger quantities. Globally, the amount of coal at the end of 2019 was estimated to be about 1.06 trillion metric tonnes, with global annual consumption of about 3.7 billion tonnes of oil equivalent (Looney, 2020). Similarly, while global proven oil reserves as at the end of 2019 was estimated to be about 1.7 trillion barrels, its consumption was about 98 million tonnes. This shows that given the estimated proven reserves and the consumption volumes, it will take centuries consume the proven reserves of coal and crude oil based on their current consumption levels.

Further, the advent of renewable energy technologies has provided a more comprehensive range of sources of energy for the foreseeable future. In addition to its environmental friendliness, renewable energy resources offer an avenue for the diversification of the energy portfolio (Johnson, 2019). Diversification helps minimise risks associated with the overreliance on a single source of energy generation. Ghana, for example, was reliant on its hydroelectric source for energy generation until the latter parts of the 20th century, when lower levels of its Akosombo Dam resulted in a general energy crisis. Since then, efforts were made to provide additional generation sources to diversify the energy mix and increase the country's energy generation capacity.

In addition to the availability of energy generation resources, the ability to transform the resources into energy-related services such as the supply of electricity is an essential aspect of energy security. This requires the availability of necessary infrastructure at various stages of power generation, transmission and distribution. This requires financing, effective regulation, as well as improvements in technologies (Bekhrad, Aslani & Mazzuca-Sobczuk, 2020). In the case of power generation, investments in dams (for hydroelectric generation) and thermal plants (for thermal generation) are needed to generate the required power. Solar energy generation requires the necessary solar panels and batteries for energy storage. The unavailability of infrastructure to harness the resources can be detrimental for power generation. Ghana suffered a major power crisis between 2012 and 2016 caused mainly by the inadequacies in the supply of fuel in powering thermal plants.

Energy transmission involves transporting power from generation sources to distribution sources. The transmission phase requires investments in substations and transmission lines. Power distribution involves power delivery from the transmission infrastructure to the end-users or consumers. In most cases, power distributors are key revenue-generating sources for agents along the power value chain (power generators and power transmitters) since they interface directly with the customers. Similar investments in substations, transformers and distribution lines are required to aid in these operations. While improved generation infrastructure is necessary to increase power generation levels, improved transmission and distribution infrastructure is necessary to reduce technical and commercial losses, which generally can affect the power supply and the financial capabilities of the entire power value chain.

Power supply challenges facing SMEs

Generally, firms suffer from two sources of power disturbances: poor quality and power outages. Power supply is deemed quality if there is stability in supply. Unstable power supply results in power fluctuations which damages machines and appliances (Cissokho & Seck, 2013). Power outages occur when the consumer experiences loss of power supply. Poor power quality and power outages are caused by a myriad of factors, including inadequate generation potential to meet increasing demand, inadequate supply of fuel for thermal plants, as well as poor distribution and transmission infrastructure resulting in high transmission and distribution losses.

Power disruptions are hindrances to SMEs in their efforts to expand their operations, including their adoption of IT-enabled services (Asare, Gopolang & Mogotlhwane*, 2012*). Technological resources are relevant for SMEs for their expansion and to take advantage of economies of scale. This nexus requires a reliable and affordable supply of power (Prasanna *et al.,* 2019). Unfortunately, SMEs are unable to operate at full capacity in the face of power challenges.

Nurudeen, Nafiu & Jibo (2018) also observed that SMEs' power consumption has the tendency of influencing employability, poverty reduction, profitability, productivity, competitive edge, and market share. The authors explained that regular power supply could reduce the cost for backup supply, and this cost reduction is expected to influence the economic contribution and performance of SMEs. Power outages lead to disruptions in the production processes, lower outputs exacerbated by higher replacement costs and restart costs. These costs contribute to reduced opportunities for competitive advantage.

Further, unreliable supply of power contributes to the unwillingness of other SMEs to pay for power generation. This has impacts on revenue generation by utility companies, with rippled effects on governments as well. In many emerging economies, unreliable power is largely an issue outside the control of SMEs. This is because the management of electricity sources are in the hands of a centralised energy operator and the primary responsibility of the SME is to ensure that bills are paid to obtain an unlimited power supply. However, while business' ability to pay tariffs is important in revenue generation for service providers, it is essential for these providers to reciprocate the efforts of their customers with a reliable supply of power (Nurudeen, Nafiu & Jibo, 2018).

There is a complex nexus between the reliability of energy supply, profitability, and the extent of income-generating activities. For instance, the unreliability of power can lead to lower production, which has the potential of reducing the propensity for business expansion (Riva et al., 2018). Business expansion has the potential to drive local services to increase income-generating activities. These complexities suggest that reliable supply is not only related to the success of a single SME but also the rippled effects in income-generating activities.

In addition to inadequate capital, and the challenges associated with the skill set and technological advancement, businesses are faced with the challenge of high electricity tariffs. Tariffs are costs of power supply from grid-connected systems. High electricity tariffs create a vicious cycle of increasing costs of operations, leading to limited capital for technological advancement, which eventually has negative impacts on the performance of SMEs (Olaoye & Talabi, 2018).

Self-generation as an option for SMEs

To cope with the challenge of disruptions in power supply and higher costs of power supply from grid-connected sources, power consumers, especially businesses, resort to self-generation. Self-generation allows the consumer to generate its own power from decentralised sources with limited dependence on the national grid. Self-generated electricity is either used as a backup for conventional energy sources or as primary sources of power for the consumer. Generally, electricity-intensive firms are more likely to be affected during power outages than their counterparts, which utilise less electricity to produce goods and services (Adewuyi & Emmanuel, 2018). For such firms, it is likely that self-generation is a viable option. The capacity for self-generation depends mainly on the size of the firm, sector, corporate structure and export potential

(Abdisa, 2020). This is arguably a contributory factor for the continued interest in self-generation for large scale companies compared to SMEs.

Self-generation requires a substantial investment for the installation of decentralised systems, which could have been directed towards other projects with higher economic prospects (Nurudeen *et al.,* 2018). As a result of financial constraints and high costs of self-generation, companies back up only critical components of their operation with self-generation or resort to self-generation in periods when grid supply is unavailable. This notwithstanding, self-generation, whether in its entirety or as a means for backup generation, can prove to be advantageous in the long term. In developed countries, research has shown that grid defection is economically viable (Peffley & Pearce, 2020). The viability is heightened with the introduction of a governance framework that supports renewable energy diffusion into the energy mix. As a result of the reduced occurrences of power fluctuations and power outages, businesses that utilise their own sources of power can enjoy higher levels of productivity as compared to those that rely on centralised sources.

Rational and profit maximising businesses would want to protect themselves from increasing occurrences of power outages as they are detrimental to their productivity. Minimising these impacts require back up generation (Olaoye & Talabi, 2018). The trade-off is the increase in costs of electricity generation from the backup source. It is essential to ensure a balance of the trade-off by selecting the form of self-generation that minimises the costs in acquiring generation capacity.

Renewable energy as an option for self-generation

The reliance on diesel backed generators as a source of power generation increases the operating costs of businesses (Cissokho & Seck, 2013). In addition to the cost of obtaining the generator, fossil fuel backed plants require the burning of fuel to generate the needed electricity, exacerbated by the associated environmental impacts. Because of the high costs associated with self-generation, it is necessary that businesses generate at optimal capacities that allow them to break even (Adewuyi & Emmanuel, 2018).

Hanna *et al.* (2017) identify three factors that drive the shift towards decentralised systems, particularly renewable energy. The first two drivers concern the reduced costs of renewable energy technologies and their storage systems, as well as the rising costs of grid-connected electricity services. The third driver is the concerted global efforts at reducing greenhouse emissions. This has driven policies that encourage the switch towards renewable energy technologies, particularly in developed economies.

In terms of its advantage over fossil fuel sources, renewable energy sources are more friendly to the environment. However, SMEs, like any other business, are more profit-oriented and would make decisions that lean towards enhancing their bottom line. Thus, for renewable energy to be a preferred source of self-generation, there is the need for the resource to prove itself as more cost-effective than fossil fuel sources.

The challenge associated with installing renewable energy sources for SMEs is the high capital cost required (Albadi *et al.,* 2020; Gabriel, 2016). Further, there is a problem with their intermittency. For example, solar technologies will not be available without sunlight, and this requires additional investment in power storage technologies. Investment in these technologies, therefore, increase the capital and installation costs of the renewable energy resource. This notwithstanding, the prices of solar panels have continuously plummeted over the past years.

Additionally, with the maturity of renewable energy technologies, it is predicted that prices can fall by 60% within the next ten years (Peffley & Pearce, 2020).

Despite the efforts towards reducing installation costs of renewable energy technologies, the capacity of SMEs to provide high capital for investment in renewable energy technologies at the expense of already existing power infrastructure is largely unavailable (Gabriel, 2016). Some large-scale companies can do so to purchase a social license and the recognition of being environmentally friendly. However, for an SME, the decision to invest in renewable energy technology either as a primary source of power generation or as a backup source goes beyond the consideration of environmental friendliness or acquiring a social license to ensuring that switching to renewable energy will achieve the best return (Pechmann & Zarte, 2017).

For an emerging economy, extra effort is required for businesses to understand the benefit of switching from grid-connected fossil fuel systems towards renewable energy systems. This begs several questions that need to be addressed; what cost-defraying policies exist to benefit the SME who would like to invest in renewable energy? How will suppliers of renewable energy services make a case for an SME to decide to invest in such technologies? Is it cost-effective for SMEs to switch from conventional sources towards renewable energy sources? What should be the optimal timing for SMEs of varying characteristics to switch towards renewable energy either as a primary source or as a backup source of power consumption? The following section presents the decision of the SME in switching to renewable energy as an asset replacement problem.

4.3 The theory of asset replacement

The assets of a business are either tangible or intangible resources that have the capability of producing positive economic values. The concept of managing assets is crucial to all businesses, especially for those whose assets are the direct source of revenue for the company. Asset management includes an integrated process of decisions such as financial, operational, engineering and maintenance. The overarching objective of managing assets is to obtain effectiveness, utilisation and return from the assets (Größler, Bivona & Li, 2015). Decisions that are not made right can cause problems for the firm, and achieving this objective may prove difficult. Key among these decisions is the decision to replace assets.

In his seminal work on the theory of replacement, Peters (1956) defined asset replacement as the process of acquiring a new asset to fulfil a particular function. This new asset will lead to the scrapping or the transfer of use of the old asset, which had performed similar roles. Firms may consider replacing assets based on cost efficiency, performance, technological improvement or equipment obsolescence. For instance, an old computer system may be replaced by a newer one for faster processing and to reduce events of machine breakdowns. The desire to replace an asset also depends on the costs that are associated with the operation and the maintenance of the asset. Old assets whose operation and maintenance costs increase at a faster rate are more likely to be replaced by the new asset. Thus, managers may decide to replace an asset that has cost savings compared to the old asset. The primary principle for asset replacement is that the new asset must provide a better economic value than the old asset. Thus, asset replacement becomes viable when the opportunity gains from the replacing asset exceeds the value of the existing asset that needs to be replaced (Perrin, 1972; Yatsenko & Hritonenko, 2017).

A critical question then emerges as to whether the replacement of assets will lead to the desired maximisation of gains as expected. This depends on the strategies of asset replacement undertaken by the firm. When an asset is replaced, the firm incurs costs for replacing the asset. This may include costs of purchasing and installing the new asset. Further, the firm foregoes the gains that are offered by the old asset. For instance, if the business wants to replace its electricity generation source, it forgoes all the benefits that the old generation source offers and gravitates towards a new source of energy. The desire to acquire a new asset must therefore arise from the fact that the new asset provides better benefits than the old asset. To value the profitability of the new asset, there is the need to evaluate the opportunity cost for retiring the old asset, i.e., business managers need to ask the question as to, what would have been the benefits or profits if the old asset had been maintained? It is therefore expected that the firm identifies the trade-offs that exist between the current state of the asset and the decision to replace it.

In considering these trade-offs that exist between the replacing asset and the replaced asset, the reasoning behind asset replacement has been extended beyond the comparison of the gains between the former and the latter. This includes providing the best option that maximises the present value of gains that will arise from the exchange, which presents a myriad of points to consider. The asset replacement problem can be formed in various ways. If the firm decides to consider a "now or never" decision, where the firm intends to carry out an immediate replacement, then there is the need to consider whether a complete replacement or a partial replacement is ideal. This also depends on the form of asset that is to be replaced. For an electricity generation system, the firm can consider whether to gravitate wholly from conventional power to renewable energy or use renewable energy for some aspects of its operations and vice versa.

The replacement problem can also be formulated by means of evaluating the age by which the old asset must be replaced by the new asset, which will maximise the present value of the earnings or cost savings. Timing is considered an essential factor, especially within a business environment riddled with uncertainties. Adkins and Paxson (2016) noted that while uncertainties and volatilities in operation costs can defer replacement, uncertainties in salvage values will hasten replacement. Other factors include and are not limited to uncertainties in technical complexities (Yatsenko & Hritonenko, 2017), age, and the lifespan of the asset (Richardson *et al.,* 2011). For a firm that is considering switching from one source of power consumption to another, uncertainties in operating costs is a critical variable for consideration. This becomes more pronounced, especially when the asset, in this case, does not directly contribute to revenue generation, unlike a transport system where assets like vehicle fleet directly contribute to revenue generation. Thus, there must be a good business case to be made for the manager of the firm or the SME to consider this form of asset replacement. This means that for the switch towards another form of energy to be economically viable for a firm, then there must be significant cost savings from the replacing asset.

4.3.1 The asset replacement problem as an exchange option

In this chapter, the asset replacement problem is formulated by estimating the optimal time necessary to obtain the maximum value. Beyond investment timing, it assesses whether it is more economically viable for the SME to undertake a complete replacement of its source of power consumption or to consider a partial replacement. The real options approach to asset replacement is to analyse the value of the option to switch from an old asset to using a new asset. Real options are preferred because of their ability to include uncertainty and capture the strategic flexibility in the estimation process.

The real option provides the right but not the obligation to consider any action to defer or expand, or contract or abandon at a predetermined exercise price for a period which is the life of the option (Armada, Kryzanowski & Pereira, 2007). An exchange option provides the holder of the option the right but not the obligation to exchange an asset for another asset (Carr, 1995). The American exchange option offers such rights to the holder at any time up to the expiration of the option. For a plain vanilla call or put option, the exercise price is always fixed, whereas the value of the asset remains stochastic. For the exchange option, the real option deals with the exchange of one risky asset for another. This requires that the two variables must be treated as two different sources of uncertainty.

Consider a firm's decision to exchange asset A for asset B, with the latter performing similar or more improved functions than the former. The payoff of the exchange option can be represented as the present value of the difference between the value of using asset A and the value of using asset B. For a European option, the payoff is given as $Max(B_T - A_T, 0)$, where B_T represents the value of the asset at maturity and A_T represents the exercise price.

The switching option can be considered as one that provides the flexibility to switch from one operating asset to the other. Such a situation considers whether the flexibility obtained is worth its additional investment cost. This chapter mainly examines whether the cost savings in self-generation using renewable energy technologies merits the extra cost that is needed to invest in renewable energy technologies. However, flexibility is included in the modelling framework when the optimality criterion favours the option that allows the utilisation of both conventional and renewable sources as one that induces the highest level of savings. The ensuing section provides the model that considers the SME's decision to switch from conventional to renewable energy as a switching option.

4.4 Model for assessment

This section presents the model for estimating the overall cost of power consumption for the firm. The model considers four scenarios for the firm, based on whether the firm prefers partial transition or a complete transition. This is a hypothetical firm that requires an average annual power consumption Ckwh of power to be used for its operations and pays a tariff of GHS T per kWh of consumption. Given the annual power consumption, the SME is required to have a power capacity of E kW (where $E = \frac{C}{hours\ of\ use}$). Similarly, the firm is assumed to have already installed conventional energy, and those initial costs are sunk.

Scenario one: Business as usual

In this scenario, the SME operates with conventional power sources and relies on backup generators when there are intermittent power supplies and is considered as the baseline model for the study. The backup generator also has the capacity to generate up to Ckwh required to run the entire operation of the SME. The amount of fuel consumed depends on the length of time the generator is in operation and the capacity of the generator. Higher generator capacities have higher fuel consumption levels. Fuel consumption at any point in time is denoted as L litres per hour. If the firm operates for D hours in a year, then, generator's duration of operation can be expressed in terms of the availability of the conventional power system. The generator also pays F_t as the cost of fuel, and pays maintenance at the cost of O_t per kWh of energy generated at period t. Like the installation cost for the traditional power system, the initial investment cost for the backup generator is assumed to be included in the cost determination model for this scenario. The total cost incurred by the business for energy supply, therefore, consists of the periodic tariffs paid and the amount of fuel used for every kWh of power generated by the backup generator (G). The total cost of energy consumption for the business-as-usual scenario is given in Equation 13.

$$E(C_1) = \sum_{t=1}^{n} \frac{[\beta T_t C + (1-\beta)(DLF_t + CO_t)]}{(1+r)^t} \qquad 13$$

The left-hand side of Equation 13 describes the expected cost for energy generation given the *business-as-usual scenario.* The first part of the numerator of the equation outlines the total cost of conventional tariff. The product DLF measures the total fuel cost. The product CO_t explains the yearly operation and maintenance costs of the generator. The parameter β represents a reliability measure of the energy generated from conventional sources. It measures the percentage of time conventional power is available within a year. The backup generation is triggered when conventional power generation is unavailable. System availability is a function of the System Average Interruption Duration Index (SAIDI) and the number of hours in a year (8760 hours in a year). The parameter β is determined in Equation 14.

$$\beta = 1 - \frac{SAIDI}{8760} \qquad 14$$

Scenario two: Using renewable energy as backup power supply

Under this scenario, the renewable energy source replaces the diesel generator as the backup source for power generation. The business obtains power from conventional sources with a system reliability β and at a tariff of $GHS\ T$ per kWh at time t. The firm activates the renewable energy source when conventional power is unavailable. This scenario assumes that the renewable energy resource is always available when it is needed (i.e., back up generation has a system availability index of 1). To produce the same level of power C_t the business requires, it needs to install a renewable energy plant with a capacity of C^RkW and a capacity factor, τ, such that the product of C_t^R and τ will be at least equal to the total energy required for the firm $\left(i.e. C^R \geq \frac{C}{\tau D}\right)$. Thus, given the capacity factor, an adequate capacity of renewable energy technology must be available to meet the required consumption of C_t.

The expected cost for operating the system explained in scenario two is given in Equation 15. Equation 15 assumes that the business installs a renewable energy plant at an initial cost of I_0 and continues to pay annual operation and maintenance costs of M per kW for the renewable energy system during its utilisation period.

Further, renewable energy technology may require batteries to provide energy saving options at periods where the naturally occurring resource (sunlight, wind or other renewable energy resources) is unavailable. For instance, solar batteries store energy during periods of availability of sunlight. During periods of unavailability, the energy stored is discharged to meet the required power capacity for the firm. The needed battery capacity depends on the power requirements of the firm and the amount of time it wants the battery to be in operation without charging. Therefore, to meet a total load requirement of CkW for H hours, the firm will require a battery capacity of CH kWh, at the cost of S per kWh at time t.

$$E(C_2) = I_0 + C \sum_{t=1}^{n} \left[\frac{\beta T_t + (1-\beta)\left(\frac{M_t}{\tau D} + S_t H\right)}{(1+r)^t} \right] \qquad 15$$

For this scenario, value is established when costs for the diesel-fired backup generator is higher than the cost incurred on managing the renewable energy system. The payoff for this scenario is given in Equation 16. The left-hand side of the equation defines the value payoff for scenario two. Equation 16 generates an implicit call option that provides the holder with the right to switch from using a diesel-fired generator to a renewable energy resource for backup power generation. The strike price for this call option is the cost the firm incurs in purchasing and installing renewable energy technology. The associated payoff is the cost savings for switching from a diesel-fired backup plant to renewable energy supported back up system, which is mainly the differences in costs of fuel, costs of operating and maintaining the renewable energy resource and the initial set-up cost of the technology.

$$V = Max\left\{0, (1-\beta)\sum_{t=1}^{n}\left[\frac{(DLF_t + CO_t) - C\left(\frac{M_t}{\tau D} + S_t H\right)}{(1+r)^t}\right] - I_0\right\} \qquad 16$$

Scenario three: Using Renewable energy as primary and backup energy source

This scenario allows the firm to completely switch from conventional and diesel-fired backup plants as sources of electricity supply to a renewable source of supply. A business that demands C units of electricity must install a renewable energy resource with capacity C^R at a capacity factor of τ. This scenario completely weans the business off payments of tariffs that are required for conventional power generation. Equation 17 provides the total cost for the business in this scenario. The first part of the right-hand side explains the investment cost for the renewable energy technology, while the second expression highlights the operation and maintenance costs, as well as the costs incurred for providing storage.

$$E(C_3) = I_0 + \sum_{t=1}^{n} \left[\frac{\frac{M_t}{\tau D} + S_t H}{(1+r)^t} \right] \qquad 17$$

Value is established when the difference between the total present value of costs incurred with a conventional energy system (Scenario 1), and installation and operation costs of renewable energy (scenario 3) returns a positive value (as expressed in Equation 18). This also generates an implicit call option where the holder has the right to invest in renewable energy at a cost of I_0 and receive payments in the form of cost savings reflecting switching from conventional energy sources to renewable energy sources (see Equation 18).

$$V_2 = Max \left\{ 0, \sum_{t=1}^{n} \left[\frac{[\beta T_t C + (1-\beta)(DLF_t + CO_t)] - C\left(\frac{M_t}{\tau D} + S_t H\right)}{(1+r)^t} \right] - I_0 \right\} \qquad 18$$

Scenario Four: A mix of renewable and conventional energy resources

The business may not have the capital to invest in a renewable energy source to meet its required energy needs. This allows for it to have an electricity supply system that comprises a mix of conventional and renewable energy sources. We denote α (where $0 < \alpha < 1$) to be the proportion of electrical system to be supported by renewable energy technology. Renewable energy technology shall supply αC amount of energy with the remaining $(1-\alpha)C$ to be provided by conventional power, with system availability of β. In the case where the conventional power system fails, the SME shall fall on diesel generators for energy provision. This study assumes that the SME is already in business, with its premises already constructed, and as a result, the installation cost for conventional power generation is already sunk. The present value of the total cost for this scenario is given in Equation 19:

$$E(C_4) = I_0 + \sum_{t=1}^{n} \left[\frac{\alpha(C^R M_t + S_t C) + \beta(1-\alpha)CT_t + (1-\beta)(1-\alpha)(DLF_t + CO_t)}{(1+r)^t} \right] \qquad 19$$

The payoff of the implicit call option which is generated for this scenario is presented in Eq. 20:

$$V_3 = Max \left\{ 0, \alpha \sum_{t=1}^{n} \left[\frac{\beta CT_t + (1-\beta)(DLF_t + CO_t) - (M_t C^R + S_t C)}{(1+r)^t} \right] - I_0 \right\} \qquad 20$$

4.4.1 Valuing the American exchange option

There have been several models developed to value exchange options. One of the pioneers of exchange options valuation is arguably the work by Margrabe (1978). Margrabe (1978) extended the Black Scholes valuation of call options to value European exchange options. However, while the model is valid for European options, it was unrealistic in favouring early exercise options. Macdonald and Siegel (1986) valued American exchange options by extending the Black-Scholes formula for valuing European options. The authors considered the exercise price and the value of the asset as stochastic variables and further assumed that the maturity period of the option is infinite. Carr (1995) extended the Geske-Johnson model of evaluating American put options to value American exchange options. For an American exchange option with maturity period T, Carr (1995) proceeded by dividing T into n equal time intervals where each time interval represents a pseudo-American exchange option with time to maturity τ (where $\tau = T/n$).

There have been other numerical methods for the valuation of American options, including finite differences as well as binomial and trinomial lattice approaches. However, the complexities of the project value functions in the call option payoff elicit several uncertain factors which cannot be well handled by these numerical solutions. Simulation approaches could value early exercise options and for state variables that exhibit general stochastic and non-stochastic processes (Longstaff& Schwartz, 2001). This study employs the Least Squares Monte Carlo (LSMC) approach by Longstaff and Schwartz (2001).

Typically, the holder of an American option decides whether to exercise immediately or delay investment by comparing the payoffs from both outcomes. The payoff for delaying (also known as the continuation value) is identified as an expected value which is conditioned on the investor holding on to the option. According to Longstaff and Shawartz (2001), the expected continuation value can be obtained by least-squares regression of the payoffs realised from the continuation on a set of basis functions on the prices of the underlying asset. Beyond its ability to compute American options values more accurately, the LSMC approach can be extended to other real-valued problems with multiple options and uncertainties (Zhang, Zhou & Zhou, 2016; Longstaff & Schwartz, 2001). The steps for the solution are provided below, sourced from Jia (2009) and Zhang *et al.* (2016).

Given an option with an expiry period of T, the interval $[0, T]$ is divided into N equal time intervals with the value $dt = T/N$, where dt is the length of each subinterval. For each time step, a simulation of K paths is done according to a specified probability distribution. This results in K paths of $N + 1$ discrete decision points. At the final observation date for path j, we obtain $F_{n+1,j}$ which is the payoff, at time $n + 1$ (See Equation 21).

$$F_{n+1,j} = Max(V_{n+1,j}, 0) \quad (21)$$

To obtain the continuation value at time n, we set $X_j = V_{n,j}$, the asset value at time n and $Y_j = e^{-rdt}(F_{n+1,j})$. The continuation value is then obtained by regressing Y on a polynomial combination in X (i.e. $X, X^2, X^3 \ldots, X^m$), for small m. For each path, $\widehat{Y_j}$ is computed by fitting the regression model for the values of the independent variables. We decide if it is better to exercise immediately or delay by comparing the continuation value $\widehat{Y_j}$ with value $F_{n+1,j}$.

$$F_{n,j} = Max\left(F_{n+1,j}, \widehat{Y_j}\right) \tag{22}$$

The recursive procedure continues by performing a rolling back process until all time steps are exhausted. For each simulated path, we also obtain the value average value. The optimal time for investment is obtained by determining the value n that provides the least upper bound for which $V_{n,j} \geq e^{-rdt}(F_{n+1,j})$.

4.5 Empirical study

The primary purpose of the empirical study is to analyse the value for SMEs to switch from conventional energy to renewable energy using the model as described in the previous section. The empirical study considers four main groups of SMEs categorised based on their extent of power consumption (See Table 4.1). The analysis also assumes that SMEs operate for an average of eight hours per day, for six days a week.

Table 4. 1: SME power consumption bands for empirical study

SME	Max power consumption per year (kWh)	Power capacity (kW)
SME A	25,029	10
SME B	62,571	20
SME C	125,143	50
SME D	375,429	100

Source: Author's Construct (2021)

4.5.1 Input parameters for valuation

Investment and fuel costs for backup generator

Generators provide backup power when conventional power is unavailable. For each of the SME categories, the study considers the procurement of diesel generators with capacities that meet the maximum energy requirements of the business. The average costs of diesel generators were obtained from various companies that provide backup generator services. Based on the average costs, we estimated the cost per kWh for each generator. The fuel consumption for a backup generator depends mainly on the capacity of the generator. Fuel consumptions for generators within the consumption bands range between 2.4 litres per hour to about 36 litres per hour. The average prices of diesel per litre were obtained from the Chamber of Bulk Oil Distributors (CBOD). Currently, Ghana operates in a deregulated market. As a result, fuel prices are determined primarily based on global prices of fuel and the strength of the Ghanaian Cedi against the dollar.

Tariff for conventional power supply

The Public Utilities Regulatory Commission (PURC) is responsible for the determination of tariffs in Ghana. The electricity tariffs are reviewed quarterly based on an adjusted formula that reflects the costs of power generation, transmission and distribution. Electricity tariffs in Ghana are also based on the amount of power usage. For instance, if a consumer utilises about 600kwh of power in a month, the person pays about GHS 0.79 (14.1 US cents) per kWh for the first 300kWh and GHS 0.84 (15 cents) per kWh for consumptions beyond 300kWh. In this study, we apply the most recent tariff adjustment made by PURC as of the end of 2020. The drift and volatility rates are also calculated for the tariffs.

Investment and operation, and maintenance costs for renewable energy

With improved technology and the growth of renewable energy capacities, global prices of renewable energy systems have reduced significantly. Between 2010 and 2019, costs of solar PVs have decreased from about $4700 per kW to about $995 per kW. Similarly, operation and maintenance cost for solar PVs range has reduced from $24.4 per kW per to about $9.5 per kW (IRENA, 2020). Prices for renewable energy installation costs were obtained from the IRENA renewable energy cost database.

System availability and capacity factors for conventional and renewable energy

Electricity systems are generally not available 100% of the time. Ghana's conventional electricity system reliability is measured by the System Average Interruption Duration Index (SAIDI) and the System Average Interruption Frequency Index (SAIFI). SAIDI and SAIFI respectively measure the average duration of power interruptions and the average number of power interruptions within a period, usually in a year. We obtained SAIDI and SAIFI estimates from Energy Commission to aid in the determination of the system reliability for conventional power generation.

The Capacity factors of solar PVs determine the actual output from installed solar technologies. The International Renewable Energy Agency (IRENA) estimates that the capacity factor for solar PVs in Ghana is about 19.5% (IRENA, 2018). This, however, depends largely on the quality of solar PV. The base values for all the indicators are given in Table 4.2.

Table 4. 2: Base values for inputs for valuation

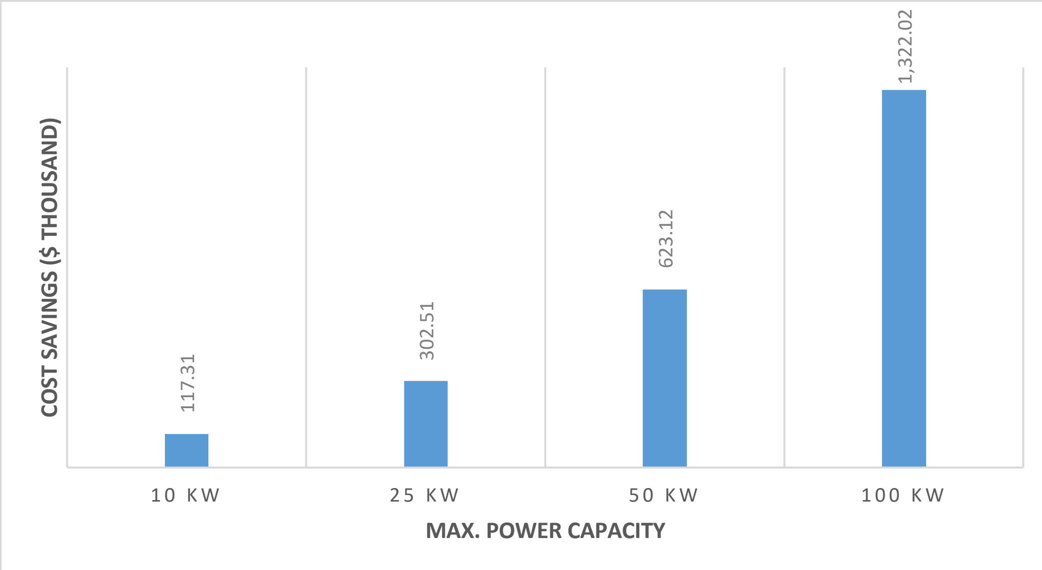
Symbol	Name/ Description	Source	Base value
H	Fuel consumption for backup generator	Various generator manufacturers	Between 2.4 litres per hour to 36 litres per hour, depending on the capacity of the plant
F_t	Fuel cost per kWh of power generated from backup the generator	CBOD petroleum price outlook (2020)	GHS 4.91 per litre in 2020
α_f	Drift rate of fuel price	Historical data of fuel prices in Ghana	0.01
σ_f	Volatility rate of fuel price	Historical data of fuel prices in Ghana	0.1
T_t	Current electricity tariffs per kwh	PURC tariff guide (2021)	0 – 300 kwh: 14.1 US cents 301-600 kwh:15 US cents > 600kwh: 23.7 US cents
α_t	Drift rate of tariffs	Historical data of electricity tariffs	0.14
σ_t	Volatility rate of tariffs	Historical data of electricity tariffs	0.25
I_0	The investment cost for renewable energy system	IRENA renewable cost database	$ 994.7/kw
α_r	Drift rate of renewable energy investment cost	Historical data of RE costs	-0.17
σ_r	Volatility rate of renewable energy investment cost	Historical data of RE costs	0.07
M_t	Annual operating and maintenance cost for renewable energy system	IRENA renewable cost database	$9/kw
β	System availability: stochastic variable that will be varied according to a specified distribution	Energy commission (SAIDI and SAIFI)	99%
τ_i	The capacity factor for renewable energy source	IRENA renewable cost database	19.5%
r	Discount rate	African Renewable Energy Access Program (World Bank)	10% (WACC for non-OECD countries)
	Base year		2020

4.5.2 Results

This section provides the option value and the optimal investment timing for the various scenarios for the SME categories identified. The option value in this regard refers to the potential cost savings for the SME for switching from conventional to renewable energy resources. The optimal investment timing, on the other hand, refers to the time where it will be most profitable (or most cost-saving) for the SME to make this switch. Table 4.3 provides the results under the various scenarios and SME categories grouped under their energy consumption bands. In addition to the option value, we determine what we term the *savings to cost ratio.* This is the ratio of the option value to the initial investment costs.

Scenario one represents the baseline scenario where the SME relies on conventional sources for its primary power supply and diesel generator for backup power supply. Under this *business-as-usual* scenario, SMEs under consumption band A (with at most 10kw capacity) will have an expected cost of about $117 thousand within the 25-year period. This will increase to about $287 thousand, $429 million and $1.25 million for the SMEs with maximum capacities of 25kw, 50kw and 100kw, respectively (See Figure 4.1). Scenarios two to four present cases where the firm introduces renewable energy to the power supply mix in varying fashions to determine the extent of cost savings.

Figure 4. 1: Expected costs under scenario one



Source: Author's Construct (2021)

Results from scenario two shows that there are no significant cost savings for introducing renewable energy as a backup source of power generation. Given an investment of about $46 thousand for an effective solar PV that provides about 29.2Mwh of power annually, the value of costs savings is just about 42 cents which represent less than 0.001% of the investment cost. This is the similar for the other SMEs with high maximum consumption bands of 25kW, 50kW and 100kW. Further, the traditional discounted cash flow valuation for all the SME consumption bands yields negative net present values. This pushes the optimal investment timing to about 21 years for SMEs with a maximum capacity of 10kw and about 20 years for SMEs with a maximum capacity of 100kW. Results from scenario two thus indicate that the SME shall not obtain substantial cost savings in the short to medium term when diesel-fired backup generators are replaced by solar panels. Basically, this asserts that the cost savings in terms of replacing diesel-fired generators with renewable energy technologies do not readily absorb the high investment cost required in this regard, and it requires that SMEs delay investment for an average of about 20 years if it wants to consider renewable energy technologies to replace diesel-fired generators for backup power generation.

Scenario three considers a complete transition, where renewable energy resources completely replace conventional power and diesel-fired generators. This scenario weans the SME of electricity tariffs and the procurement of fuel for the backup generator and its associated operation and maintenance costs. The only costs applicable to the SME are the operation and maintenance costs as well as the battery replacement costs over the life of the solar PV. The SME with about 10kw power capacity obtains an option value of about $54 thousand, which gives a cost savings percentage of about 116% over the life of the technology. SMEs with higher capacities obviously obtain significantly higher cost savings. SMEs with a maximum power consumption of 25 kW, 50 kW and 100 kW experience cost savings of about $144 thousand, $305 thousand and $695 thousand, respectively, over the life of the PV. The results also show that increasing power capacity is associated with increasing capacity cost savings percentage. It is worth noting that the option for a complete transition from conventional to renewable energy favours an immediate exercise of the option.

The fourth scenario considered a partial transition from conventional to renewable energy. This level of transition recognised the high investment costs required for a complete switch to renewable energy technologies. The starting point of this was to assume a 50-50 mix of conventional and renewable energy. The results show significant cost savings, although the magnitude of cost savings is comparatively higher under scenario three. However, the ratio of cost savings to the investment cost is higher for each of the SME consumption bands in scenario three compared with that of scenario two. This is because of the reduced costs of investment required for the transition. Lower representation of renewable energy in the power supply can lead to reduced investment cost for renewable energy. However, this does not necessarily translate into higher cost savings in relation to the investment costs.

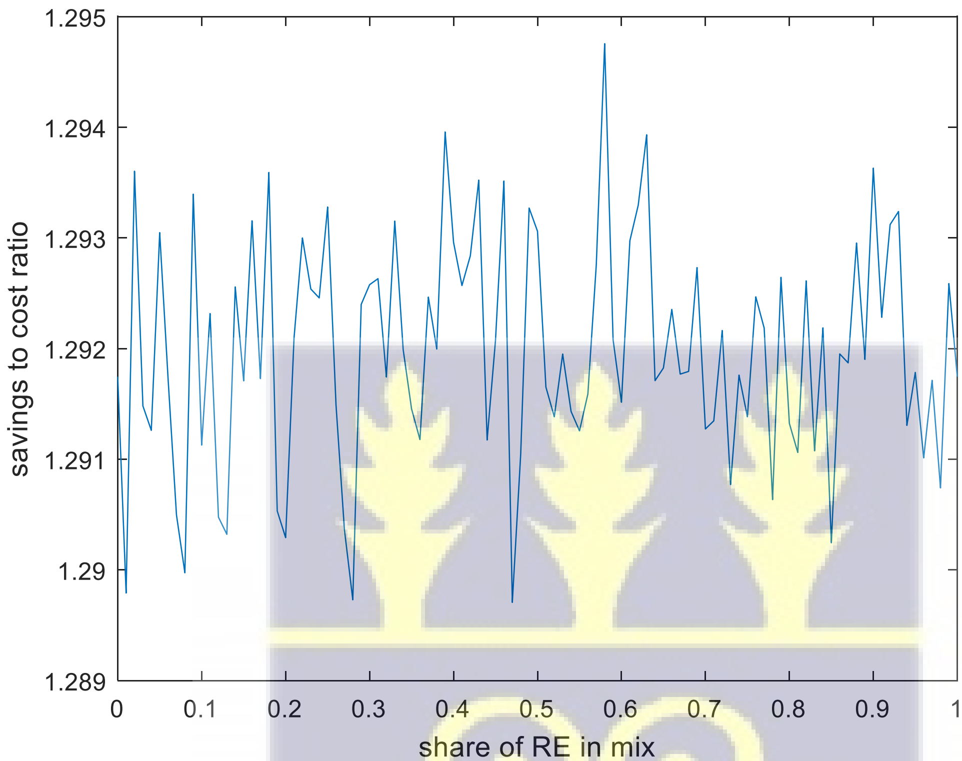
Table 4. 3: Option values and investment timing for identified scenarios

	Option value	Investment cost	Savings to cost ratio	Investment timing (years)
Scenario two				
10 kw	0.43	46,366.19	0.00%	21.28
25 kw	0.96	115,915.47	0.00%	21.1
50 kw	2.20	231,830.93	0.00%	20.65
100 kw	6.04	463,661.87	0.00%	20.23
Scenario three				
10 kw	54,054.38	46,366.19	116.60%	Immediate
25 kw	144,033.10	115,915.47	124.30%	Immediate
50 kw	305,638.97	231,830.93	131.80%	Immediate
100 kw	684,336.50	463,661.87	147.60%	Immediate
Scenario four				
10 kw	28,173.74	23,183.09	121.50%	Immediate
25 kw	74,892.18	57,957.73	129.20%	Immediate
50 kw	158,542.83	115,915.47	136.80%	Immediate
100 kw	353,684.72	231,830.93	152.60%	Immediate

Source: Author's Construct (2021)

To determine the proportion of renewable energy in the mix, which will maximise the savings to cost ratio (scenario three), the option was evaluated under several representations from 0% of renewable to 100% of renewable energy at a given interval of 1%. The results do not show an increasing or a decreasing pattern of the cost savings ratio, as shown in Figure 4.2. Figure 4.2, however, shows that for a 25kw capacity, the cost savings ratio peaked at an energy mix that has a renewable energy representation of about 58 per cent. These peaks, however, change at different runs of the model, given the inherent volatilities in the estimation. Obtaining the most optimal level of mix will depend on several constraints faced by the firm, including budget constraints, firm size, and energy capacity, among others. Optimisation techniques such as linear programming methods are required to determine the optimal mix that minimises the cost of power consumption for the SME. This will be the focus of the next chapter.

Figure 4. 2: Option values for scenario 4 under different shares of RE in energy mix



Source: Author's Construct (2021)

4.5.3 Sensitivity analysis

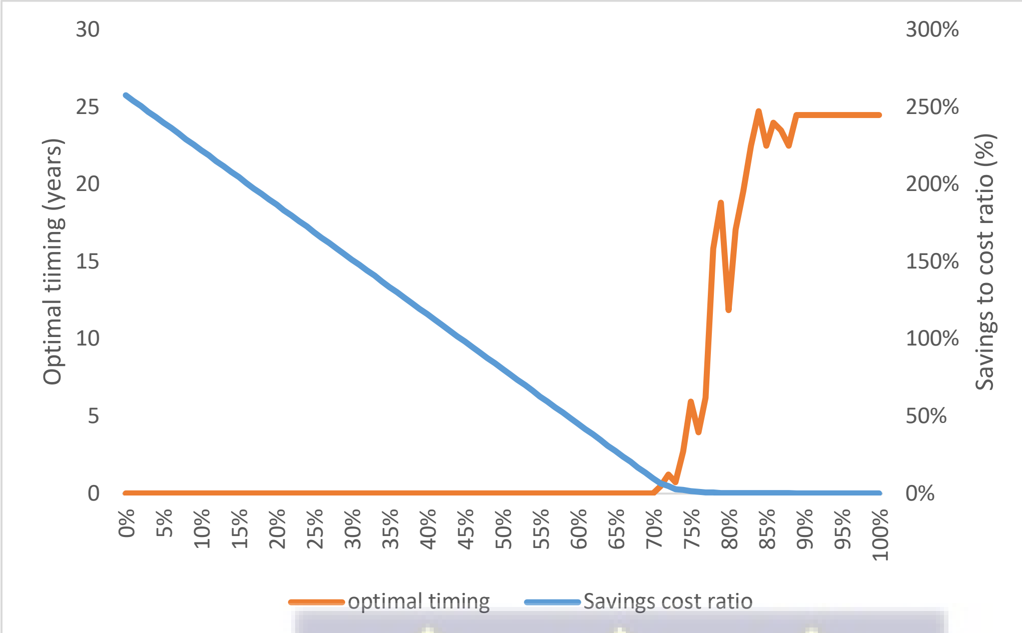
The value of cost savings (described as the option value) is affected by many factors. This section examines the changes in the option value as well as the optimal investment timing given changes in some input factors. For the sensitivity analysis, we consider four factors in total; two of which relate to conventional power utilisation and the remaining two, which pertains to renewable energy generation. These input factors are conventional system availability, conventional electricity tariffs, investment cost for renewable energy technologies and the capacity factor of renewable energy technology. Scenarios two and three are used to carry out the sensitivity analyses.

Changes in system availability

Generally, a more reliable conventional energy system favours the use of conventional energy hence reducing the value of cost savings in scenarios two and three. For scenario two, increasing the system availability reduces the savings to cost ratio. When the conventional system availability is about 70% or less, the investment decision in scenario two favours immediate investment within an increasing savings to cost ratio. However, this is quite impracticable, especially for the Ghanaian conventional electricity system. Generally, system availability of 70% or less means that within a year, the SME or a power consumer suffers from power outages for about two and a half months, which is quite impracticable for a regular functioning conventional energy system. The results also depict that it is advisable to delay investments for back up renewable energy systems when conventional or traditional energy systems have higher system availabilities. Back up generation is triggered only when conventional power is not available. This means that for a period where conventional power is reliable, massive investment in renewable energy resources as backup power will not be cost-efficient (See Figure 4.3).

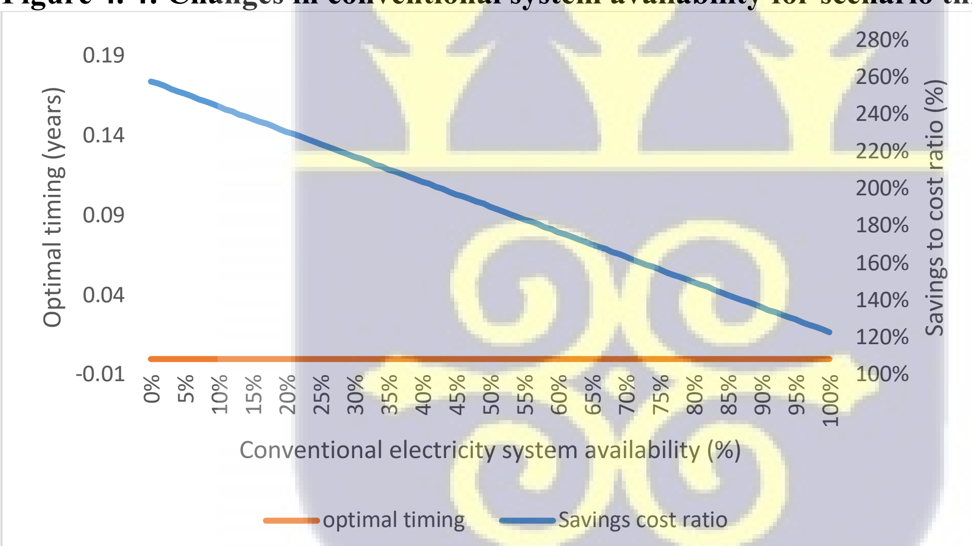
In scenario three, increasing system availability tend to reduce the savings to cost ratio. However, unlike scenario two, scenario three favours immediate investment for every value of the conventional energy's system availability. The savings to cost ratio is significantly high at over 100%, even for a fully reliable conventional energy system. Thus, although improving the system availability of conventional systems has the potential to reduce the value of cost savings, it is unable to offset the impact of substantial cost savings arising from the non-payment of tariffs (See Figure 4.4).

Figure 4. 3: Changes in conventional system availability for scenario 2



Source: Author's Construct (2021)

Figure 4. 4: Changes in conventional system availability for scenario three



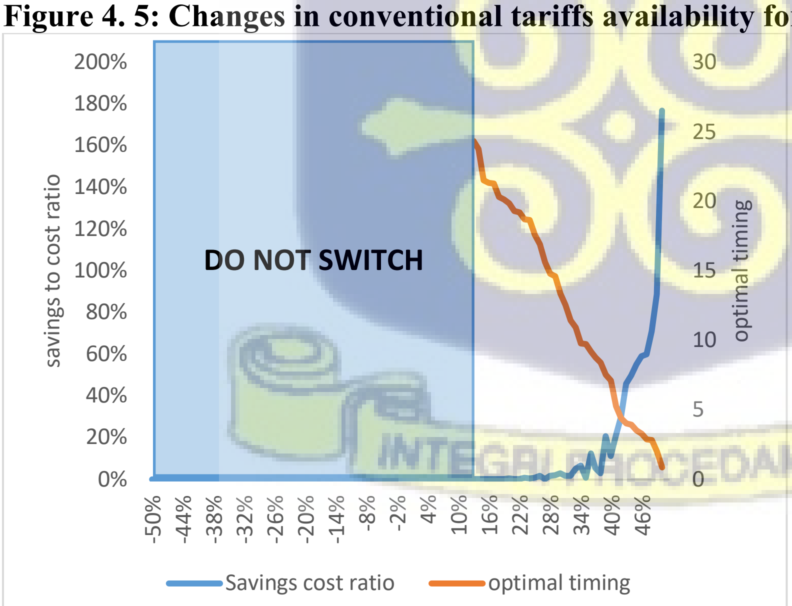
Source: Author's Construct (2021)

Changes in electricity tariffs

The results show that savings to cost ratios and optimal investment timing are highly sensitive to changes in conventional energy tariffs. Investment in renewable energy generation is highly favoured when there is an increase in conventional electricity tariffs. For scenario two, it suggests investment in renewable energy as backup is beneficial only when current tariffs increase at an annual rate beyond 10%. Therefore, it is not advisable for SMEs to use renewable energy sources as backup sources when the rate of increase of electricity tariffs is less than 10%. However, in instances where a switch to renewable energy becomes profitable, immediate investment is not a preferred option. Immediate investment is only preferable when tariffs increase at an annual rate above 46% (See Figure 4.5).

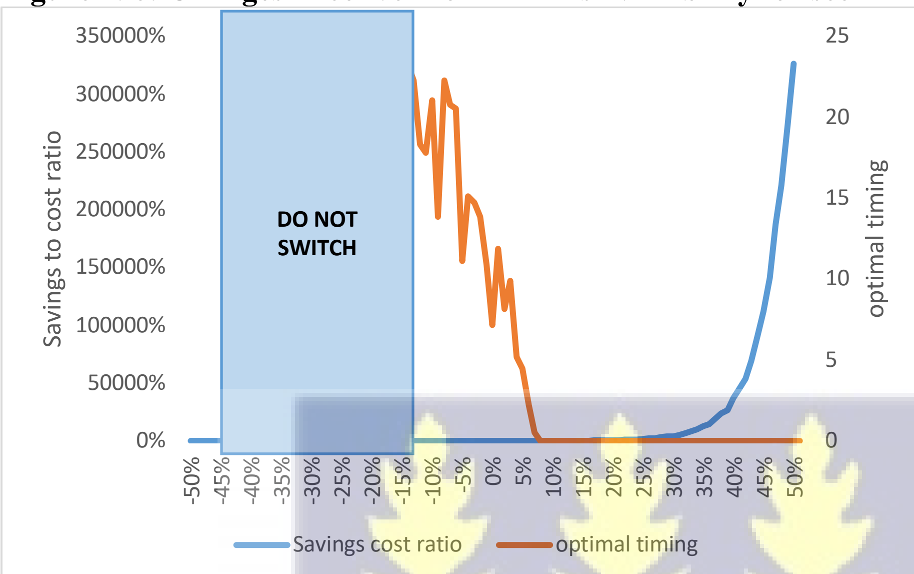
For scenario three, the model favours investment in renewable energy even when conventional energy tariffs are reducing. For instance, at an annual reduction rate of about 15%, the model indicates that investment in renewable energy can yield substantial savings to cost ratios. However, this reduction rate would require that investment is delayed for at least 22 years. Immediate investment is permitted when there is a minimum annual rate of change of electricity tariffs of about 5% (see Figure 4.6).

Figure 4. 5: Changes in conventional tariffs availability for scenario one



Source: Author's Construct (2021)

Figure 4. 6: Changes in conventional tariffs availability for scenario three



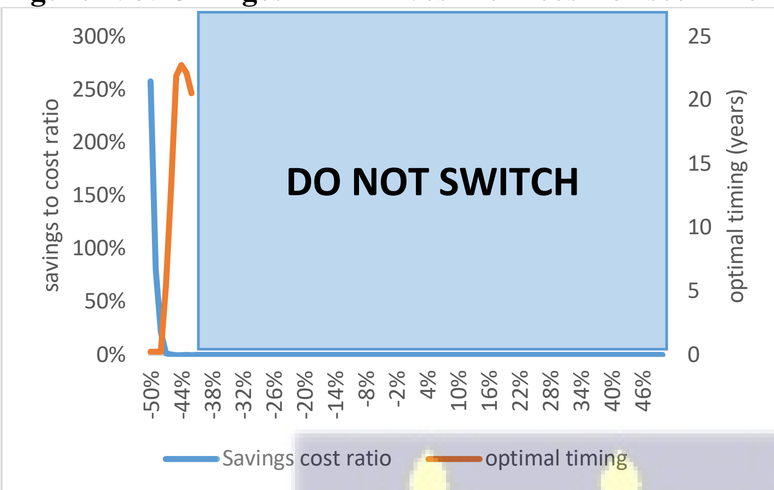
Source: Author's Construct (2021)

Changes in investment cost for RE

Generally, the costs of purchasing and installing renewable energy technologies are falling. This fall in price encourages investment in renewable energy technologies. However, the fall in investment costs does not substantially justify an instantaneous investment in renewable energy as a backup source. The model justifies immediate investment in renewable energy as backup sources when the annual rate of reduction investment cost is beyond 50%, giving savings to cost ratio of about 250% (see Figure 4.7).

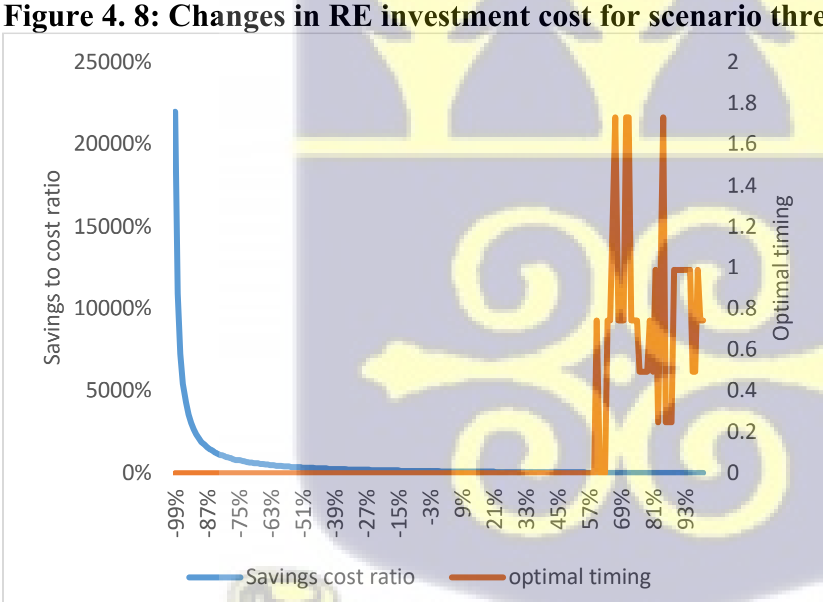
Under scenario three, increasing costs for renewable energy technologies reduce the savings to cost ratio for the SME. The business obtains significant cost savings even when renewable energy investments grow at a rate of 100% yearly, although it is advisable to delay investments at points where the rate of increase is high. Beyond an annual increment of 61%, optimal investment timing toggles between waiting for about one to two years (see Figure 4.8).

Figure 4. 7: Changes in RE investment cost for scenario one



Source: Author's Construct (2021)

Figure 4. 8: Changes in RE investment cost for scenario three



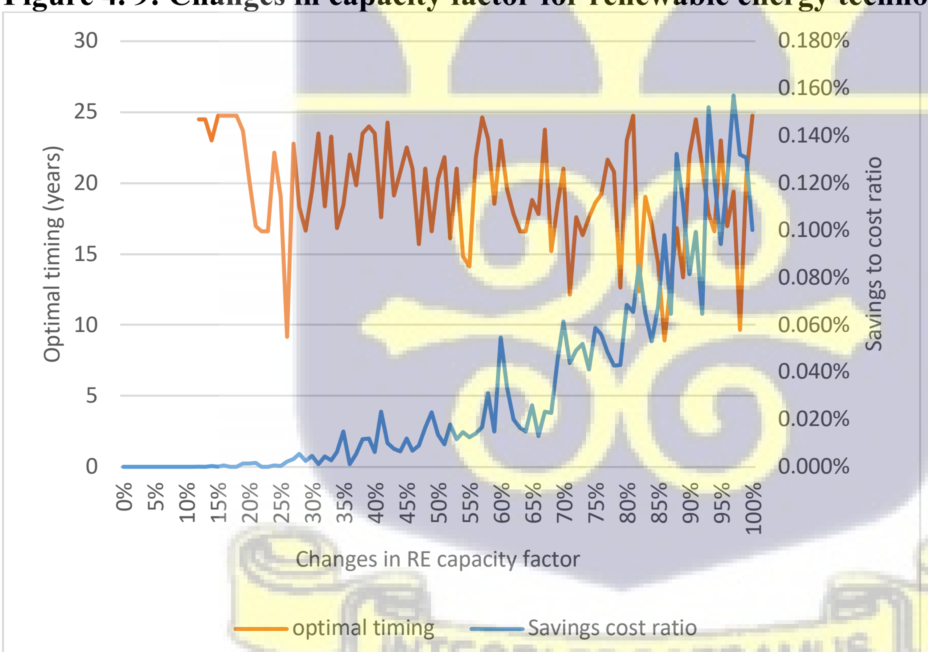
Source: Author's Construct (2021)

Changes in capacity factor for renewable energy

Improvements in the capacity factors for renewable energy increases the savings to cost ratio marginally for scenario two as shown in Figure 4.9. However, this does not significantly reduce the waiting period for switching to using renewable energy as a backup resource. Thus, immediate investment for using renewable energy as backup is not justified irrespective of the improvement in capacity factors.

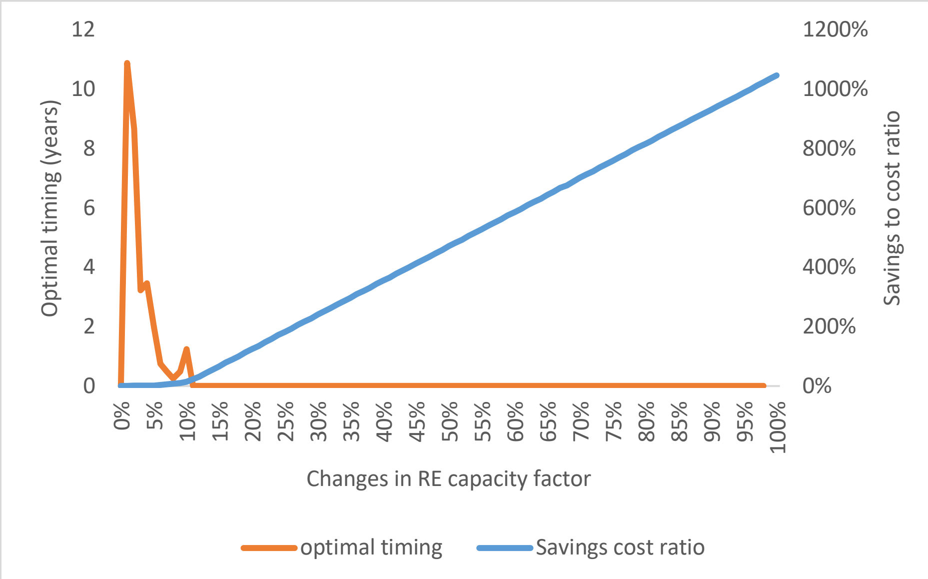
For scenario three, it is not advisable for the SME to consider an immediate complete switch from conventional to renewable energy when renewable energy capacity factors are low. Immediate investment becomes more pronounced, however, when capacity factors of renewable energy technologies increase beyond 10% as shown in Figure 4.10. Currently, the capacity factors of solar energy technologies range between 20 to 30%. Current improvements in renewable energy technologies present a higher likelihood of renewable energy technologies with higher capacity factors.

Figure 4. 9: Changes in capacity factor for renewable energy technologies (scenario two)



Source: Author's Construct (2021)

Figure 4. 10: Changes in capacity factor for renewable energy technologies (scenario three)



Source: Author's Construct (2021)

4.6 Discussions and conclusions

Renewable energy investment is advantageous mainly for economic and environmental reasons. Technological advancement has increased the reliability and the stability of supply, reducing incidences of lower voltages and erratic supply of power. These make switching to renewable energy a cost-saving venture for SMEs. However, the mode of switching to renewable energy generation is essential for an SME whose objective is to maximise the gains in terms of cost savings.

This study makes a business case for renewable energy adoption by SMEs by developing a real options model which evaluates renewable energy investments in Ghana. The study considers uncertainties in electricity tariffs, future renewable energy investment costs as main economic factors that can drive renewable energy investments among SMEs. It also finds other technological factors such as the capacity factor for renewable energy technologies as well as system availabilities of conventional power generation as essential areas of consideration for renewable energy investments. The study analyses investment decisions of SMEs based on three main scenarios. The first scenario considers the case where renewable energy is used as a backup resource. The second scenario examines the situation where the SME completely switches completely from conventional to renewable energy while the third scenario considers a partial switch from conventional energy to renewable energy.

One of the issues of renewable energy generation is the high investment costs required for its installation. Although these costs have reduced significantly, it continues to be an inhibiting factor for renewable energy generation among SMEs in developing countries. These increasing costs, however, are absorbed by the cost savings in terms of the non-payment of electricity tariffs if the business reduced its reliance on grid-connected electricity generation. Thus, the economic gains of renewable energy generation are more profound in areas with high electricity tariff regimes. Investment in renewable energy technologies must therefore be made with the mindset of reducing the payment of conventional electricity tariffs from grid-connected electricity generation.

Generally, the results justify investments in renewable energy technologies by SMEs. Thus, SMEs there is a value for SMEs to switch from conventional power to renewable energy technologies. However, the SME must consider the form the switching would take. For example, the results of the study show that using renewable energy as back up generation does not provide significant reduction in electricity tariffs. At high system availabilities of conventional energy technologies, the likelihood of generating significant cost savings resulting from replacing diesel-fired backup generators with the renewable energy technologies is lower.

On the other hand, A complete or partial transition to renewable energy resources, however, provide significant cost savings to the SME. Unlike the situation with using renewable energy technologies for backup supply, a complete transition to renewable energy technologies guarantees that the SME is weaned from tariff payments. It is important to note that this, however, arises with a significant initial investment, which the SME may not have the financial muscle to raise. This explains the need for an incremental or partial switch to renewable energy where the technology powers a portion of the firm's operations, and the remaining power is supplied by conventional energy technologies. In addition to an outright purchase of renewable energy technologies, there are other payment options that are available to SMEs for. For instance, lease to own and power purchase agreement options provide the incentive for the supplier of the RE technology to invest on behalf of the SME while periodic payments are made to amortise the investments of the supplier of the resource.

The results align with what Fridgen et al. (2018) noted, that the deployment of PV units leads to reductions in electricity tariffs. However, it is essential to note that generating significant cost savings occurs only with a substantial initial investment. One of the barriers to renewable energy generation is the high investment costs required for its installation. Although these first investment costs have dropped significantly, they continue to inhibit investment in renewable energy generation among SMEs in developing countries. SMEs may not have the financial muscle to meet these investment requirements. Thus, there is a need for such businesses to have integration options that also meet their financial capabilities. This explains the need for an incremental or partial switch to renewable energy. Thus, the renewable energy powers a portion of a firm’s operations, and conventional energy technologies supply the remaining share of power. Key financing modalities for SMEs are considered in the next chapter of this thesis.

In addition to an outright purchase of renewable energy technologies, other payment options are available to SMEs for this choice. For instance, some suppliers of renewable energy technologies in Ghana provide lease to own and power purchase agreement options. These options allow the SME to make periodic payments to amortise the installation costs over a period (ACEP, 2021).

The real options model can be used for economic or financial valuation in several disciplines. A generalisation of these results for other contexts is possible if the correct values are used to describe the various parameters. However, it is critical to assess whether the parameters properly reflect the context within which this model will be applied.

The main limitation of this study is its inability to determine the optimal mix of conventional and renewable energy generated power that will seek to maximise the ratio of cost savings to the investment cost for SMEs. This is resolved in the next chapter as it explores an approach to dealing with an optimal mix of renewable and conventional energy generation systems in the face of constraints such as budget requirements and capacity levels.

CHAPTER FIVE

STUDY THREE: CAPACITY PLANNING AND USING TARIFF SAVINGS TO FINANCE CAPITAL INVESTMENTS FOR RENEWABLE ENERGY PROJECTS: AN ALTERNATIVE FOR SMES

Abstract

Energy capacity planning is essential to ensure adequate or continual supply of electricity and has been practised among utilities and large-scale power-intensive companies. However, the contribution of SMEs to economic growth and their inherent challenges in obtaining affordable and reliable supply makes capacity planning an important consideration for them. This chapter develops a linear programming model to understand long term capacity expansion plans for SMEs, taking into consideration the optimal mix for renewable energy penetration using capacity and budget constraints. The chapter mainly focuses on the ability of the SME to finance these projects using debt financing. The results of the model evaluation indicate that notwithstanding the high lending rates, SMEs can make some minimal integration of renewable energy technologies in addition to their conventional power generation sources. Also, as firms are more constrained financially, renewable energy investments can be made possible without storage capacities, compared to situations where enough funds are available.

5.1 Introduction

Energy capacity planning is essential for ensuring an adequate supply of electricity to meet demand. Capacity planning, or generation expansion plans, focuses on what energy is required, when needed, and where it could be generated (Ramkumar & Rajesh, 2021). It is an approach to assess energy needs and to determine the required levels of investment. For example, utility companies periodically assess generation capacities to identify the optimal mix for the varying energy sources that can meet the energy demands of their customers. These assessments require that future energy demand is accurately forecasted to avoid the incidence of generating excess over the required generation or shortage in supply.

Similarly, energy-intensive industries such as the mines and refineries also plan their energy needs in anticipation of dynamics in supply, environmental concerns, and the cost of energy supply. (Igogo *et al.,* 2021). Typically, one overarching objective for these firms is to meet energy demand or supply while minimising the total costs (Ferrari, 2021).

Much as capacity planning is relevant for utility companies and other large-scale firms, its importance for Small and Medium Scale Enterprises cannot be overemphasised. SMEs contribute immensely to national development (Abor & Quartey, 2010; Amoah & Amoah, 2018), and this contribution suggests that their challenge to the reliability and affordability of power supply (ACEP, 2021) must be curtailed in any way possible to ensure productivity. SMEs must be able to plan generation in a way that meets their long-term energy demands and anticipation for business expansion. Further, SMEs must opt for generation sources that are economical, reliable, and environmentally friendly.

Literature has largely documented the socioeconomic and environmental benefits of renewable energy integration. These include the ability to meet energy demand, ensure energy diversification (Gil *et al*., 2021) and the provision of a cost-saving mechanism (Suberu *et al.,* 2013). Thus, the benefit of renewable energy technologies goes beyond environmental connotations to include economic benefits. Therefore, the emphasis on the economic benefits of self-generation through renewable energy penetration is vital for any renewable energy supplier or advocate for climate change and energy transition.

SMEs in Ghana generally rely on conventional power generation sources, where they are primarily connected to the national grid. The primary option for self-generation is diesel-fired generators which are used mainly as backup sources for power generation. For SMEs to reap the benefits of energy transition, consideration must be made to allow for either a hybrid connection with grid-connected systems or a complete transition to renewable energy technologies. However, while it is essential to stress the need for renewable energy penetration among small businesses, ensuring that available investment capacity exists to afford the transition must be a pivotal point to consider.

Given the capital-intensive nature of renewable energy investments (Narbel, 2013; D'Orazio & Popoyan, 2019), SMEs must have a plan that enables them to make the necessary investments seamlessly. The investment plan must examine the respective sources of financing and the ability to secure funding. However, the main challenge for SMEs is access to funds (Abraham & Schmukler, 2017; Nguyen, Nguyen, Dang, & Nguyen, 2019), which creates a barrier for them to take advantage of the opportunities that renewable energy integration offers. Therefore, accessing finance to fund such investments is necessary for SME development. There are various sources of financing, and firms would typically opt for one that provides the least cost of debt. However, the actual cost of financing depends on many factors which are not within the control of the SME. These uncontrollable factors suggest that SMEs would have to adjust to the terms of financial institutions while maintaining an appreciable investment capacity with the least cost of financing within the long term.

As already indicated, capacity planning is important at both micro and macro levels. Afful-Dadzie, Mallet & Afful-Dadzie (2020) examined the influence of unmet demand and costs of energy generation on decision to invest in renewable energy generation in the Global South, using Ghana as a case study. The study indicates that these constraints do not allow countries in the Global South to meet their targets for renewable energy generation. Kemausour & Ackon (2017) examined the importance of using distributed generation systems such as community mini-grid and off-grid renewable energy technologies as efficient means to advance Ghana's target of national electrification. Gadzanku (2019) also examined Ghana's power systems to identify optimal approaches for effective generation planning. While these studies are important for the country's generation planning, the focus on generation planning among SMEs in response to unreliable power supply requires additional attention. Research on capacity expansion at the firm level, particularly SMEs, have not been given the required prominence. However, given SMEs' importance to economic growth, they need to identify their capacity needs and provide approaches to financing investments into renewable energy technologies to reap similar benefits.

This chapter presents a model that determines the optimal renewable energy capacity for an SME that minimises its net present cost of energy generation. The study contributes to literature in the following ways: first it provides an optimal generation mix for SMEs that minimises cost by considering capacity and budget constraints; second, it offers an approach to financing that minimises the SMEs exposure to use funds meant for business expansion or its operations; lastly, the capacity planning model introduces a budget constraint that restricts payments to allow for cost savings to be used to plan the amortisation of loans from financial institutions..

This chapter is categorised into five sections. The second section reviews the concept of capacity expansion and the means of financing such capacity expansion projects. The third section highlights the model used in meeting the objective for the study. Finally, an assessment of the model is done with a case study outlined in section four, while the study's conclusions are presented in section five.

5.2 The concept of capacity planning and financing capacity planning projects

The goal of capacity planning or Generation Expansion Plans (GEP) is to schedule the design and construction of new power plants which satisfy certain technical requirements, costs, and environmental conditions (Careri et al., 2011). Generation expansion plans are designed for strategic reasons, primarily for planning investments in power capacities for the medium to long term. This planning horizon could be as short as a day or last for decades (Pereira, Ferreira & Vaz, 2017).

A Generation Expansion Plan (GEP) is a useful decision-making model which determines the power needs and assesses the combination of energy sources that can meet power demand. Such a plan can also be used to determine the optimal time and appropriate location for investments, given resource constraints. The geographical location for power generation is particularly essential for sources largely dependent on renewable energy resources such as sunlight and wind. These plans can be complex as demand and potential generation sources increase and therefore require effective coordination between system planning and the actual implementation to ensure optimum outcomes. Capacity planning is not only ideal for increasing system capacities. Instead, it is an integrated mechanism that determines an optimal allocation of generation sources within a power system, whether renewable or non-renewable.

Uncertainties characterise generation expansion problems. Traditionally, these uncertainties are associated with demand, fuel availability, cost of energy generation (fuel costs, capital costs, labour costs, etc.), economic growth of the country, geopolitical issues that affect the country, and the regulatory environment (Oree, Hassen & Fleming, 2017). Therefore, in handling such uncertainties, the investor or asset owner must be mindful of estimating various parameters and the degree of associations among them. In examining the correlation between uncertainties for two main GEP parameters; load and wind generation intensity, Park & Baldick (2016) indicated that knowledge of the relationship between uncertain parameters improves the accuracy of the capacity planning model.

Renewable energy systems are increasingly becoming integral in the power mix for most countries. Fluctuations in generation output primarily characterise the uncertainties in renewable energy technologies. The more they generate, the more uncertainties they have (Oree *et al.,* 2017). Newer forms of uncertainties are mainly due to the intermittency of renewable energy resources. The influx of renewable energy technologies in the market also introduces additional risk of obtaining inferior technologies whose power generation abilities are below par. Hence, the investor must incorporate the likelihood of these generation imbalances within the model to account for lower RE penetration.

Capacity expansion models have a myriad of constituents depending on the contextual reality and the objective of the off-taker (Chen et al., 2018). As a result, the assumptions considered when planning capacity generation must be realistic and conform to the needs of the consumer. The constituents of capacity planning can be broadly classified into two; the overall objective and the constraints of meeting the objective. In many capacity expansion problems, the goal is to select a mix of power generation options that maximises a positive payoff or minimises a cost or negative externality.

Maximisation approaches focus on increasing an outcome that contributes an inflow to the investor or utility. These inflow variables include maximising the generation at peak load, profits, and the volume of renewable power generation (Luz, Moura & de Almeda, 2018). While maximising peak generation capacities ensure that generation will meet demand/load to reduce the likelihood of unserved energy, maximising renewable power generation ensures that more solar, wind, biomass, and small-scale hydro sources are integrated into the renewable energy systems. Minimisation models on the other hand largely focus on minimising economic variables that introduce significant costs or negative outcomes in general, which include capital and operation costs and costs from excess power generation (Afful-Dadzie *et al.*, 2017; Chen et al., 2018; Diawuo & Kaminski, 2018).

Capacity expansion models have also evolved from meeting only economic objectives to include other goals. Currently, fuel availability, environmental concerns, geopolitics, and energy security are among the concerns and considerations that drive capacity expansion models and decisions (Oree *et al.,* 2017). In addition to cost minimisation, Zhang, Zhao & Xie (2018) considered an optimal mix that minimises risks in power generation, including fluctuations and variabilities in the unit costs of power generation. Another essential aspect of the generation expansion model is examining the optimal timing for system expansion (Park & Baldick, 2016), which has been a recurrent theme in this thesis. Mostly, the determination of optimal timing is linked to another general objective. For instance, assessing the optimal timing for investments that minimises the cost of investments.

Newer approaches to meeting the objective of capacity planning do not diffuse the importance of cost. Instead, they suggest that approaches towards planning have improved to handle multiple objectives, including cost reduction and adherence to environmental standards. For instance, as part of meeting emission reduction targets outlined in the Paris Agreement, one of Ghana's Nationally Determined Contributions (NDCs) commits to increasing the share of renewable energy in the energy mix to 10% by 2030. To realise these targets, they must be included in a generation expansion model, which will involve an incremental addition of RE systems that could meet the target by the said date. The plan must also account for tariffs, power demand, the capacity of renewable energy systems and the cost of generating electricity from the various sources (thermal, large-scale hydro, and renewable energy).

The optimal generation mix in a capacity expansion problem is generally subjected to various restrictions, commonly referred to as constraints in a linear programming problem. These restrictions shape the investor's objectives (in this case, utility company or government) to be met (Koltsaklis & Dagoumas, 2018). The constraints give an idea of what is necessary to consider in a power generation plan: security, economic, environmental, regulatory, and technical considerations.

Energy security constraints in a generation expansion model ensure that there is some buffer available to ensure that reserve power is always available to meet fluctuations in demand and supply patterns. In large scale utility generation problems, this is known mainly as the reserve margin (Pereira et al., 2017). An optimal reserve margin must not be too much to warrant high-capacity charges (especially in take-or-pay contracts with independent power producers). However, it must be enough to meet unmet demand in events of the failure of some critical generation systems. In Ghana, the reserve margin is set at 20% of the overall system capacity (Ministry of Energy, 2019).

The reliability of a system depends on its ability to respond to customers' demands (Wang *et al.,* 2017). Demand constraints in capacity expansion problems ensure that the production of the various generation capacities meets the required system load. For a utility company, this is the same as meeting the demand of customers. Estimating future demand must be done with the utmost level of accuracy. Several models have been formulated to forecast demand in different capacity planning, including time-series regression models and optimisation techniques (Samuel, Krishnamoorthy, Ananthan & Pitchai, 2021). For example, Ghana's Integrated Power System Master Plan (IPSMP) (Energy Commission, 2019) recognised that Gross Domestic Product (GDP) is a good predictor for power generation, explaining over 99% of the total variation. The model estimated a base case power demand centred on annual GDP growth of 6% and an uppercase power demand based on a GDP growth of 8%.

Other constraints include power capacity constraints which ensure that the power output for each generating source meets the maximum capacity of the power plant. Mathematically, the expected power output from the generation sources must be cumulatively less than or equal to their generation capacities. A key component of renewable energy capacities is the capacity factor which is a measure of the availability of the energy source (Pedraza, 2019)

Lastly, capacity planning projects largely depend on the budget and financing capacity of the investors. Budget constraints ensure that future generation expansion plans are realistic and applicable (Afful-Dadzie *et al*., 2017; Birge & Louveaux, 2011). For developing countries, budget constraints are significant points to consider for capacity additions because of limited funds.

5.2.1 Capacity planning for SMEs

Sustainable capacity planning is essential to ensure the continuity of power supply (Luz et al., 2018). SMEs highly dependent on power must ensure that they always have adequate supply. The cost of unserved capacity for the SME results in productivity losses. In response, businesses have shifted towards self-generation options, which has allowed them to reduce their dependency on the grid. This shift is mainly in response to high tariff costs, grid power intermittency, environmental sustainability, among others. An SME with a diesel generator or a solar PV installed must understand its capacity to meet power demands. This involves a thorough evaluation of its current to medium-term power demands and plans for expansion amidst future power generation requirements. Key issues worthy of note for such an evaluation include the source of power generation, optimising the power generation mix, and the necessary sources of financing.

Research on capacity expansion has focused mainly on utility companies and power regulatory authorities as they are responsible for ensuring adequate power supply to end-users. However, at the firm level, the conversation around generation planning has not generated much concern for both large scale and small-scale companies. This notwithstanding, capacity planning among SMEs is necessary as these businesses begin to consider short, medium, and long-term power generation options. Again, sustainable energy supply is as essential to a business as it is to a utility company. Thus, capacity planning must not only be the preserve for national electricity planning but also at the micro-level of which SMEs are an integral part.

The power generation scale for SMEs is comparatively small, indicating that the inherent complexities may not be comparable to large-scale utility companies or the national scale. However, some objectives in the generation expansion problems of SMEs are similar to national electricity generation planning. An example is the objective of cost minimisation, which is one of the widely determined objectives for capacity planning. SMEs are primarily concerned about their bottom line through revenue maximisation and cost minimisation. Thus, the businesses' options for cost reduction are welcomed, which requires that the generation mix provides the least cost in the long term. Secondly, environmental concerns have become an essential consideration in capacity planning at the national and firm levels. These concerns have necessitated businesses to consider transitioning from fossil fuel sources to renewable energy resources. Thus, SMEs can plan in a way that maximises their contribution to environmental sustainability.

Despite these similarities, there are some notable differences between capacity planning at the national and firm levels. Generation expansion models for large-scale utilities rely on the need to schedule power plants based on capacity availability and cost of power generation (Oree et al., 2017). For example, Ghana primarily operates the merit order system where the cheapest source is brought on stream first. It is for this reason that hydro sources serve as a baseload for Ghana's power system. SMEs may not have to consider such on/off schedules depending on the scale of investment. However, the concept of unit commitment is equally essential for SMEs concerning providing additional generation capacity to their energy mix. SMEs running for 24 hours can schedule grid-connected systems to be on stream in the evenings or at times where renewable energy capacities are unavailable. This reduces the need for energy storage which provide additional cost to the SME.

One of the main benefits of capacity planning is to ensure flexibility. Power sector flexibility is the ability of the power sector to respond rapidly to changes in power sector variables such as system capacity and demand (Chen et al., 2018). SMEs that rely primarily on the centralised grid have lower flexibilities because the response towards system failure does not come from them but from the system generators. A capacity plan with alternative generation sources enhances flexibility in selecting available sources on-demand and at a lower cost.

As already indicated, capacity planning ensures that the available supply capacity matches power demand, with an additional buffer for situations of fluctuations in demand and supply patterns. However, it is essential to prevent oversupply resulting from the excess generation, especially for SMEs with limited investment capacities. Among SMEs, it is important to address the situation of excess supply, ensure power system reliability, and allow the SME to generate the required power to meet its demand.

Integrating renewable energy into the power mix among SMEs can be advantageous for long-term cost savings and contributions to the environment. Globally, investments in renewable energy capacities are growing. Research and development in various forms of renewable energy technologies continue to abound. However, it is essential to ask the critical questions while we continue to salivate over the prospects of renewable energy adoption; what financial capabilities are available for SMEs to adopt renewable energy systems? The need to respond to this question is essential, especially in the presence of barriers such as high investment costs and SMEs' limited knowledge of the scope of renewable energy generation capacities (ACEP, 2021).

One of the foremost challenges of capacity planning is accessing financing. Afful-Dadzie et al. (2017) highlighted the challenge of insufficient capital for nations to implement substantial expansions. The same can be said for SMEs. However, while access to funding may be considered a challenge, it is essential to ensure that such a challenge is curtailed. Inadequacy of capital has plagued SMEs in developing countries, and this continues to stall plans towards power generation. Financial barriers must however not be allowed to inhibit investments into newer sources of power generation.

The preceding arguments show that financing is at the heart of renewable energy penetration particularly among SMEs. After the SME has assessed its capacity needs, it must identify how to source the funds required and the mix of options available to minimise the financing cost. Therefore, these generation expansion decisions must consider the cost of obtaining finance.

5.2.2 Financing capacity expansion investments

Generally, financing is a critical component for SMEs to remain sustainable (Abor, 2008). Capacity planning and its benefits will not be achieved if the requisite funding is unavailable to the SME. Capacity planning projects that involve either a full or partial switch of power generation sources are likely to be capital intensive. Therefore, access to finance is of the essence to ensure the sustainability of innovative capital projects (Abdulsaleh & Wortington, 2013). Extant research has already established that one of the primary challenges facing SMEs is access to capital to run operations or capacity expansion. SMEs are generally less likely to secure funds compared to large scale companies, irrespective of their importance to the economy, and especially in job creation (Abraham & Schmukler, 2017).

This challenge is fuelled by market imperfections such as information asymmetries and weak creditor protection systems (Abraham & Schmukler, 2017), exacerbating the supply side challenge of funds provision. Moreover, the challenge worsens when the requirement for funding is extended to innovations such as switching from conventional sources to renewable technologies, introducing uncertainties regarding the performance of the new technologies. This shows that beyond information asymmetry, uncertainties on the performance of these new technologies, which are less mature than conventional power sources, create risk for financial institutions to provide adequate funding for such ventures.

Innovation is critical for the growth and success of SMEs, whether product or process innovation. Additionally, the use of new inputs for production can also be classified within the innovation pathway. For instance, more efficient power generation sources can reduce the operational cost of the business. However, funding such innovations depends mainly on adequate capital (Wellalage & Fernandez, 2021). Thus, irrespective of the form and nature of innovation, financial institutions would generally assess the profitability potential of the firm to ascertain its creditworthiness (Abdulasseh & Worthington, 2013). Thus, the SME must make a case of the potential profitability of the business to justify support.

Sources of funding for small businesses

Notwithstanding the financial challenges, SMEs must secure financing to ensure the continuity of their investments. There are various sources from which SMEs could obtain funding. These sources of financing for SMEs are either internal or external. Internal sources are mainly in the form of the firm's retained earnings or internally generated funds. External sources of finance are funds that are secured outside the firm's internal operations and could also be classified as informal or formal (Abdulsaleh & Wortington, 2013). These include funding from informal sources such as family and friends, trade credit and business angels, whereas formal external sources include loans from financial institutions (debts) and equity partners through the listing on the stock exchange.

The pecking order theory, propounded by Myers & Majluf (1984), provides a hierarchy of preferences towards the financing sources of firms in an order of the increasing level of information asymmetry. The theory suggests that firms exhaust internal funding options before considering external funding. As a result, firms will turn to debts if they require additional financing and turn to equity financing if more funding is needed (Abdulsaleh & Wortington, 2013; Abor, 2008).

Internal financing occurs mainly in the early stages of the SMEs development, where the owner largely relies on personal savings. As the firm expands, it depends on its retained earnings to support its operations. Internal funding sources are relevant for SMEs as there is a low likelihood of making repayments with interests and does not require collateral and other higher costs peculiar to external funding sources (Rao, Kumar & Madhavan, 2018). Informal financing sources such as family and friends provide lower or no returns since motivation by financiers is primarily driven by the desire to help the investor, thus providing the firm with an increased preference for such financing source.

Although not explicitly an internal source of funding, trade credits can be classified as an informal funding source relevant to SMEs. Trade creditors are primarily suppliers of goods and services who delay their request for payments (Abdulsaleh & Wortington, 2013). This source of financing is ideal for short term projects and essential in environments with limited funding opportunities from financial institutions. Trade creditors largely suffer from less information asymmetry than financial institutions, mainly because they are in direct business with the firm (Nguyen, Nguyen, Dang, & Nguyen, 2019). Thus, where banks are unwilling to lend, trade creditors provide additional lending support.

Despite the importance of the above-listed funding sources to SMEs, they may not be adequate for expansion and other capital-intensive projects the firm would like to undertake (Abor, 2008). For example, a project to install new renewable energy capacities will require money that internal or informal sources of financing cannot readily absorb. Therefore, the firm must begin to consider other funding sources, typically from formal external sources (debt or external equity). In these instances, the amount of money required for optimal investments is mainly limited due to the small capacity of the informal sources. Thus, the SME resorts to external and formal funding sources to curtail this challenge, primarily debt and equity financing.

The Modigliani-Miller theorem explains that given the prevalence of certain conditions, such as the absence of agency and bankruptcy costs, absence of information asymmetry and absence of transaction costs, the value of a firm is independent of its capital structure (Fatica, Hemmelgarn & Nicodème, 2013). However, these conditions do not necessarily prevail, given the advantage of one funding source over the other at specific points in time. Thus, the choice of equity or debt depends mainly on the conditions that prevail in the market.

The pecking order theory goes ahead to rank debt financing options before equity financing. Debt financing involves procuring interest-bearing instruments, which are primarily secured by asset collateral with term structures and tenure, spanning from short-term to long-term (Eton, Mwosi, Mutesigensi, & Ebong, 2017). For a capital-intensive project such as a firm switching towards renewable energy sources, long term capital will be a more plausible financing option. Beyond the requirement of adequate capital, debt financing has reduced tax commitments. Generally, interest payments that account for debts are tax-deductible (Fatica *et al., 2013;* Abor, 2008). Thus, the tax commitment of the SME is reduced because of interest payments and amortisation of debts.

Debt financing could either be long-term or short-term. Short term debts are advantageous in terms of relatively lower interest rates and lower costs of floatation. Among SMEs that use debt financing, Masiak et al. (2019) noticed that they essentially resort to short-term debt financing instruments such as credit lines, bank overdrafts and credit card overdrafts. However, for higher capital cost requirements, funds with longer tenure are required, allowing the firm to recoup investments within a realistic timeframe to justify the investment. Hence, financial institutions and firms will have to balance the trade-offs between long-term debt and short-term debt financing, as well as the conditions for creditworthiness.

Equity financing is the last source of financing on the hierarchy of the pecking order theory. It allows businesses to raise capital through the sale of shares. This funding source is long term, and shareholders share in the ownership, as well as the profit and losses of the firm. Compared to debt financing, tax-deductibility may not be a possibility under equity financing. Dividends are shared with shareholders after taxes have been paid. The issue of tax deductibility provides a preference of debt financing to equity financing.

Additionally, the perception is that external funding options make owners/managers vulnerable to relinquishing the control of their firm to other external partners (Wong, Holmes, & Schaper, 2018).

As explained by Wong *et al* (2018), The risk of losing controlling interest will cause managers to reduce their level of equity funding. This level of perceived control is seen mainly in equity financing than debt financing, although the latter also has some appreciable level of control. Abdulsaleh & Wortington (2013) also explained that issuing additional equity can dilute ownership levels in a firm. As a result, high contributors have high ownership and more control of the firm. SME owners who may want to avoid such changes in ownership and control of the firm may not agree to use equity financing. Thus, to keep the firm's control in check, firms, in particular SMEs, will choose debt financing over equity financing.

The stock exchange is one of the main platforms to secure formalised equity financing. However, the requirements for listing on the stock exchange lowers the likelihood for SMEs to be listed. A consideration of the tangible costs (direct and indirect costs for listing, costs of ensuring compliance and costs of admission on the stock exchange), and intangible costs (opportunity costs for management, the need to establish market structures) lowers the desire of SMEs to list on the stock market (World Federation of Exchanges, 2016). For example, the stated share capital required for listing on the Ghana Stock Exchange (GSE) First Official List is about GHS 20 million which can be relatively high for SMEs.

The costs and challenges inhibiting SMEs from listing on GSE First Official List led countries to develop and create alternative markets to enable SMEs to raise finance and trade accordingly. In Ghana, the Ghana Alternative Market (GSE-GAX) was established in 2013 as a parallel market operated by the Ghana Stock Exchange. The minimum stated capital required for listing on GSE-GAX is GHS 250,000 which is significantly lower than the requirement for listing on GSE First Official List. The target was to have at least ten companies listed on GSE-GAX by 2015 (USAID, 2017). In 2018, the management of GSE-GAX targeted to list 50 firms by 2020. However, as of June 2021, only seven companies were listed on GSE-GAX. The reasons for such low adoption could be related to lower levels of awareness or the inability of SMEs to meet the conditions of the relatively less stringent Ghana Alternative Market, which increases the affinity for debt financing among SMEs.

Cost of debts

Obtaining financing involves some level of cost which must be borne by the business looking for finance. An equity holder must be compensated for bearing the risk of assuming part ownership of a firm. Similarly, a financial institution must be compensated for providing funds to the firm, which it could have been used to serve other purposes. Thus, firms must pay interests on their equities or debts depending on the form used in raising capital. Capital structure theories specify that companies must identify an optimal mix of debt and equity financing that provides the minimum cost of financing. However, the preceding arguments have shown SMEs' affinity to debt financing than equity financing, suggesting that while large-listed firms could take advantage of obtaining a balance between equity and debt financing, SMEs would have to secure debt funding at a minimum cost.

Generally, interest rates are used to identify the costs of the debt being sought. The cost of debt or level of interest rates is shaped by issues such as tenure and the level of information asymmetry (Nguyen *et al.,* 2019). If firms can repay their loans, they are deemed credit-worthy and are more likely to receive preference in subsequent loan applications (Salifu, Tofik-Abu, Rahman, & Sualihu, 2018). Credit unworthiness introduces risks of loan defaults, and financial institutions tend to deal with these defaults by providing little or no access to credit unworthy firms. However, financial institutions cannot ignore the demand for funds and must at several points in their existence, provide financial assistance to SMEs.

The need to assist SMEs can be shaped by the bank's decision or by a mandatory regulatory requirement. For instance, Ghana's central bank (Bank of Ghana) is planning to roll out a mandatory minimum loan to deposit ratio that will enable banks to offer loans to private businesses, particularly SMEs. This means that financial institutions would have to identify ways of navigating the challenge of identifying the costs of debt through intensive cost monitoring (Masiak *et al.,* 2019). However, monitoring may either seem cost-inefficient or impractical, as it requires financial institutions to provide alternatives such as collateral requirements or increasing interest rates. The latter becomes a preferred option particularly in the situation where the SME does not have the required collateral that justifies the amount of debt.

How do firms navigate the challenge of high interest rates demanded by financial institutions? One option is to examine the amount of debt required for the capital project. This is because the ability to repay loans also depends on the size of the fund (Acquah & Addo, 2011). Thus, while controlling for the rate of interest, the size of the fund becomes another point to consider. Firms could gradually build up their reserves with incremental capital for their investments to a point where they have the affinity to secure bigger funds for bigger expansions. This approach is also particularly important for a capital project such as installing an alternative source of power generation. For such an investment, the SME must determine the minimum capacity that must significantly reduce the long-term cost of energy generation, while offering the ability of the SME to repay the loan.

5.3 Model specification

The model for optimising renewable energy generation by SMEs is a cost minimisation model, and is concerned with choosing the generation capacity that minimises the Levelized Cost of Electricity (LCOE) for the entire duration of the renewable energy technology and is subject to capacity and financial constraints. LCOE measures the lifetime cost of energy produced from a generation plant over its lifetime. The LCOE has been calculated for many single power plants, which provides different LCOEs for different generating plants. This chapter, however, examines LCOE for a hybrid between renewable energy sources and conventional energy sources. It is expected that the integration of renewable energy in the energy mix will minimise the LCOE.

5.3.1 Objective function

Consider a firm that utilises conventional energy from the grid and consumes about $G\ kwh$ of energy at time t. The firm would like to switch from consuming energy from traditional sources to generating its energy from renewable sources. To benefit from significant cost savings, the investor must increase investments in renewable energy. Considering the level of investment required for such a switch and the budget required, it may be essential for the investor to consider a partial switch from conventional to renewable energy. The firm, therefore, faces the problem of deciding the capacity of renewable energy to include in the energy mix to minimise its Levelized cost of electricity generation.

The total cost of generating energy from a renewable source for the firm is a function of the initial cost of installing a plant with a capacity of R kW, with a lifetime of T which generates E kWh of electricity for a given period t. The investment requires an amount of I_0, which is the product of the capacity of a renewable energy plant and the unit price of the renewable energy capacity (X per kW). It also requires respectively, operation and maintenance costs of M_t and storage costs of S_t per kW of renewable energy capacity. Also, the cost of generating conventional energy is given as the tariff paid at a rate of W_t per kWh. For this energy mix, Equation 23a gives the firm's total cost of electricity generation over the life of the renewable energy technology.

The first term on the right-hand side of the equation measures the capital cost for installing the renewable energy technology. The second term measures the present value of the operation and storage costs of the renewable energy technology, as well as the tariffs required for generating W_t kWh of electricity.

$$L = RX + \sum_{t=1}^{T} \frac{(M_t + S_t)R_t + W_t C_t}{(1+r)^t} \qquad \text{23a}$$

The initial cost of installing the renewable energy technology is financed by a loan that pays an interest i over a loan period of N (where $N \leq T$). The loan is amortised by making periodic payments of A, at each period n, over its tenure, where A is the periodic annual payment required to generate a present value equal to I_0 at a rate of i for N years (See Equation 23b). The total cost of generation, therefore, changes to reflect the annual payments as given in Equation 23c. Thus, the first term on the right-hand side of Equation 23c replaces the first term of the right-hand side of Equation 23a. It denotes the present value of the equal periodic payments made to amortise the loan.

$$A = \frac{RXi(1+i)^n}{(1+i)^n - 1} \qquad \text{23a}$$

$$L = \sum_{n=1}^{N} \frac{A}{(1+r)^n} + \sum_{t=1}^{T} \frac{(M_t + S_t)R + W_t C_t}{(1+r)^t} \qquad 23c$$

5.3.2 Model Constraints

The ensuing subsections describe the constraints applied in the model. These constraints are the total energy required by the firm, the capacity factor of the renewable energy generation, and wear and tear of the renewable energy technology which reduces its efficiency. Also, budget constraints are considered in the model.

Total energy needs

The plant requires energy from both conventional and renewable energy sources. This study assumes that the firm shall operate a single renewable energy source that will produce energy worth E kWh at time t. The remaining energy demand will be supplied from conventional sources, which provides C_t amount of energy from the grid (Equation 24).

$$C_t + E_t = G_t, \forall t \qquad 24$$

Capacity factor of renewable energy technology

The amount of electricity generated by renewable energy technology depends on the capacity of the renewable energy technology and the amount of capacity factor available as shown in Equation 25. Therefore, equation 25 assumes the energy generated by renewable energy is a product of the capacity of renewable energy, the amount of time (H measured in hours) the technology is used and the capacity factor of the renewable energy technology τ_t.

$$E_t = H_t \tau_t R, \forall t \qquad 25$$

Wear and tear of renewable energy capacity

With time, the effectiveness of renewable energy generation is reduced due to the gradual wear and tear of the equipment. Therefore, it is assumed that on a periodic basis, the wear and tear cause the generation capacity of the installed renewable energy technology to reduce at a rate of α as shown in Equation 26.

$$E_t = E_{t-1}(1 - \alpha), \forall t \in [2, N] \qquad 26$$

Budget constraints

At the end of each period, the firm must make annual payments to amortise the investment cost for the renewable energy generation equipment. One of the main benefits of switching to renewable energy technologies is reducing the firm's commitment to paying electricity tariffs. A novel application of this study is to allow these tariff savings to repay the loan amount within its stipulated tenure. In the situation where the savings from the tariff is not enough to offset the loan at a given time, the firm will choose to top up by allocating a portion of its expenditure towards repaying the loan. Equation 27a depicts that the amount available to repay the loan must be at most the tariff saving, B_t, from installing renewable energy, and a portion of the firm's expenditure given that the tariff savings is not enough to meet the required payment amount. The additional amount from the firm is defined as a proportion (identified as γ) of B_t. B_t is also defined as the difference between cost of energy if 100% of its energy is supplied by conventional electricity (*initial conventional tariffs)* and the cost incurred for consuming W_t kwh of conventional energy (after installing a renewable energy capacity of R kW (Equation 27b). This allows a substantial part of the installation of renewable energy technology to be financed from cost savings from electricity tariffs.

$$A \leq (1 + \gamma)B_t \quad \text{27a}$$

$$B_t = W_t G_t - W_t C_t \quad \text{27b}$$

5.4. Empirical study

For the empirical study, we consider an SME with a generation capacity of 25kW working 8 hours/day, six days/week for 50 weeks, giving a total annual energy requirement of 60,000 kWh. The firm can increase its generation capacity by 10% every five years due to business expansion. Therefore, the firm is considering installing a solar PV plant with a useful life of 25 years and a capacity factor of 20% that can meet either part or the entirety of its annual energy requirement. However, it faces the challenge of determining the renewable energy capacity to install that can provide the minimum cost of energy generation over the life of the Solar PV.

5.4.1 Input parameters for valuation

Tariff data from the Public Utilities Regulatory Commission (PURC) indicates that the average commercial tariff rate is about GHS 0.85 ($0.15) per kWh. In addition, historical data from PURC show that the tariffs follow a Geometric Brownian Motion with an average drift rate of 12% and a volatility of 27%. Therefore, a simulated forecast of future electricity tariffs is generated as projected tariffs for the planning period.

The capital cost of renewable energy generation continues to witness significant reductions over the years because of an optimised manufacturing process, reduced labour costs and enhanced module efficiency. Between 2019 and 2020, the Levelized Cost of Energy for solar PVs has declined by about 13% (IRENA, 2021). As of 2020, solar prices have reduced to about $883 (GHS 5068) per kW. Conservatively, this study used an average price of $1000 (GHS 5740) per kW as the average price of solar PVs.

Operation and Maintenance (O&M) costs of renewable energy technologies have reduced over the past decade. For example, between 2010 to 2020, average O&M costs for solar PVs have decreased from $24.7/kW per year to about $9.4/kW per year. Projecting this to the future means that O&M costs shall continue to decline over the period. However, mindful of the possibility of an eventual increase in O&M costs and the local currency depreciation, this study assumes that the costs will record an increase at an annual rate of 1%.

The SME shall finance the capacity costs of renewable energy by taking a loan from the financial institution at a given lending rate over a specific repayment period. The loan is financed over the repayment period by providing equal annual payments. Typically, the loan's repayment tenure depends on the free cash flows available to the SME to make yearly payments. This study assumes that the SME is offered a medium-term loan whose tenure ranges between 5 to 10 years. Ghana's average cost of borrowing by commercial banks as of January 2020 was about 23.06%, reducing to about 21.1% by December 2020. As of March 2021, the average commercial lending rate was approximately 20.9%. Table 5.1 presents a summary of the input parameters required for the empirical study.

Table 5. 1: Summary of input parameters

Symbol	Name/ Description	Source	Base value
H	Fuel consumption for backup generator		Between 2.4 litres per hour to 36 litres per hour, depending on the capacity of the plant
W_t	Current electricity tariffs per kWh	PURC tariff guide (2021)	0 – 300 kWh: 14.1 cents 301-600 kWh:15 cents > 600kWh: 23.7 cents
α_w	Drift rate of tariffs	Historical data of electricity tariffs	0.14
σ_w	Volatility rate of tariffs	Historical data of electricity tariffs	0.25
I_0	The investment cost for renewable energy system	IRENA renewable cost database	GHS 5183/kW
M_t	Annual operating and maintenance cost for renewable energy system	IRENA renewable cost database	GHS 51/kW/year
C_t^R	The capacity of the installed renewable energy system	Calculated based on the power capacity of the SME and the capacity factor for renewable energy	
τ_i	The capacity factor for renewable energy source	IRENA renewable cost database	19.5%
r	Discount rate	African Renewable Energy Access Program (World Bank)	12% (WACC for non-OECD countries) adjusted by two percentage points to reflect local currencies
i	Average commercial bank lending rate	Bank of Ghana	20.6%
	Base year		2021

Source: Author's Construct (2021)

5.4.2 Available renewable energy investment options and scenarios

The study considers three options available for the SME in its bid to connect to a renewable energy generation source. The first option is the *immediate investment* option, where the firm decides on an instantaneous investment in solar PV. For this option, the SME purchases the technology at the current price and shall benefit from cost savings relative to estimated grid electricity tariffs between now and the next T years.

The second option is the *delayed investment option*, where the SME decides to delay investments for k years where $k \in [1, T]$. Thus, the SME instals the solar PV plant at time k and shall benefit from cost savings relative to grid electricity tariffs between period k and $T + k$. Given this period of delay in investment, the objective function in Equation 23 is transformed as shown in Equation 28a.

$$L = \sum_{n=k+1}^{N+k} \frac{A}{(1+r)^n} + \sum_{t=k+1}^{T+k} \frac{(M_t + S_t)R}{(1+r)^t} + \sum_{t=k+1}^{T+k} \frac{W_t C_t}{(1+r)^t} \qquad 28a$$

Where $A = \frac{R_k X i (1+i)^n}{(1+i)^n - 1}$

Equation 28a represents the present value of the cost of energy generation at time k. The first term of the equation explains the present value periodic amounts paid to amortise the loan. The second term represents the present value of the operation and maintenance costs, as well as storage costs of the renewable energy technology. Finally, the third term represents the present value of the tariffs paid to supply energy from the grid. Thus, to identify the present value of the investment, 6a can be discounted further to period zero, as shown in Equation 28b.

$$L_0 = \frac{L}{(1+r)^k} \qquad 28b$$

The firm is required to choose k such that the prices of solar PV technologies would continue to reduce. The combined effect of the reduction in prices of Solar PV and the increasing trend in grid electricity tariffs can afford substantial savings in electricity tariffs. Also, improved technology through advanced research and development can enhance the capacity factors of renewable energy technologies. Delaying investments in renewable energy also allows the investor to minimise uncertainties, thereby giving better optics for investment. Generally, it is estimated that the prices of solar PVs can reduce by an additional 29% to 35% over the next five years.

The third option is the *resource pooling option.* The *resource pooling option* considers a group of m SMEs that decide to pool resources to obtain financing to construct a solar PV plant that can meet their communal annual energy requirements. To ensure the practicality of this option, SMEs must be in proximity to each other (ideal for an industrial area setting). Also, SMEs must be willing to pool resources together to secure finance for the project. The *resource pooling option* provides benefits of economies of scale, where prices of solar PVs can reduce by about 20% to 25%. In addition, O'Shaughnessy, Nemet, & Darghouth (2018) identified that customer aggregation presents significant opportunities for reducing the costs of solar PVs. Also, the bank's perceived risk of default is reduced to an extent since unionised representatives of SMEs can engender trust, compared to single SMEs sourcing for finance, thereby increasing the likelihood of obtaining long term financing at competitive rates.

Four different scenarios are considered for each option, which involves a combination of loan interest rates (low and high) and loan tenure (long-term and short-term). Table 5.2 provides a summary of the investment options and scenarios used in valuing the solar PV investment. The first scenario is described as the *most optimistic scenario,* representing a situation where the firm obtains a loan at a longer-term and lower interest rate. This scenario records the least annuity factor (i.e., the multiplier that determines the annual payments). The second scenario, described as the *quasi-optimistic scenario,* describes a longer repayment term and a high interest rate. The annuity factor for this scenario is greater than that of the *most optimistic scenario*, denoting an increased cost of debt. The remaining scenarios are described as *quasi-pessimistic* and *most pessimistic,* characterised by high annuity compared to the two initial optimistic scenarios.

Table 5. 2: Description of scenarios

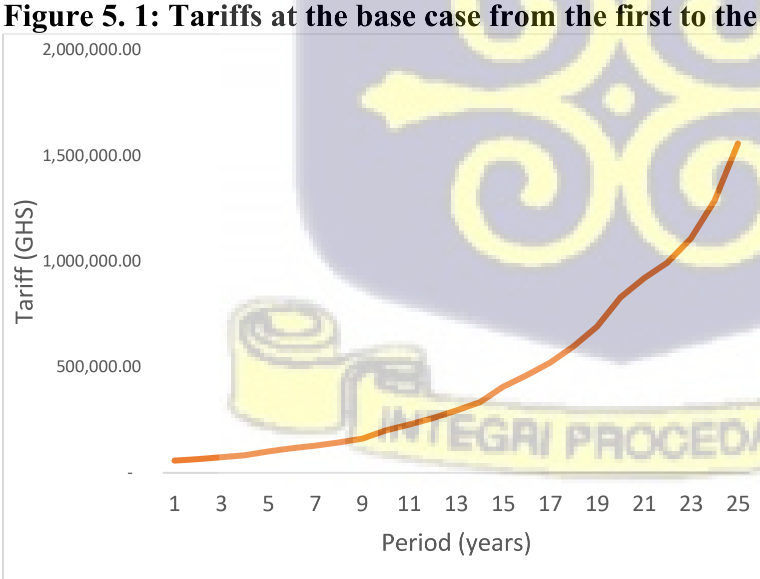
Scenario	Description	Tenure	Interest rate	Annuity factor
Most optimistic	Long term, low interest rate	10	16%	0.207
Quasi-optimistic	Long term, high interest rate	10	22%	0.255
Quasi-pessimistic	Short term, low interest rate	5	16%	0.305
Most pessimistic	Short term, high interest rate	5	22%	0.349
Investment options				
Delayed investment: $k = 5$; capacity factor = 30%				
Resource pooling option: RE reduces by 20%.				

Source: Author's Construct (2021)

5.4.3 Results of empirical study

At the base level, where the company does not consider any investments in renewable energy, the present value of the total energy costs of the firm over the 25-year interval is estimated to be about GHS 1.723 million (about $300 thousand). Therefore, the Levelized Cost of Energy (LCOE) for the base case amounts to GHS 3.45/kWh. The firm's annual electricity tariffs are estimated to increase from GHS 57,000 ($9930) at the end of the first year to about GHS 1.557 million ($271 thousand) at the end of the 25th year (See Figure 5.1), primarily due to increasing electricity tariffs.

Figure 5. 1: Tariffs at the base case from the first to the 25th year



Source: Author's Construct (2021)

The immediate investment option

Under the immediate investment option, investment in renewable energy is preferred only under the *most optimistic scenario,* which is a more favourable option with less cost of debt financing. However, such investment must be carried out with no investment in energy storage. Given no investment in storage, the model allows for an optimal solar PV capacity of 5KW, which provides an annual electricity generation of about 2410kWh, representing a maximum of about 4% of total electricity required by the firm. The initial capital needed for such a capacity is about GHS 28,800 ($5,017), requiring the firm to make an annual GHS 5,900 to the financial institution.

The firm is required to amortise the loan with tariff reliefs obtained from installing the solar PV capacity. Given a capacity of 5kW, the firm makes savings of about GHS 2,290 in the first year and requires an additional amount from its revenues. This additional amount is estimated at a maximum of 10% of the total electricity bill if the firm had not considered the option of investing in solar PVs (initial conventional tariffs). The total savings in the first-year amounts to GHS2,290, which increases to about GHS30,000 by the 25th year. Given a loan repayment tenure of 10 years, the firm will no longer rely on its revenues after the 9th year. At this investment, the LCOE amounts to GHS3.44/kWh with savings of GHS0.01/kWh over the life of the technology (See Table 5.3).

Table 5. 3: Costs and optimal generation under the immediate investment option

Scenario	Total cost (GHS million)	Optimal RE capacity	Total generation
Most optimistic	1.715	5 kW	2410KWh
Quasi-optimistic	1.723		
Quasi-pessimistic	1.723	Do not invest in RE	
Most pessimistic	1.723		

Key assumptions:
No storage technology required
Max allowable revenue: 10% of total initial conventional tariff
Max allowable period: 9 years

Source: Author's Construct (2021)

Sensitivity analysis of the immediate investment scenario

Increasing the amount of its revenue allocated to repaying the loan provides the firm with the option to increase its generation capacity. For example, suppose the firm decides to increase the allowable amount from 10% of initial conventional tariffs to 20%. In that case, the optimal installed capacity will be about 10.05kW, which can generate about 4,821kWh of electricity at the end of the first year, representing about 8% of the total electricity needs of the firm. Thus, the firm increases its long-term electricity costs from GHS 0.016/kWh to about GHS 0.031/kWh. However, it will no longer rely on its revenues to repay the loan after the 9th year. Generally, increasing revenue allocation increases the amount of savings. The results show that for every 10% increase in revenue allocation, the present value of savings over the investment period increases by about GHS 0.016/kWh, providing a more cost-saving potential. The results of the sensitivity analysis are provided in Table 5.4.

Table 5. 4: Sensitivity analysis of immediate investment scenario

Allowable revenue allocation	RE capacity (kW)	RE capacity (% of total generation)	Investment cost (GHS'000)	Annual payment req. (GHS'000)	LCOE (GHS/kWh)	PV of savings (GHS/kWh)
0%	0.00	0%	-		3.45	0.000
10%	5.02	4%	28.83	5.96	3.44	0.016
20%	10.04	8%	57.65	11.93	3.42	0.031
30%	15.07	12%	86.48	17.89	3.41	0.047
40%	20.09	16%	115.30	23.86	3.39	0.063
50%	25.11	20%	144.13	29.82	3.38	0.078
60%	30.13	24%	172.96	35.78	3.36	0.094
70%	35.15	28%	201.78	41.75	3.34	0.110
80%	40.18	32%	230.61	47.71	3.33	0.125
90%	45.20	36%	259.44	53.68	3.31	0.141
100%	50.22	40%	288.26	59.64	3.30	0.157

Source: Author's Construct (2021)

As earlier indicated, the immediate investment option does not consider investment for batteries to store renewable energy capacities. Also, the model does not allow investment in storage technologies, irrespective of the amount of initial conventional tariff allocated to offset the loan. Thus, in the situation where renewable energy is not available, the SME can opt to use energy from the grid to complement the intermittency of renewable energy technologies. Again, the SME could benefit from additional tariff savings in an environment when net metering is fully operational. However, the operationalization of net metering depends largely on the effectiveness of government policies. The Renewable Energy Act (Act 832) makes provisions for encouraging self-generations using renewable energy. It is important that government fully implement the scheme to encourage self-generation and ensure the benefit of renewable energy integration.

The delayed investment option

The delayed option provides an opportunity for the SME to delay investments for several years. For this case, we delay investment for the next five years. This delay means that the lifespan of the technology would be translated to the 30th year. Consequently, the relative increase in tariffs over that period significantly increases the cost of energy generation. Also, it has been discussed that the delayed investment option can lower the cost of renewable energy technologies. However, this study assumes a conservative price of about GHS 6,000 per kW of installation, taking note of the Ghanaian market's inflation and exchange rate volatilities, which can offset the impact of global price reductions in Solar PV technologies.

Unlike the situation with the immediate investment option, delaying investments provide a better outlook for the investor. First, the model allows some solar PV investment across all the possible scenarios on interest rates and tenure of loans. Second, it is possible to provide an appreciable level of investment in storage across all scenarios. Third, the delayed option allows solar PV investment even when the company does not plan to top up their *initial conventional tariffs* with their revenues to repay the loan. Again, this is unlike the immediate investment scenario, which required a commitment to top up annual savings with additional payments to defray the loans.

At the baseline, the present value total cost of energy generation for the delayed investment option is about GHS 1.943 million, accounting for an LCOE of about GHS3.71/kWh for the life of the technology. Therefore, the LCOE for the delayed investment option is lower than the immediate investment option. The deferred period is also accounted for in the valuation, increasing the number of years required. It also accounts for the increasing electricity tariffs beyond the 25^{th} year.

For the *most optimistic scenario,* the model allows the SME to invest about 33kW of renewable energy technology, which generates up to about 26% of the total electricity generation required by the SME. In addition, this option allows the SME to invest in batteries, which provides approximately 38% of the working period, equivalent to about 3 hours. As a result, the LCOE of the energy mix is about GHS 3.63/kWh with savings of GHS0.07/kWh over its lifetime. Thus, the amount of savings per kWh for the *most optimistic scenario* under the delayed investment option is significantly higher than that of the immediate investment option. Additionally, the delayed investment option allows the SME to invest in storage devices to be used when the natural resource is unavailable and increases the reliability of electricity generation. The SME can increase generation capacity above what the model recommends if it decides not in invest in additional storage capacities.

Under the *quasi-optimistic scenario,* the model allows the SME to invest about 30kW in renewable energy, generating about 24% of the required energy. Batteries can last for a maximum of 2.5

hours (31% of the time). The LCOE amounts to GHS 3.69/kWh, which provides savings of about GHS 0.02/kWh.

The *quasi-pessimistic scenario* allows investment of up to about 28.9kW of renewable energy, representing about 25% of the total energy required. The LCOE over the period considering the energy mix amounts to about GHS 3.70/kWh over the 25 years. The cost savings earned for renewable energy integration over the life of the technology amounts to GHS 0.01/kWh. Given the investment of 29kW of solar PV capacity, the model also allows the firm to invest in storage capacities that can store energy for up to 2 hours (25% of the time).

The *pessimistic scenario* allows an investment of about 29.6kW of solar PV capacity with battery storage that can last 1.5 hours (18.75% of the time). Thus, the LCOE is about GHS 3.66/kWh, with cost savings of about GHS 0.05/kWh over the life of the technology (See Table 5.5). For the scenario more generation capacity can be added if the SME does not invest in storage capacities.

Table 5. 5: Costs and optimal generation under the delayed investment option

Variable	optimistic	quasi-optimistic	pessimistic	quasi-pessimistic
Baseline (no RE investment) (GHS'000)	3,424.71	3,424.71	3,424.71	3,424.71
Baseline LCOE (GHS/kWh)	3.71	3.71	3.71	3.71
Optimal RE capacity (kW)	33.11	30.26	28.92	29.62
RE capacity (% of total generation)	26%	24%	23%	24%
Investment cost (GHS'000)	198.67	181.57	173.53	177.74
Annual payment required (GHS'000)	41.11	46.28	53.00	62.07
Years of additional revenue required	1	3	5	5
Battery life (hours)	3	2.5	2	1.5
LCOE (GHS/kWh)	3.63	3.69	3.70	3.66
PV of savings (GHS/kWh)	0.07	0.02	0.01	0.05

Source: Author's Construct (2021)

The *pessimistic scenario* seems to outperform the *quasi-pessimistic scenario* in terms of the capacity of solar PV and the cost savings, primarily because the *pessimistic scenario* allows for reduced investment in storage capacities. At a restricted battery capacity of 1.5 hours, the *quasi-pessimistic scenario* provides significant cost savings amounting to about GHS 0.16/kWh at a recommended solar PV capacity of 339kW, representing 27% of the total energy requirement. The model shows the significance of the battery costs in valuing renewable energy investments.

Sensitivity analysis of the delayed investment option

The sensitivity analysis is conducted like what was done in the immediate investment option, i.e., based on increasing revenue allocation to making annual payments to offset the loan. Suppose the firm decides not to expend any additional revenues to make the payments. In that case, the required renewable energy generation capacity will be about 30.1kW, which provides about 24% of the total energy generated. Increasing the allowable revenue allocation provides a higher amount of renewable energy capacity for the firm, which improves savings. Generally, for every 10% increase in allowable revenue allocation, the present value of savings increases by about GHS 3,700, representing an increase of about GHS 0.007/kWh.

Table 5. 6: Sensitivity analysis of the delayed investment scenario

Allowable revenue allocation	RE capacity (kW)	RE capacity (% of total generation)	Investment cost (GHS'000)	Annual payment req. (GHS'000)	LCOE (GHS/kWh)	PV of savings (GHS/kWh)
0%	30.10	24%	180.61	61.87	3.642	0.067
10%	33.11	26%	198.67	68.06	3.635	0.074
20%	36.12	29%	216.74	74.25	3.628	0.080
30%	39.13	31%	234.80	80.44	3.622	0.087
40%	42.14	34%	252.86	86.62	3.615	0.094
50%	45.15	36%	270.92	92.81	3.608	0.101
60%	48.16	39%	288.98	99.00	3.601	0.107
70%	51.17	41%	307.04	105.19	3.595	0.114
80%	54.18	43%	325.10	111.37	3.588	0.121
90%	57.19	46%	343.16	117.56	3.581	0.127
100%	60.20	48%	361.23	123.75	3.575	0.134

Source: Author's Construct (2021)

The pooled investment options

For the resource pooling option, this study considers a group of SMEs who cumulatively require 1MWh of electricity generation. As indicated, the SMEs benefit from economies of scale and the unionised groups provide an appreciable assurance of creditworthiness. Thus, the resource pooling option can provide a relatively lower debt cost than the other options where individual SMEs seek financing from financial institutions. However, given this option, the study considers only the *optimistic* and *quasi-optimistic* scenarios for valuation.

At the baseline, the energy cost amounts to GHS 25.67, which amounts to a levelized cost of GHS 3.09/kWh. Under the *optimistic scenario*, the model allows for a solar PV capacity investment of about 975kW, generating up to 47% of the total energy required. However, storage is available for half an hour (about 6% of the time). Therefore, the total LCOE over the life of the solar PV considering the energy mix amounts to GHS 2.82/kWh with an associated cost savings of GHS 0.27/kWh. Further, repaying the loan requires a top-up with revenues from the SMEs pegged at a minimum of 10% of the initial conventional generation cost. The top-up will be necessary for eight years.

The model does not allow for investment in storage capacities for the *quasi-optimistic scenario.* For this scenario, the model provides an investment of 937kw power of solar PV technologies which can provide about 45% of the total energy required by the SMEs. The LCOE amounts to GHS 2.79/kWh with associated savings of GHS 0.3/kWh. A comparison of the LCOEs between the immediate investment option (for a single SME) and that of the pooled investment option indicates significant savings. This result shows the SMEs pooling resources to seek finance for their renewable energy investments.

Sensitivity analysis of the pooled investment model

When the group of SMEs decide to put additional revenues to repay the loans, it offers them the opportunity to increase renewable energy capacity. For instance, if additional revenues of 30% of the initial conventional energy tariffs are added to the savings used in repaying the debt, annual capacity would increase to about 1.1MWh. This capacity can generate about 51% of the total energy required, given a battery storing power for about 30 minutes. Also, the present value of savings increases from GHS 0.25/kWh (when no additional investment is added) to about GHS 0.32/kWh if 30% of the initial conventional energy tariff is added. Generally, for every 10% increase in allowable revenue allocation, the model allows for a 4.3 percentage point increase in the proportion of total energy capacity to be served by renewable energy. This increase in the renewable energy capacity increases the cost savings by GHS 0.025/kWh (see Table 5.7).

Table 5. 7: Sensitivity analysis of the delayed investment scenario

Allowable revenue allocation	RE capacity (kW)	RE capacity (% of total generation)	Investment cost (GHS'000)	Annual payment req. (GHS'000)	LCOE (GHS/kWh)	PV of savings (GHS/kWh)
0%	886.81	43%	4,072.23	751.25	2.84	0.25
10%	975.49	47%	4,479.45	826.37	2.82	0.27
20%	1,064.17	51%	4,886.67	901.50	2.79	0.30
30%	1,152.85	55%	5,293.89	976.62	2.77	0.32
40%	1,241.53	60%	5,701.12	1,051.75	2.74	0.35
50%	1,330.21	64%	6,108.34	1,126.87	2.72	0.37
60%	1,418.89	68%	6,515.56	1,202.00	2.69	0.39
70%	1,507.57	72%	6,922.78	1,277.12	2.67	0.42
80%	1,596.26	77%	7,330.01	1,352.25	2.64	0.44
90%	1,684.94	81%	7,737.23	1,427.37	2.62	0.47
100%	1,773.62	85%	8,144.45	1,502.49	2.59	0.49

Source: Author's Construct (2021)

Impact of delayed investments on the pooled investment model

SMEs experience better benefits and improved cost savings when they consider the need to delay investments until a specific period. Investment delays are advantageous only when there is an assurance of further reductions in the price of renewable energy technologies, and there is the indication of increased electricity tariffs. Under this option, there is much incentive for installing renewable energy capacities with better storage capabilities.

At the optimistic scenario, the model allows for a renewable energy capacity of 608kW capable of providing about 29% of the required total energy generation. The total energy cost yielded a levelized cost of GHS 3.12/kw/h. This investment does not require additional investment from renewable sources as the cost savings can be used to repay the loan obtained from the financial institution. Renewable energy with a 4.5-hour storage capacity has not been realised in any investment options and scenarios discussed in this section. Compared to the delayed investment scenario (for a single SME), investment pooling offers a higher proportion of renewable energy capacity and a lower cost of energy generation. At a restricted battery life of 3 hours, the proportion of renewable energy required will be about 16 percentage points higher than the single SME. Also, the LCOE over the life of the technology for the pooled investment option will be GHS 2.73/kWh, lower than that for the single SME with an LCOE of GHS 3.6/kWh, as shown in Table 5.8.

Table 5. 8: Costs and optimal generation under the pooled investment option (with delays)

Variable	optimistic	quasi-optimistic	pessimistic	quasi-pessimistic
Baseline LCOE (GHS/kWh)	3.17	3.17	3.17	3.17
Optimal RE capacity (kW)	608.76	586.10	549.28	548.41
RE capacity (% of total generation)	29.2%	28.1%	26.4%	26.3%
Investment cost (GHS'000)	2795.41	2691.35	2522.32	2518.32
Annual payment required (GHS'000)	515.70	686.01	770.34	879.41
Years of additional revenue required	0.00	0.00	2.00	4.00
Battery life (hours)	4.50	3.00	2.50	2.00
LCOE (GHS/kWh)	3.12	3.08	3.12	3.10
PV of savings (GHS/kWh)	0.05	0.09	0.06	0.08

Source: Author's Construct (2021)

5.5 Discussions and conclusions

Small and Medium Enterprises could be weaned off the electricity tariffs obtained from self-generation through renewable energy technologies. The reliability of renewable energy technologies is also assured through advancing technologies and battery storage capacities that provide backup power when renewable energy resources are unavailable for energy generation. However, the decision to invest depends mainly on adequate financial ability, which eludes many SMEs. The problem of obtaining the initial funding allows for a minimum penetration of renewable energy in the energy mix and, most importantly, an investment plan that does not significantly impact the firm's resources for its primary operations.

This study developed a linear programming model to analyse an electricity capacity plan for SMEs under budget and technology constraints. The model seeks to identify the optimal mix of renewable and conventional energy technologies that minimise the present value of total energy generation cost over the life of the renewable energy technology under capacity and budget constraints.

SMEs that face difficulties raising adequate capital to invest in renewable energy projects can afford to do so using debt instruments. However, the cost of raising the money and the power storage capacity are significant factors to consider for investments. SMEs do not necessarily have to switch wholly from conventional to renewable energy sources to take advantage of cost savings from the non-payment of electricity tariffs. Generally, every kWh of renewable energy that replaces a kWh of conventional energy provides some cost savings for the SME in terms of non-payment of tariffs. Thus, irrespective of the cost of borrowing, a firm can instal a minimum renewable energy capacity that offers the opportunity to benefit from cost savings.

Under an immediate investment option, the results show that savings from non-payment of conventional electricity tariffs would account for a small amount of renewable energy installation. However, irrespective of this amount, there are some cost savings that can be enjoyed by the SME. The immediate investment scenario does not provide investments in storage facilities. This notwithstanding, the SME can switch to conventional options when the renewable energy technology becomes intermittent. Thus, immediate investment in renewable energy technologies would still yield an appreciable level of cost-savings benefits.

SMEs that intend to undertake immediate investments must have some initial capital to undertake such projects. The firm can obtain the additional amount required for the investment using debt instruments. The availability of such initial capital ensures that the amount of money needed to repay the loans is reduced, allowing cost savings to amortise the loan in subsequent years. Alternatively, SMEs that do not have such initial capital but would like to invest in renewable energy technologies immediately can obtain financing that offers a grace period before the actual loan repayment schedule kicks in. This approach allows for the SME to make adequate savings to make debt repayments. SMEs must be creditworthy to engender the trust and willingness of financial institutions to provide such grace periods.

Delaying investments also provides a reasonable justification to use conventional electricity savings to repay loans. However, SMEs must ensure that they do not delay for too long a period where they cannot benefit from cost savings anymore. While it will be complex for an SME to explicitly determine an optimal delay period, an examination of the business context could be a useful starting point. For instance, the SME can refer to periodic reports that project the prices of renewable energy technologies. Also, a thorough investigation of the firm's country-specific macro-economic conditions is beneficial. These are mainly exchange rates and inflation rates which can even offset the reducing costs of renewable energy technologies. Generally, delays must be afforded only within the short to medium term.

The study also recognises the benefits of investment pooling, where firms come together through union representatives to secure financing for big-ticket investments in renewable energy technologies. SME aggregation provides benefits from economies of scale, and the use of unionised groups can ensure that information asymmetry is reduced, which could impact the cost of borrowing. However, to benefit from this form of aggregation, SMEs may be required to consider significant structural changes to their electricity connections, requiring substantial investments. For this reason, the pooled option would be beneficial for SMEs within an industrial enclave that is structurally suited for such levels of integration.

Irrespective of the funding challenges of SMEs, they can benefit from the installation of renewable energy technologies. This chapter provides approaches and options, including renewable energy capacities within a firm's energy mix that minimises their total cost of energy generation. It contributes to the growing literature on capacity planning models and renewable energy integration by extending the model to SMEs, which has received less attention. The model is suitable for all forms of SMEs, irrespective of the amount of energy generation requirements, power capacity requirements, or operation length. Secondly, the paper makes a novel contribution to the capacity planning model by introducing a budget constraint that restricts payments to allow for only cost savings to be used to plan the amortisation of loans from financial institutions. The model generated allows for several practical implications for investment, as outlined in the preceding paragraphs of this section.

Despite the success in extending the capacity planning model to small and medium-sized enterprises, the constantly changing phase of business requires that the model be improved periodically to capture time and context-specific variables. A significant suggestion for future research would be to include diesel-powered generators in the model, which would account for backup power systems for conventional energy generation. Also, the inclusion of diesel-powered generators would lead the consideration of some potential sources of uncertainty, such as the outlook of fuel prices.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The issue of mitigating the impacts of climate change has spurred the transition from conventional fossil fuel energy generating sources to renewable energy sources across many jurisdictions. While the integration of renewable energy began with an initial objective towards environmental sustainability, it has metamorphosed into an economic and business conversation. Renewable energy integration provides environmental benefits and is a potential source of revenue generation for businesses, individual investors, and governments. Therefore, countries that seek to benefit from the transition must see it as an opportunity rather than a threat. However, envisaging the transition as an opportunity does not mean a complete abandonment of conventional generation sources. Thus, government policies must seek to address their context-based issues, impacting their gains and losses. In addition, strategies must ensure a balance of the trade-offs between renewable energy integration and conventional energy utilisation.

Ghana is a signatory to various regional and global protocols that seek to minimise the extent of CO2 emissions. Renewable energy integration has been highlighted as an effective way to achieve the objective. Beyond ensuring environmental sustainability, renewable energy integration in Ghana can be a driving force to achieving universal electricity coverage. Island communities that find it challenging connecting to the grid can take advantage of mini grids powered by renewable energy technologies. These stand-alone systems can ensure energy security using hybrid technologies.

Renewable energy penetration in Ghana depends on adequate investments through partnerships between private investors and the government. Therefore, decisions in the investment must be made in a way that considers various sources of uncertainties and risks inherent in the market. The identified risk factors include political, policy, climate, technological and demand risk factors. These factors either aid or offset the return on investments in renewable energy technologies in one way or another.

Ghana's energy sector is particularly beset with debt sustainability, perceived excess capacity, and transmission and distribution sector reliability challenges. Government policies must seek to curtail these challenges while ensuring universal access to electricity. However, while the national electrification agenda can present an opportunity for renewable energy investment, the perceived challenge of excess generation capacity stifles the government's decision to invest in renewable energy resources.

Although state agencies primarily manage the electricity value chain in Ghana, there are options for self-generation through other available small scale energy generation sources. These options are generally available for Small and Medium Scale Enterprises (SMEs) who face the challenge of the power sector reliability. In addition, self-generation could prove cost-effective and environmentally sustainable if SMEs employ renewable energy technologies. These benefits could form the basis of a good business case for governments to either wholly or partially switch to renewable energy technologies.

This thesis sought to provide decision-making strategies for large scale and small-scale renewable energy investments within an uncertain environment. Three independent studies were carried out with specific objectives to achieve the overall aim of the study. This section provides a summary of the findings of the various independent studies.

Ghana's renewable energy master plan seeks to align with the country's objective of obtaining at least 10% renewable energy penetration in the energy mix. The plan provides an outlook for investment in various forms of renewable energy technologies, including utility-scale solar photovoltaics. Meeting the objectives for the study requires adequate private sector participation, which means that investments must generate the needed value to engender the buy-in of the private investor.

Objective one

The first study sought to evaluate the investment potential of utility-scale renewable energy investments under various risks factors. Using a binomial lattice approach to real options analysis, the study finds that the current investment environment does not generate the necessary value for such utility-scale renewable energy investments. This notwithstanding, the results do not necessarily suggest the curtailment of investments in utility-scale renewable energy technologies.

The study results advance the conversation of delaying investments to allow the settling of uncertain factors inherent in the market. However, delaying investments create opportunity losses which include competitor's entry into the market. The rule of thumb is to ensure that the rate of opportunity losses is less than the rate of return on the investment. It is also necessary to ensure that investors understand and realise the optimal time to delay investments to minimise their exposure to opportunity losses. For this study, the investor can delay for a maximum of about eight years, depending on several factors. These factors include the inherent volatility and the opportunity cost of delaying, and the risk-free rate.

The volatility has the highest effect on the option valuation, resulting from the upside potential of the binomial lattice. One of the main factors that increase the upside potential of renewable energy investments is the price per kWh of energy generated, which is identified by the feed-in tariffs (FITs). In the context of Ghana, FITs offered providers of utility-scale renewable energy technologies the opportunity to sell power at a higher cost. However, the amendment to the renewable energy act has repealed the FIT concept to introduce competitive pricing. The decision to competitively price renewable energy investments is primarily because of the costs of renewable energy technologies approaching grid parity.

While investors may no longer obtain the benefits of FITs for Ghana, this study recommends that government policies must be tailored towards creating demand for renewable energy to drive the value renewable energy investment upwards. These policies would increase the purchase obligations of renewable energy by distribution companies or allow increased offtake of renewable energy power generation sources for energy transmission and distribution.

Objective two

The second study examined the costs and benefits of SMEs to self-generate by switching from conventional energy to renewable energy technologies. The study considered three significant options: using renewable energy as backup power supply, a complete transition towards renewable energy technologies and lastly, a partial switch to renewable energy technologies. For a partial switch to renewable energy, a portion of the firm's operations is supplied by renewable energy, while the remainder is supplied from conventional energy sources. The evaluation uses the Least Squares Monte-Carlo technique based on a switching options approach to real options analysis.

The results show that significant investment value is created when SMEs switch either wholly or partially to renewable energy technologies. The value creation is primarily due to the non-payment of electricity tariffs for every amount of renewable energy technology installed. However, the option of using renewable energy technologies as a backup source of energy supply may not provide substantial benefits. Using renewable energy as backup sources means that conventional energy sources become the primary source of renewable energy technologies are introduced only when traditional power is unavailable. Thus, the firm continues to pay substantial tariffs and does not enjoy much savings from the non-payment of electricity tariffs. The option of using renewable energy as backup is viable only when the conventional sources are highly unreliable.

SMEs intending to self-generate through renewable energy technologies must understand the factors that impact the value of switching from conventional to renewable energy. These factors can be generally classified as technological and cost factors. The two technological factors are the system availability of conventional energy and the capacity factor of renewable energy. On the other hand, the cost factors are conventional tariffs and the cost of renewable energy technologies.

Increasing the system capacity factor of renewable energy technologies increase the value created by the technologies. Advancement in research and development for high-quality renewable energy technologies can lead to increased capacity factors. Given these developments, SMEs can trust the future of renewable energy technologies to provide a reliable power supply. As already stated, conventional energy sources' decreasing system availability factors give credence for using renewable energy technologies as backup sources. Although increasing conventional energy system availability can improve its reliability, high tariffs offset it, providing additional value for renewable energy technologies.

Renewable energy investment is favoured under high conventional tariffs. Generally, electricity tariffs for commercial customers (mainly businesses) are higher than that of residential customers. Also, historical tariff data show a higher likelihood of tariff increments in future. These two occurrences provide a more positive outlook towards self-generation using renewable energy technologies. Generally, the high investment costs of these technologies can be offset by the significant savings from high electricity costs. Similarly, less investment value for renewable energy investments is created when renewable energy technologies are high. However, with the current outlook for the cost of renewable energy technologies, there is a lower likelihood of costs increased compared to conventional tariffs.

SMEs can select from a broader range of options for renewable energy technologies. However, the decision to invest or not to invest in renewable energy technology depends on the firm's financial capability. This result highlights the importance of identifying the relevant funding approach to enable SMEs to benefit from renewable energy integration and leads to the third and final study of the thesis.

Objective three

The third study focused on identifying alternative funding options for SMEs to invest in renewable energy technologies. It also builds on the results on partial switching to determine the optimal proportion of renewable energy generation that minimises the long-term cost of energy generation under capacity and cost constraints. Using a linear programming model, the study outlines how firms can finance renewable energy technologies using debts given various investment options: immediate investment, delayed investment, and pooled investment options.

Generally, the study results show the possibility for SMEs to finance renewable energy investments using debt instruments. However, the installation capacities differ depending on the cost of debt and the amount available to amortise debts. The third study presents savings on conventional electricity tariffs to amortise loans taken from financial institutions. This approach reduces the burden of SMEs to use funds necessary for their operations rather than amortise loan commitments. The SME is offered a higher affinity to increase installation capacities when enough disposable income from its operations to amortise incomes. Further, increasing the proportion of renewable energy leads to increased savings. The benefits of increased cost savings occur in latter periods, which are characterised by higher electricity tariffs.

Considering the investment options, the study results show that SMEs who consider immediate investment in renewable energy needs to have some initial capital to top up with the loans they collect from financial institutions. This is because the tariffs in the immediate periods are not substantial to meet loan amortisation requirements. Financial institutions can provide a time lag between loan disbursement and actual amortisation of loans to afford SMEs to reap significant savings before they begin to make loan repayments.

Other options for SMEs include delaying investments to benefit from high tariffs and increased capacity factors of renewable energy technologies. Another investment option worth considering will be the need for SMEs to pool resources together to secure funding for renewable energy integration. SME aggregation through unionised groups provide the opportunity for large scale installations that provide additional benefits of economies of scale. SMEs operating within an industrial enclave stands a better chance of reaping the benefits of SME aggregation as electrical connections are easily facilitated.

6.2 Conclusions and recommendations

The benefits of renewable energy integration can be realised at both utility-scale and small-scale levels if governments, investors and businesses pay attention to the key factors that drive profitability. This study has provided strategies for large scale investors to invest in utility-scale renewable energy technologies and for SMEs to integrate renewable energy technologies into their energy mix.

These studies have practical implications for governments, investors, and managers of Small and Medium Scale Enterprises regarding renewable energy investments. It provides tailor-made strategies that reflect the changing business environment and consider other uncertainties that seek to affect the returns on renewable energy integration. Largely, research on the economics of renewable energy and the decisions thereof have focused on utility companies and large-scale investments with less attention given to SMEs. This study bridges that gap in the literature and offers more rigorous approaches towards investment appraisal and decision-making strategies towards renewable energy integrations among SMEs. A summary of the recommendations is as given below:

1. The government of Ghana must create a conducive environment for utility scale renewable energy investments to thrive. This include lifting the moratorium on providing licences for utility-scale renewable energy generation and embedded generation.
2. The government of Ghana must enforce the purchase obligations that require power generation sources to increase their uptake of power from renewable energy sources.
3. For SMEs to benefit from substantial cost savings, renewable energy technologies must be part of their primary sources of energy consumption. SMEs that want to use renewable

energy technologies must not consider utilising renewable energy technologies as back up sources for power supply. Utilising such technologies for back up supply do not provide substantial economic benefits in terms of cost savings.

4. SMEs can finance their renewable energy investments using debt instruments which are amortised with tariff savings obtained through renewable energy installation.
5. SMEs who do not have adequate capital for immediate investment in renewable energy can delay investments within the short term to account for increased savings
6. It is important for SMEs to pool resources together through unionised groups to facilitate funding for renewable energy investments.

This study does not present an exhaustive strategy for the renewable energy industry. However, it provides a good starting point for increased research and advocacy for renewable energy integration for governments and SMEs within the African sub-region.

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